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Incêndios florestais no Brasil e efeito do fogo em comunidades de formigas e em estrutura de vegetação lenhosa do bioma cerrado

Aline das Graças Costa
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Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Ciência Florestal, para obtenção do título de *Magister Scientiae*.

Orientador: Fillipe T. Pereira Torres

Coorientador: Gumercindo Souza Lima

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Assentimento:

Aline das Graças Costa
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Fillipe Tamiozzo Pereira Torres
Orientador

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“O correr da vida embrulha tudo,
a vida é assim: esquenta e esfria,
aperta e daí afrouxa,
sossega e depois desinquieta.
O que ela quer da gente é coragem”
Guimarães Rosa

RESUMO

COSTA, Aline das Graças, M.Sc., Universidade Federal de Viçosa, julho de 2019. **Incêndios florestais no Brasil e efeito do fogo em comunidades de formigas e em estrutura de vegetação lenhosa do bioma cerrado**. Orientador: Fillipe Tamiozzo Pereira Torres. Coorientador: Gumercindo Souza Lima.

Incêndios florestais ameaçam áreas protegidas, como Unidades de Conservação (UCs) federais, muitas delas situadas em zonas de conflito pelo uso da terra. O comportamento do fogo varia entre regiões, tornando essencial conhecer as características locais para orientar ações eficazes. Alguns ecossistemas, como o Cerrado, dependem do fogo, mas sua vegetação inclui paisagens savânicas, florestais e campestres, nas quais o fogo pode alterar a estrutura do habitat, a flora e a fauna. Este trabalho reúne três artigos, publicados após a defesa, que avaliaram as causas de incêndios florestais, a estação normal do fogo em UCs e os efeitos do fogo em comunidades de formigas e em estrutura arbórea de formações savânicas e florestais do Cerrado. O primeiro avaliou as causas de incêndios florestais em UCs federais brasileiras no período de 2006 a 2012, o período de maior ocorrência de incêndios no país e os estados com maiores ocorrências de incêndios. Os eventos de causas "Desconhecidas" foram os mais frequentes, com média de 120,14, e estatisticamente diferente dos demais. As causas "Incendiários" e "Queima para Limpeza" apresentaram o mesmo número de eventos, com média de 64,29, se diferindo das demais. Minas Gerais foi o estado com o maior número de ocorrências. O número de incêndios foi maior de julho a outubro com média de 50,61 eventos, sendo considerado o período de estação normal de fogo. O segundo avaliou a influência do fogo em comunidade de formigas nas formações savânicas e florestais do Cerrado. O trabalho foi realizado na UC Reserva Natural Serra do Tombador (RNST) em Goiás após um evento de incêndio que atingiu a área. Foram instaladas 40 armadilhas do tipo pitfall nas formações, subdivididas em áreas queimadas e áreas não queimadas: Floresta Queimada (FQ) e Não Queimada (FNQ) e Cerrado Queimado (CQ) e Não Queimado (CNQ). O episódio de fogo não apontou diferença na abundância na formação florestal, diferente dos tratamentos na formação savânica, que apresentou maior abundância de formigas no CQ. Os resultados demonstram maior diversidade e distribuição na formação savânica atingida pelo fogo, diferente da formação florestal, demonstrando que o fogo pode impactar negativamente na diversidade de gêneros na fitofisionomia florestal. O terceiro avaliou a influência do fogo na estrutura de componentes arbóreos em formações savânicas e florestais do Cerrado. O trabalho foi realizado na mesma RNST, onde foram lançadas 28 parcelas em três níveis de inclusão (N1, N2 e N3), distribuídas nas formações savânicas e florestais com constituição arbórea. A formação savânica não atingida pelo fogo foi superior em indivíduos, família e espécies comparado à atingida. No Nível 1 de inclusão, o CNQ apresentou densidade (DA) de 537,5000 ind/ha, área basal (DoA) de 4,2553 m^2/ha e volume (Vol) de 1,0797 m^3/ha. Já o CQ apresentou valores inferiores de densidade (53,49% inferior), dominância (27,25%) e volume (34,43%). No Nível 2, o CNQ apresentou DA 85,85% e DoA 88,99% superior à área queimada. No Nível 3, o CQ obteve DA 76.92% inferior e DoA, 84,81% inferior. O índice de diversidade do CQ foi inferior ao CNQ em todos os níveis. A similaridade total e por nível da área queimada com a não queimada da formação savânica foi baixa, sendo similaridade 0,00 no Nível 3. Na FNQ foi superior em número de indivíduos, família e espécies à FQ. No Nível 1, o FNQ apresentou DA de 909,3750 ind/ha, DoA de 18,0939m^2/ha e volume de 19,8342m^3/ha. Os valores foram pouco inferiores na área atingida pelo fogo, com DA 12,71%, DoA 1,85% e Vol 3,27% inferiores. No nível 2, a FNQ apresentou 70,30% de DA e 62,85% de DoA superior a FQ. No Nível 3, a FNQ apresentou DA 89.58% e DoA 83,40% superior. A diversidade da formação florestal foi superior à formação atingida pelo fogo em todos os níveis. Houve similaridade entre FQ e FNQ na área total (0,60) e no nível 1 de inclusão (0,59), porém a similaridade decresceu com a diminuição do nível de inclusão.

Palavras-chave: ecologia do fogo; impactos ambientais; manejo preventivo do fogo

ABSTRACT

COSTA, Aline das Graças, M.Sc., Universidade Federal de Viçosa, July, 2019. **Forest fires in Brazil and the effect of fire on ant communities and the structure of woody vegetation in the Cerrado biome**. Adviser: Fillipe Tamiozzo Pereira Torres. Co-adviser: Gumercindo Souza Lima.

Fire behavior varies among protected areas such as federal Conservation Units (CUs), making an understanding of local characteristics crucial for effective action. The Cerrado biome depends on fire, and its vegetation includes savanna, forest, and grassland landscapes. This work brings together three articles, published after the defense, that evaluated the causes of forest fires, the normal fire season in CUs, and the effects of fire on ant communities in the Cerrado. The first evaluated the causes of forest fires in Brazilian federal CUs from 2006 to 2012, the period of greatest fire occurrence in the country, and the states with the highest incidence of fires. The "unknown" causes were the most frequent, with an average of 120.14, and statistically different from the others. The causes "Arson" and "Burning for Deforestation" presented the same number of occurrences, with an average of 64.29, differing from the others. Minas Gerais was the state with the highest number of occurrences. The number of fires was higher from July to October, with an average of 50.61 occurrences, considered the normal period for wildfires. The second study evaluated the influence of fire on ant communities in Cerrado formations. The work was carried out in the Serra do Tombador Natural Reserve (RNST), in Goiás, after a fire that affected the area. Forty pitfall traps were installed in the formations, subdivided into burned and unburned areas: Burned Forest (FF) and Unburned Forest (NBF), and Burned Cerrado (BC) and Unburned Cerrado (UCC). The fire episode did not show a difference in abundance in the forest formation, unlike the treatments in the Cerrado formation, which showed a greater abundance of ants in the area affected by the fire. The results demonstrate greater diversity and distribution in the savanna formation affected by fire, unlike the forest formation, showing that fire can negatively impact species diversity in the forest physiognomy. The third study evaluated the influence of fire on the structure of tree components in savanna and forest formations of the Cerrado. The work was carried out in the same RNST, where 28 plots were installed at three inclusion levels (N1, N2, and N3), distributed in savanna and forest formations with tree composition. The savanna formation unaffected by fire showed superiority in individuals, families, and species compared to the affected one. At Inclusion Level 1, the CNQ presented a density (DA) of 537,500 individuals/ha, basal area (DoA) of 4.2553 m^2/ha, and volume

(Vol) of 1.0797 m³/ha. On the other hand, the burned area (CQ) presented lower values for density (53.49% lower), dominance (27.25%), and volume (34.43%). At Level 2, the unburned area (CNQ) showed a diversity index (DA) 85.85% higher and a dominance index (DoA) 88.99% higher than the burned area. At Level 3, the burned area (CQ) showed a DA 76.92% lower and a DoA 84.81% lower. The diversity index of the CQ was lower than that of the CNQ at all levels. The total and specific similarity by level of the burned area with the unburned area of the savanna formation was low, with a similarity of 0.00 at Level 3. The unburned area (FNQ) was superior to the burned area (FQ) in number of individuals, families, and species. At Level 1, the FNQ presented an individual density (DI) of 909.3750 individuals/ha, a coverage area (AC) of 18.0939 m²/ha, and a volume of 19.8342 m³/ha. These values were slightly lower in the area affected by fire, with DI 12.71% lower, AC 1.85% lower, and Vol 3.27% lower. At Level 2, FNQ showed DI 70.30% higher and AC 62.85% higher than FQ. At Level 3, FNQ showed DI 89.58% higher and AC 83.40% higher. The diversity of the forest formation was greater than that of the formation affected by fire at all levels. There was similarity between FQ and FNQ in the total area (0.60) and at inclusion level 1 (0.59). However, the similarity decreased with the reduction in the inclusion level.

Keywords: fire ecology; environmental impacts; preventive fire management

SUMÁRIO

1. INTRODUÇÃO GERAL

Os incêndios florestais estão entre as principais pesquisas ambientais e ecológicas do mundo (Zhang et al., 2016), sendo considerados ameaças constantes à conservação de áreas protegidas, como as Unidades de Conservação (UCs) (Koproski et al., 2011), áreas destinadas à manutenção da biodiversidade e que abrigam espécies raras e endêmicas (Bontempo et al., 2011; Marcuzzo et al., 2015). Nas últimas décadas, com a intensificação das mudanças climáticas, os incêndios florestais estão aumentando em todo mundo (Jolly et al., 2015) devido a influência da temperatura (Hansen et al., 2010) que favorece a ignição e, principalmente, a propagação do fogo. O incêndio florestal é, também, um potencial contribuinte para essas mudanças, visto que a combustão emite elevadas concentrações de CO_2 (van der Werf et al., 2006; Jolly et al., 2015).

A maior parte das UCs brasileiras está inserida em áreas com usos de terra distintos e ligada ao contexto socioeconômico da região e das atividades de seu entorno, sendo possível correlacionar as causas com as atividades de proprietários vizinhos (Torres et al., 2016). Causas antrópicas são as principais causas de incêndios em florestas no Brasil, ocorridas principalmente por incendiários (incêndio proposital) e uso do fogo para limpeza de pastagens que atingem áreas florestais (Soares, 2009; Aximoff e Rodrigues, 2011).

O comportamento do fogo varia com a região, tornando necessário se conhecer as características locais para se compreender e tomar medidas eficientes com relação às ocorrências de incêndios (Pezzatti et. al., 2013). O fogo molda a paisagem, muda a estrutura do habitat, flora e fauna, reduzindo drasticamente as florestas e outros ambientes naturais (Aximoff e Rodrigues, 2011; Camargo et al., 2018), especialmente nos trópicos, locais onde há maior ocorrência de incêndios (Cochrane, 2010), podendo ser benéfico em ecossistemas que dependem da manutenção de estados ecológicos dinâmico, enquanto em ecossistemas caracterizados por uma condição climática estável, os incêndios podem ser altamente prejudiciais (Hoffmann, 2009).

O Cerrado brasileiro (savana) é um grande ecossistema propenso e evoluído sob a influência do fogo (Pivello, 2011). Sua vegetação é composta por diferentes paisagens ao longo de gradientes ambientais e de perturbação do fogo, como fisionomias savânicas, em maiores proporções, campestres e formações florestais (Pinto et al., 2009; Bueno et al., 2018). No entanto, o aumento do desmatamento para pastagens e culturas agrícolas utilizando o fogo ameaçam a sua integridade (Sano et al., 2010), tornando-o a savana tropical mais ameaçada do mundo (Araújo e Almeida-Santos, 2013). Embora o ecossistema de savana e suas espécies estejam adaptados ao fogo, a frequência crescente de incêndios de alta intensidade afeta negativamente o ecossistema através do aumento da mortalidade de pequenas plantas lenhosas e promoção de gramíneas (Oliveras et al., 2013).

Em fisionomias típicas florestais, a ocorrência de incêndios dificulta a regeneração natural (Santos et al., 2018), pois florestas tropicais são ambientes mais sensíveis a incêndios, onde um único evento de fogo pode alterar drasticamente a estrutura da vegetação (Barlow et al., 2003). A inflamabilidade das savanas e florestas tropicais tende a aumentar por fatores como fragmentação e mudanças no uso da terra (Veldman, 2016). Os efeitos de incêndios em ambientes florestais podem ser monitorados por bioindicadores (Silveira et al., 2013). Entre os grupos que são utilizados para bioindicação, as formigas têm recebido destaque (Santos et al., 2006), pois são indicadores de degradação ou conservação de diferentes áreas (Silva et al., 2013) e de impacto do fogo (Philpott et al., 2010). O fogo provoca efeitos diretos ou indiretos sobre as formigas alterando a estrutura de seus habitats, prejudicando a riqueza de espécies e a composição de seus grupos funcionais (Andersen et al., 2012; Silveira et al., 2012; Paolucci et al., 2016).

A flora do Cerrado apresenta espécies adaptadas, tolerantes e dependentes do fogo (Hoffmann et al., 2009) devido a sua vegetação heterogênea, com diferentes formações savânicas e diferentes tipos de florestas (Ribeiro e Walter, 2008; Haidar et al., 2013). O fogo é um dos fatores que pode alterar a composição e estrutura de uma floresta (Lopes et al., 2009), sendo que essas mudanças podem indicar níveis de degradação após um distúrbio como um incêndio.

Informações sobre as principais causas de incêndios florestais, bem como o efeito do fogo em grupos indicadores em biomas heterogêneos são importantes para o manejo sustentável e conservação da vegetação. Assim, o objetivo desse trabalho foi avaliar as causas de incêndios florestais e a estação normal do fogo em Unidades de Conservação federais brasileiras e o efeito do fogo em comunidades de formigas e em estrutura arbórea de formações savânicas e florestais do Bioma Cerrado.

Para atender aos objetivos propostos, esta dissertação foi estruturada em três artigos científicos, apresentados no formato em que foram publicados após a aprovação da defesa. A seguir, são descritos os três trabalhos que compõem o estudo:

Artigo 1: Causas e período de ocorrência de incêndios florestais em Unidades de Conservação federais do Brasil de 2006 a 2012 (versão publicada na íntegra disponível em: https://periodicos.ufsm.br/cienciaflorestal/article/view/69028);

Artigo 2: Influência do fogo sobre a comunidade de formigas em ambientes savânicos e florestais do Bioma Cerrado (versão publicada na íntegra disponível em: https://www.scielo.br/j/floram/a/9zn7gwYjTqPhFY3hzLw9y6v/?lang=en);

Artigo 3: Influência do fogo na estrutura de vegetação lenhosa de formações savânicas e florestais do Bioma Cerrado (versão publicada na íntegra disponível em: https://link.springer.com/article/10.1007/s11676-022-01573-3).

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2. REFERÊNCIAS

Andersen, A. N.; Woinarski, J. C. Z; Parr, C. L. Savanna burning for biodiversity: fire management for faunal conservation in Australian tropical savannas. **Austral Ecology**, n. 37, p. 658–66, 2012.

Araujo, C. O.; Almeida-Santos, S. M. Composição, riqueza e abundância de anuros em um remanescente de Cerrado e Mata Atlântica no estado de São Paulo. **Biota Neotropica**, v. 13, n. 1, p. 264-275, 2013.

Aximoff, I.; Rodrigues, R. C. Histórico dos incêndios florestais do Parque Nacional do Itatiaia. **Ciência Florestal**, v. 21, n. 1. p. 83-92, 2011.

Barlow, J.; Peres C. A.; Lagan B. O.; Haugaasen T. Large tree mortality and the decline of forest biomass following Amazonian wildfires. **Ecology Letters**, v. 6, p. 6–8, 2003.

Bontempo, G. C.; Lima, G. S.; Ribeiro, G. A.; Doula, S. M.; Silva, E. Registro de Ocorrência de Incêndio (ROI): evolução, desafios e recomendações. **Biodiversidade Brasileira**, v. 1, n. 2, p. 247-263, 2011.

Bueno, L. M.; Dexter, K. G.; Pennington, R. T.; Pontara V.; Neves, D. M.; Ratter, J. A.; Oliveira-Filho, A. T. The environmental triangle of the Cerrado domain: ecological factors driving shifts in tree species composition between forests and savannas. **Journal Ecology**, v. 106, p.2109-2120, 2018.

Camargo, A. C. L., Barrio, R. O. L., de Camargo, N. F., Mendonça, A. F., Ribeiro, J. F., Rodrigues, K. M. F., Vieira, E. M. Fire affects the occurrence of small mammals at distinct spatial scales in a neotropical savanna European. **Journal of Wildlife Research**. v.64. n.63, 2018.

Cochrane, M. A.; Schulze, M. D. Fire as a recurrent event in tropical forests of the eastern Amazon: effects on forest structure biomass and species composition. **Biotropica**. v.31, p.2-16, 2010.

Haidar, R. F.; Fagg, J. M. F.; Pinto, J. R. R.; Dias, R. R.; Damasco, G.; Silva, L. C. R.; Fagg, C. W. Florestas estacionais e áreas de ecótono no estado do Tocantins, Brasil: Parâmetros estruturais, classificação das fitofisionomias florestais e subsídios para conservação. **Acta Amzônica**, v. 43, p. 261–290, 2013.

Hansen, J. R.; Ruedy, R.; Sato, M.; Lo, K. Global surface temperature change. **Reviews of Geophysics**, 48, 1-29, 2010. doi:10.1029/2010RG000345

Hoffmann, W. A.; Adasme, R.; Haridasan, M.; de Carvalho, M. T.; Geiger, E. L.; Pereira, M. A. B.; Gotsch, S. G.; Franco, A. C. Tree topkill, not mortality, governs the dynamics of savanna–forest boundaries under frequent fire in central Brazil. **Ecology** v.90, p.1326–133, 2009.

Jolly, W. M.; Cochrane, M. A.; Freeborn,P. H.; Holden, Z; A.; Brown, T. J.; Williamson, G. J.; Bowman, D. M. J. S. Climate-induced variations in global wildfire danger from 1979 to 2013. **Nature Communications**, 6 (7537), 2013. doi: 10.1038/ncomms8537

Koproski, L.; Ferreira, M. P.; Goldammer, J. G.; Batista, A. C. Modelo de zoneamento de risco de incêndios para Unidades de Conservação brasileiras: o caso do Parque Estadual do Cerrado (PR). **Floresta.** v. 41, n. 3, p. 551-562, 2011.

Lopes, S. F.; Vale, V. S.; Schoavini, I. Efeito de queimadas sobre a estrutura e composição da comunidade vegetal lenhosa do cerrado sentido restrito em Caldas Novas, Goiás. **Revista Árvore**. V. 33, n. 4, p. 695-704, 2009.

Marcuzzo, S. B.; Araújo, M. M.; Gasparin, E. Plantio de espécies nativas para restauração de áreas em Unidades de Conservação: um estudo de caso no sul do Brasil. **Floresta.** v. 45, n. 1, p. 129-140, 2015.

Oliveras, I.; Meirelles, S. T.; Hirakuri, V. L.; Freitas, C. R.; Miranda, H. S.; Pivello, V. R. Effects of fire regimes on herbaceous biomass and nutrient dynamics in the Brazilian savanna. **International Journal of Wildland Fire** v.22, p.368–380, 2013.

Paolucci, L. N.; Maia, M. L. B.; Solar, R. R. C.; Campos, R. I.; Schoereder, J. H.; Andersen, A. N. Fire in the Amazon: impact of experimental fuel addition on responses of ants and their interactions with myrmecochorous seeds. **Oecologia** v.182, p.335–346, 2016.

Pezzatti, G. B.; Zumbrunnen, T.; Bürgi, M.; Ambrosetti, P.; Conedera, M. Fire regime shifts as a consequence of fire policy and socio-economic development: an analysis based on the change point approach. **Forest Policy and Economics** v. 29, n.2013, p.7-18, 2013.

Philpott, S. M.; Perfecto. I.; Armbrecht, I. Parr, C. L. **Ant diversity and function in disturbed and changing habitats.** In: Lach L, Parr CL, Abbott KL (eds) Ant Ecology, Oxford University Press, New York, p.137–156, 2010

Pinto, J. R. R., Lenza, E.; Pinto, A. S. Composição florística e estrutura da vegetação arbustivo-arbórea em um Cerrado Rupestre, Cocalzinho de Goiás, Goiás. **Revista Brasileira de Botânica,** v. 32, 23-32, 2009.

Pivello, V.R. The use of fire in Brazil: past and present. **Fire Ecology**, v.7, p.24-39. 2011.

Ribeiro, J. F.; Walter, B. M. T. **Fitofisionomias do bioma Cerrado.** In: Sano, S. M.; Almeida, S. P. (Eds.). Cerrado: Ecologia e flora, Planaltina, DF: EMBRAPA-CPAC, p. 151-212, 2008.

Sano, E. E; Rosa, R; Brito, J. L. S; Ferreira, L. G. Land cover mapping of the tropical savanna region in Brazil. **Environmental Monitoring Assessment,** v.166, p.113-124, 2010.

Santos, J. F.; Soares, R. V.; Batista, A. C. Perfil dos incêndios florestais no Brasil em áreas protegidas no período de 1998 a 2002. **Floresta,** v. 36, n. 1, p. 93-100, 2006.

Santos, J. F. C.; Gleriani, J. M.; Velloso, S. G. S.; Souza, G. C. A.; Amaral, C. H.; Torres, F. T. P.; Medeiros, N. G.; Reis, M. Wildfires as a major challenge for natural regeneration in Atlantic Forest. **Science of The Total Environment**. v. 650. p.8019-821, 2018.

Silva, L. C. R.; Hoffmann, W. A.; Rossatto, D. R.; Haridasan, M.; Franco, A. C.; Horwath, W. R. Can savannas become forests? A coupled analysis nutrient stocks and fire thresholds in central Brazil. **Plant and Soil**, v. 373, p. 829–842, 2013.

Silveira, J. M.; Barlow, J.; Andrade, R. B.; Mestre, L. A.; Lacau, S.; Cochrane, M. A.; Responses of leaf-litter ant communities to tropical forest wildfires vary with season. **Journal Tropical Ecology,** v.28, p.515–518, 2012.

Soares, R. V**. Estatísticas dos incêndios florestais no Brasil.** In: Soares, R. V.; Batista, A. C.; Nunes, J. R. S. Incêndios Florestais no Brasil: o estado da arte. Curitiba, p. 1-20, 2009.

Torres, F. T. P.; Lima, G. S.; Costa, A. G.; Félix, G. A.; Silva Júnior, M. R. Perfil dos incêndios Florestais em Unidades de Conservação brasileiras no período de 2008 a 2012. **Floresta,** v.46, n. 4, p. 531-542, 2016.

Veldman, J. W. Clarifying the confusion: old-growth savannahs and tropical ecosystem degradation. **Philosophical Transactions of the Royal Society**. v.371, 2016.

Zhang, Y.; Lim, S.; Sharples, J. J. Modelling spatial patterns of wildfire occurrence in South-Eastern Australia, Geomatics, **Natural Hazards and Risk**, v.7, n.6, p.1800-1815, 2016.

3. ARTIGO 1: CAUSAS E PERÍODO DE OCORRÊNCIA DE INCÊNDIOS FLORESTAIS EM UNIDADES DE CONSERVAÇÃO FEDERAIS DO BRASIL DE 2006 A 2012

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Artigos

Causes and period of occurrence of forest fires in Brazilian federal protected areas from 2006 to 2012

Causas e período de ocorrência de incêndios florestais em unidades de conservação federais brasileiras de 2006 a 2012

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ABSTRACT

Forest fires, regardless of their causes, represent one of the greatest threats to biodiversity in Brazilian protected areas. Collecting data on the causes, periods, and sites with the highest occurrence of fires allows for the adoption of more effective prevention strategies. The aim of this study was to characterize forest fires in Brazilian federal protected areas from 2006 to 2012, thus contributing to improving the knowledge of the dynamics of fires in these areas. Data were obtained from Fire Occurrence Records (ROIs, in Portuguese) available in the National Fire Information System (SISFOGO, in Portuguese) database. The total number of records found was 2,259, of which 88.2% had reported causes. Among the records with a reported cause, 42.2% correspond to unknown causes, 26.7% to debris burning, and 18.5% to arson events, which shows that the majority of fires with a known cause are the result of accidental or intentional human action. Forest fires were more frequent from July to October, with a mean of 50.6 occurrences per year, influenced by the annual precipitation distribution. Minas Gerais, Rio de Janeiro and Ceará were the states with the highest number of records, with 19.8%, 15.5%, and 12.0%, respectively. Forest fires reported without any cause information or reported as unknown cause indicate, respectively, a poor use of the tool (ROI) or an unsatisfactory expertise in identifying the cause of the fire, resulting in an obstacle for planning actions to prevent and fight forest fires in protected areas.

Keywords: Fire behavior; Fire management; Fire occurrence record; Fire prevention

RESUMO

Os incêndios florestais, independentemente de suas causas, representam uma das maiores ameaças à biodiversidade nas unidades de conservação brasileiras. A coleta de dados sobre as causas, períodos e locais com maior ocorrência de incêndios possibilita a adoção de estratégias de prevenção mais eficazes. O objetivo deste estudo foi caracterizar os incêndios florestais nas unidades de conservação federais brasileiras de 2006 a 2012, contribuindo assim para aprimorar o conhecimento da dinâmica dos incêndios nessas áreas. Os dados foram obtidos a partir dos Registros de Ocorrência de Incêndio (ROIs) disponíveis no banco de dados do Sistema Nacional de Informações sobre Fogo (SISFOGO). O número total de registros encontrados foi de 2.259, dos quais 88,2% indicavam a causa do incêndio. Entre os registros com a causa indicada, 42,2% corresponderam à categoria "causa desconhecida", 26,7% à queima para limpeza e 18,5% à incendiários, o que evidencia que a maioria dos incêndios com causa conhecida decorre da ação humana acidental ou intencional. Os incêndios florestais foram mais frequentes de julho a outubro, com uma média de 50,6 ocorrências por ano, influenciados pela distribuição anual da precipitação. Minas Gerais, Rio de Janeiro e Ceará foram os estados com maior número de registros, com 19,8%, 15,5% e 12,0%, respectivamente. Os incêndios florestais registrados sem informação de causa ou registrados como "causa desconhecida" revelam, respectivamente, mau uso da ferramenta (ROI) ou conhecimento insatisfatório na identificação da causa do incêndio, resultando em um obstáculo para o planejamento de ações de prevenção e combate a incêndios em unidades de conservação.

Palavras-chave: Comportamento do fogo; Manejo do fogo; Registro de ocorrência de incêndio; Prevenção de incêndio

1 INTRODUCTION

Fire is one of the most important agents of disturbance in ecosystems, being widely used by humans to manage the land (PIVELLO, 2011). Fire is called forest fire when it escapes human control and reaches vegetation (AXIMOFF; RODRIGUES, 2011). This subject is widely studied in several countries (ZHANG; LIM; SHARPLES, 2016), as it causes economic, social, and environmental impacts, such as the destruction of forests and other natural environments (CAMARGO; BARRIO; CAMARGO; MENDONÇA; RIBEIRO; RODRIGUES; VIEIRA, 2018). Forest fires are increasing around the world, fragmenting and degrading the landscape and causing an imbalance between fire occurrences and ecosystem recovery (ADÁMEK; BOBEK; HADINCOVÁ; WILD; KOPECKÝ, 2015).

In recent decades, climate change has promoted a favorable season for forest fires around the world. Fires are highly influenced by climatic factors, which may have induced the recent global spread of forest fires. If this trend continues, the advancement of forest fires will increase even further (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015). In addition, forest fire itself can favor climate change, as it is a major source of greenhouse gases, especially CO_2 (SETIANI; DEVIANTO; RAMDANI, 2021).

Over the past three decades, global average temperatures have increased by ≈ 0.2°C per decade (HANSEN; RUEDY; SATO; LO, 2010), which favors the spread of fires. Forest fires require a combination of oxygen, combustible material and an ignition source to occur (PÉREZ-SÁNCHEZ; JIMENO-SÁEZ; SENENT-APARICIO; DÍAZ-PALMERO; CABEZAS-CEREZO, 2019). Ignition is influenced by temperature, relative humidity, precipitation and wind speed. Such climatic factors also affect the rate of fire spread and thus the intensity of forest fires, which is increased on hot, dry days (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015).

In Brazil, forest fires are a constant threat to protected areas (PAs) (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). These PAs are intended to maintain biodiversity (MARCUZZO; ARAÚJO; GASPARIN, 2015) and the occurrence of fires reduces its forest cover. Harboring rare, endemic, and endangered species, many Brazilian PAs are located in fire-sensitive biomes or in small and isolated areas in an anthropic matrix (such as crops and built-up areas). Such settings are detrimental to the conservation of the areas, which is already compromised by forest fires (BONTEMPO; LIMA; RIBEIRO; DOULA; SILVA; JACOVINE, 2011).

The landscape matrix where Brazilian PAs are located is often composed of different types of land use, which vary with the economic activity of the region and immediate surroundings (IBAMA, 2007). The process of land occupation and conversion of natural vegetation into crops, where fire is used as a management technique, exposes PAs to forest fires (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). In this scenario, the profile of forest fires reflects the type of activity carried out by rural landowners in the surrounding areas, making it possible to correlate the fire causes with the activities observed (IBAMA, 2007). The main causes of forest fires in PAs are anthropogenic, mainly due to arson events and out-of-control debris burning (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). Natural caused forest fires in Brazil are triggered exclusively by lightning (PIVELLO, 2011).

In Brazil, the 1,004 existing federal PAs cover 1,717,976 km², distributed across all biomes (MMA, 2019). The analysis of the spatial distribution of fires makes it possible to determine the areas of greatest incidence and, thus, to establish specific prevention and combat strategies for each region or biome. Fire seasons must be known in order to structure effective prevention and combat programs, keeping them active exclusively in the most critical months as to ensure their economic viability and, at the same time, to avoid large-scale fires (IRLAND, 2013).

Fire behavior varies according to the region, thus requiring knowledge about local characteristics for the adoption of effective measures (PEZZATTI; ZUMBRUNNEN; BÜRGI; AMBROSETTI; CONEDERA, 2013). The most frequent causes must be known in order to take preventive action against forest fires in PAs (TORRES; RIBEIRO; MARTINS; LIMA, 2010) and awareness of the period of occurrence is crucial for the prevention techniques to be applied at the appropriate time. This study aimed to assess the causes of forest fires in Brazilian federal PAs from 2006 to 2012, developing a diagnosis that will assist public managers and stakeholders in their decision-making related to forest fires.

2 MATERIAL AND METHODS

The data consists of Fire Occurrence Records (ROIs, in Portuguese) of federal PAs and were obtained from the National Fire Information System (SISFOGO, in Portuguese), managed by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, in Portuguese) through the National Center for the Prevention of Forest Fires (PREVFOGO, in Portuguese).

ROIs provide a variety of information, such as causative agents and likely cause of the fire, with 33 and 26 different options, respectively, for each. These fire causes were categorized as proposed by the Food and Agriculture of Organization (FAO) (SANTOS; SOARES; BATISTA, 2006). FAO does not provide a category titled "unknown cause" as they consider it can cause inaccurate reporting (SOARES, 1988). However, this category was included in this study due to the large number of records. Thus, the causes were grouped into seven categories, namely: I) unknown; II) miscellaneous; III) campfire and related; IV) arson fire; V) forest exploitation; VI) debris burning; and VII) lightning. The FAO category titled "miscellaneous" includes hunting, high voltage cable, wind-borne spark, fireworks, balloon drop, reignition, and others.

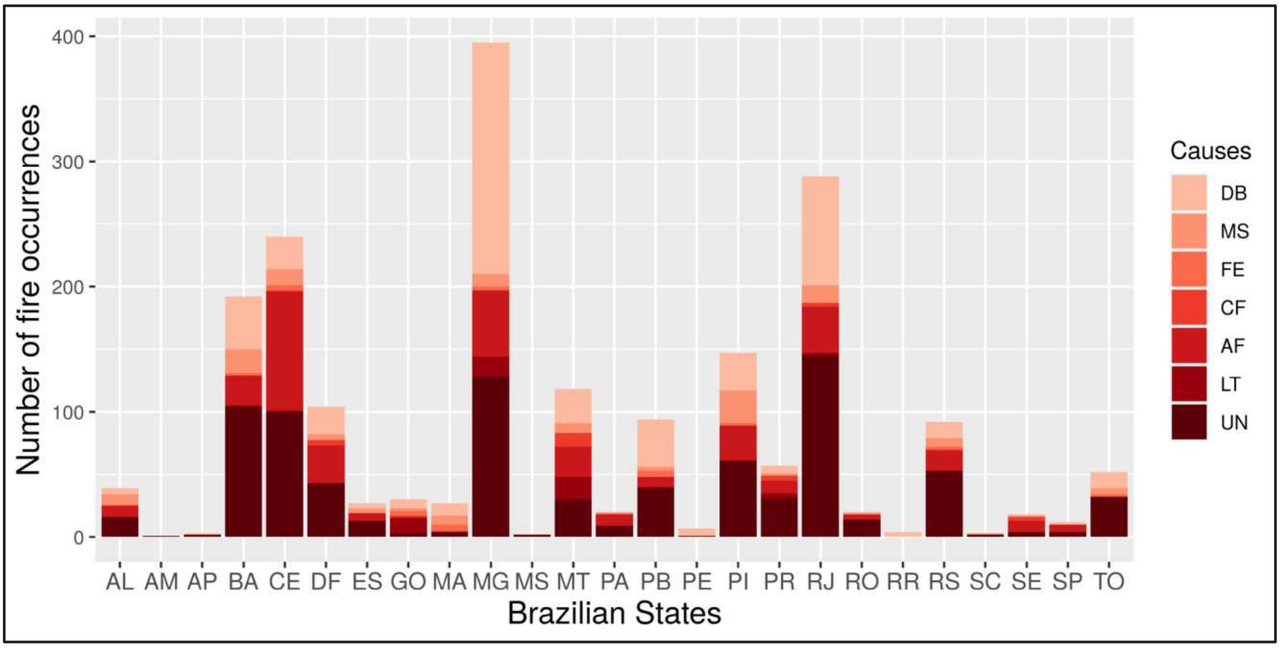
The period assessed span from 2006 to 2012 due to data availability in SISFOGO. Statistical analysis was performed using R software, applying Generalized Linear Modeling (GLM) under Poisson error distribution corrected for overdispersion. Model simplification was performed by contrast analysis, grouping treatment levels up to a change in deviation of $P<0.05$, determining the effects of categorical explanatory variables (months, Brazilian states, and causes of fires) in the continuous response variable (number of fire occurrences).

3 RESULTS

The number of occurrences recorded from 2006 to 2012 was 2,259, of which 88.2% had a reported cause for the fire. The remaining occurrences (11.8%) did not have their causes reported, indicating an unsatisfactory fire origin investigation. The variables "year" and "cause" were both statically significant ($p<0.001$). Fires with unknown causes were the most frequent, with a mean of 120.14 per year, and statistically different from the other cause categories ($p>0.05$). The fires caused by arson and by debris burning had the same number of records, with a mean of 64.29 per year. The categories "campfire and related", "forest exploitation", "lightning", and "miscellaneous" were statistically equal ($p>0.05$) and had a mean of 9.47 per year. The categories “smokers” and “railroads” are provided by FAO, however, no records for either were observed in this study.

Among the 27 Brazilian states, including Distrito Federal, only Acre and Rio Grande do Norte had no fire occurrences recorded from 2006 to 2012. The state with the highest number of occurrences was Minas Gerais (with a mean of 56.42 per year), which also stood out for being the only in which debris burning was the main cause of fires, surpassing fires of unknown causes (Figure 1). Besides Minas Gerais, the states with the highest number of fires were Ceará and Rio de Janeiro ($p>0.05$), with a mean of 37.71 per year, followed by Mato Grosso, Piauí, and Bahia ($p>0.05$), with a mean of 21.76 per year, and Alagoas, Tocantins, Paraná, Rio Grande do Sul, Paraíba, and Distrito Federal ($p>0.05$), with a mean of 10.42 per year. The other states had a mean of 1.91 per year.

Figure 1 – Number of fire occurrences by state and cause in Brazilian federal protected areas from 2006 to 2012. Legend: debris burning (DB), miscellaneous (ML), forest exploitation (FE), campsite or related (CS), arson fire (AF), lightning (LT), unknown (UN)



Source: Authors (2023)

Combined, eight federal PAs concentrated 395 occurrences, of which 26% occurred in the Sempre-Vivas National Park, 18% in the Serra do Cipó National Park, and 15% in the Serra da Canastra National Park.

The states with the highest number of federal PAs are Bahia (137), Minas Gerais (107), Rio de Janeiro (83), and São Paulo (63) (MMA, 2019). An empirical index obtained by dividing the number of occurrences by the number of federal PAs was calculated for a comparison between states, with results of 1.40; 3.69; 3.47; and 0.19, respectively, for the aforementioned states. The state with the highest index was Piauí (10.50), which has 14 federal PAs and 147 fire records, standing out for having 40% of all fire occurrences in the country caused by hunting (23 of 57 records).

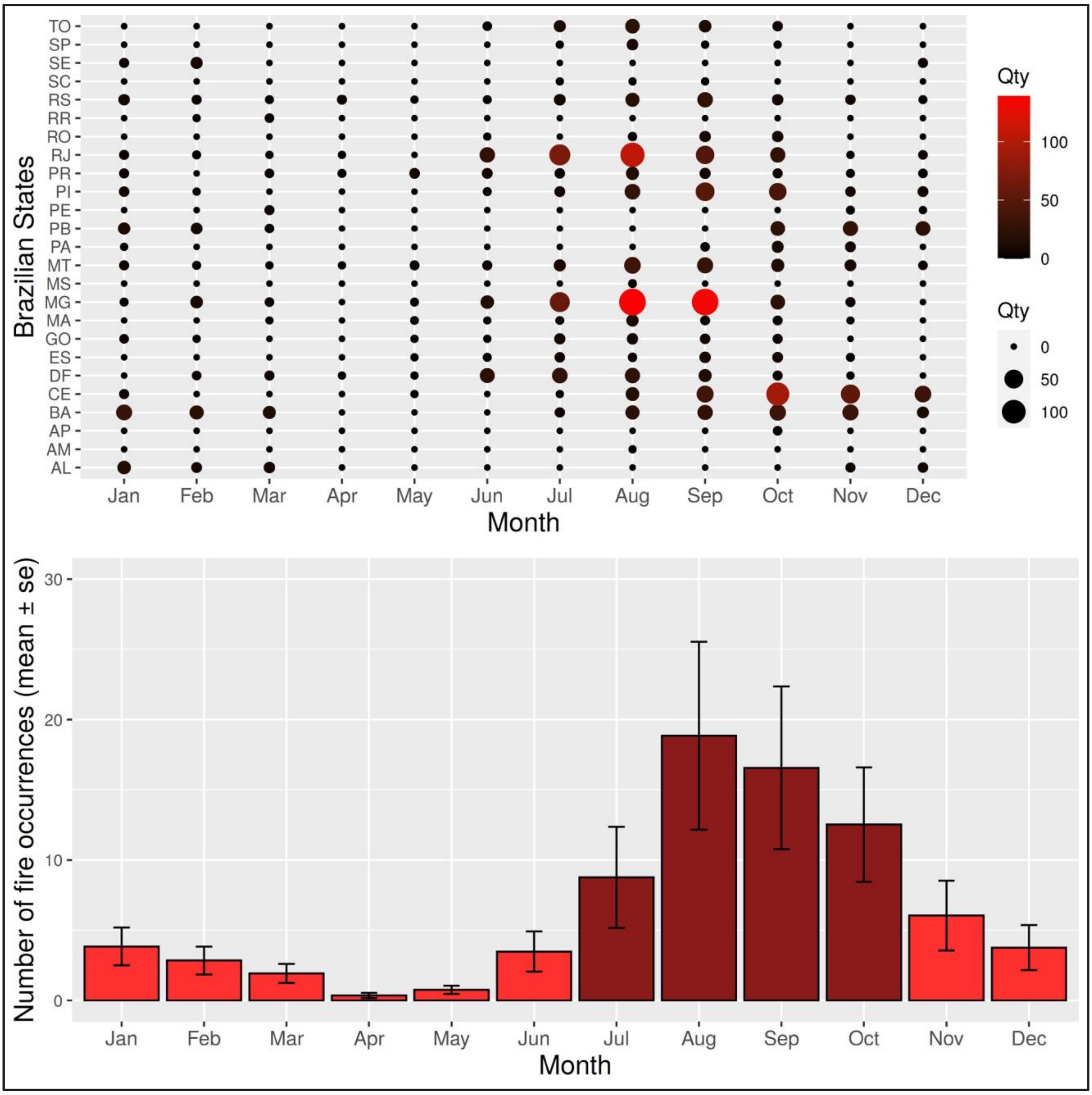
The number of fires was higher from July to October ($p>0.05$), corresponding to the critical period for fires in Brazilian federal PAs, with a mean of 50.61 events per year (Figure 2).

4 DISCUSSION

The records without a specified fire cause, as well as those recorded as "unknown cause", reveal a failure in the fire investigation or in the preparation of the ROIs, which need to be carefully filled out in order to issue a reliable report (IBAMA, 2007). The lack of regularity in the recording of forms and the incomplete data sent to PREVFOGO by several PAs may occur due to inadequate structure and insufficient personnel or the absence of basic information, such as the size of the burned area, geographical coordinates, cause of the fire and type of vegetation affected (IBAMA, 2007). This indicates the need for investment in training, equipment, and tools to obtain reliable data on the occurrence and prevention of fires in PAs (BONTEMPO; LIMA; RIBEIRO; DOULA; SILVA; JACOVINE, 2011).

The amount of fires caused by debris burning, arson, and "unknown cause" was similar to that found by Torres, Lima, Costa, Félix and Silva Júnior (2016), who evaluated federal PAs between 2008 and 2012. The fire causes mentioned above are the most common in the majority of regions, propitiated by human activities around PAs (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016).

Figure 2 – Number of fire occurrences by month and state in Brazilian federal protected areas from 2006 to 2012 (top graph). Mean and standard error (se) per month for fire occurrences in Brazilian federal protected areas from 2006 to 2012 (bottom graph)



Source: Authors (2023)

The socioeconomic activities developed by people trigger forest fires (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). Agricultural fires reach the surrounding vegetation, becoming the main cause of fires in tropical forests (BARLOW; PARRY;

GARDNER; FERREIRA; ARAGÃO; CARMENTA; BERENGUER; VIEIRA; SOUZA; COCHRANE, 2012). Fires caused by debris burning occur due to inadequate burning techniques for land preparation and pasture renewal, carried out between winter and early spring, when the vegetation is dry and there are favorable meteorological conditions for fire spread (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013).

Environmental awareness actions focused on the rational use of fire are important for landowners neighboring PAs to learn and properly apply burning techniques, in accordance with environmental legislation. The diagnosis of burning techniques used around PAs is essential for their managers to design and implement a participatory environmental education program (MAGALHÃES; LIMA; RIBEIRO, 2012).

Criminal fires have diverse and complex motivations and, therefore, it is crucial to know the period of occurrence of these fires to intensify surveillance in PAs (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013), aiming to prevent the crime and penalize those involved.

Fires with unknown or criminal causes also occur recurrently in countries with environmental characteristics different from Brazil. In Bohemia Switzerland National Park (BSNP), located in the Czech Republic, 83% of fires are of unknown cause (ADÁMEK; BOBEK; HADINCOVÁ; WILD; KOPECKÝ, 2015). In southern France, fires caused by arsonists account for 42% in areas larger than 100 hectares (including pyromaniacs, hunters, and fishermen), followed by unknown cause (30%) and negligence (20%) (GANTEAUME; JAPPIOT, 2013).

The results of this study corroborate with the low occurrence of fires caused by smokers or railroads reported in other studies. In the period between 1998 and 2002, the category “smoker” corresponded to 1.65% of the occurrences in protected areas, while the category “railroads” corresponded to 0.11% (SANTOS; SOARES; BATISTA, 2006). Whereas between 1994 and 1997, the category “smokers” corresponded to 6.1% and the category “railroads” corresponded to 1.6%, also being among the categories with the lowest occurrence (SOARES; SANTOS, 2002).

Lightning is the only cause of natural fires in Brazil, however, this type of fire is not frequent, corresponding to less than 1.5% of reported cases in PAs (SANTOS; SOARES; BATISTA, 2006), as they occur predominantly in the rainy season (SILVA JUNIOR; TEODORO; DELGADO; TEODORO; LIMA; PANTALEÃO; BAIO; AZEVEDO; AZEVEDO; CAPRISTO-SILVA; ARVOR; FACCO, 2020), when combustible material has a higher humidity. The "miscellaneous" category has low occurrence and includes causes that do not fit into the other categories (SOARES, 1988).

The PAs in Acre and Rio Grande do Norte are located exclusively within the geographic boundaries of these states, i.e., they do not share their territories with neighboring states. Both states are among those with the lowest number of PAs nationwide, with 12 and 11, respectively (MMA, 2019). On the other hand, the state of Minas Gerais encompasses 107 federal PAs (MMA, 2019). However, most of the PAs (60%) in Minas Gerais exhibit unsatisfactory management effectiveness and 87% do not have a management plan, leading to noncompliance with the main objectives for which these PAs were created (LIMA; RIBEIRO; GONÇALVES, 2005).

The higher occurrence of forest fires in the state of Minas Gerais may be related to the extended dry season throughout most of the territory (SOARES; SANTOS, 2002). Minas Gerais also stood out regarding the number of forest fire occurrences between 1994 and 1997, with 62.7% of the reported cases, followed by São Paulo with 14.2% and Paraná with 9.6% (SOARES; SANTOS, 2002), which corroborates the results of the present study. In addition, from 1998 to 2002, Minas Gerais accounted for 50.3% of the reported cases, followed by Espírito Santo and Bahia, with 24.8% and 10.1%, respectively (SANTOS; SOARES; BATISTA, 2006).

Forest fires caused by debris burning have a greater chance of getting out of control when they occur during the dry period that predominates in Minas Gerais. During this critical period, farmers usually use fire to renew pastureland or for debris burning (PIVELLO, 2011). A large part of the population has no equipment to carry out prescribed burning. Moreover, there is a lack of knowledge about firefighting techniques and the most favorable hours and period of the year for conducting prescribed burning (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013). Thus, it is essential that environmental agencies provide information on the rational use of fire, in order to minimize its negative effects, as well as raise awareness among the population about the most appropriate periods for burning, and the availability of alternative management techniques (RODRÍGUEZ; SOARES; BATISTA; TETTO; BECERRA, 2013).

In Minas Gerais, among fires of anthropic cause, those caused by arsonists occur in large proportion. These criminal events are difficult to prevent, since their motivations are diverse and complex. In this sense, it is essential to combine preventive and inhibitory actions, such as environmental education and surveillance (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013).

Ceará encompasses 46 federal PAs, of which three also cover neighboring states (MMA, 2019). The climate is hot and dry, with high average temperatures (23 to 27ºC) and negative annual water balance (BARRETO; SANTOS; CRUZ, 2012). These characteristics favor the ignition and spread of fire (SOARES; SANTOS, 2002).

In Rio de Janeiro, a maximum fire alert was declared in October 2007 by the State Secretary of the Environment (SEA, in Portuguese) and the State Forestry Institute (IEF, in Portuguese), due to the extended dry season that favored the increasing number of fire occurrences in the state (IEF/RJ, 2007). It is worth noting that there are many municipalities in Rio de Janeiro, especially the state capital, with sugarcane crops, where management is based on debris burning (FERNANDES; COURA; SOUSA; AVELAR, 2011).

The higher occurrence of fires between July and October is due to the dry season experienced by most of the Brazilian territory and corresponds to the period between winter and spring. During this period, farmers commonly use fire to manage their agricultural areas, despite the low humidity of the combustible material on the ground and the favorable meteorological conditions for fire propagation (SOARES; SANTOS, 2002). Furthermore, it is worth mentioning that frosts, which are common in the southern region of the country, create favorable conditions for fires to occur (SEGER;

BATISTA; TETTO; SOARES; BIONDI, 2018). The fires in PAs reported between 1994 and 1997 by Soares and Santos (2002) were concentrated in a similar period, with 82.4% of the occurrences from June to October. The same pattern was observed by Santos, Soares and Batista (2006) between 1998 and 2002, in which 68.9% of the fires occurred in the same months. Arson can occur throughout the year, under the most varied meteorological conditions, and tend to affect larger areas when they occur in the dry season (SOARES; SANTOS, 2002). In order to reduce such occurrences, environmental education and surveillance actions are essential, especially during the critical fire period (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013). Knowledge about the months with the highest occurrence of fires is of utmost importance, since it allows planning more effective preventive actions (SOARES; SANTOS, 2002). Fire prevention is more feasible, operationally and economically, than firefighting (SOARES; SANTOS, 2002). Combat actions include high costs related to setting up the operation and suppressing the fire itself. There are also economic losses due to the destruction of forest resources (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015).

5 CONCLUSIONS

The main causes of forest fires in federal PAs from 2006 to 2012 were “unknown”, “debris burning”, and “arson”. The high number of fires recorded with an unknown cause reveals a need for improving the investigation of fire causes. The fires caused by debris burning, in turn, point to a need for environmental education actions within the communities surrounding the PAs, as well as technical guidance on the rational use of fire. The recurrence of fires caused by arsonists indicates that surveillance also needs to be improved.

The period with the highest fire occurrence was from July to October, when PAs managers should be ready to execute firefighting actions that were planned during the period of lowest occurrence (November to June).

The Brazilian state with the highest occurrence of fires in federal PAs during the evaluated period was Minas Gerais, and debris burning was the main cause recorded. The state of Piauí also stood out, since there was a significant number of fire occurrences recorded even though there is a small number of federal PAs in its territory.

The diagnosis of fires in Brazilian federal PAs regarding their causes and period of greatest occurrence enables the development of prevention and firefighting strategies suited to each situation. Failures in filling out the ROIs could be minimized through training of PA personnel, especially fire brigades, thus providing information for improving environmental education and surveillance programs.

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REFERENCES

ADÁMEK, M.; BOBEK, P.; HADINCOVÁ, V.; WILD, J.; KOPECKÝ, M. Forest fires within a temperate landscape: a decadal and millennial perspective from a sandstone region in central Europe. **Forest Ecology and Management**, Amsterdam, v. 336, p. 81–90, 2015.

AXIMOFF, I.; RODRIGUES, R. de C. Histórico dos incêndios florestais no Parque Nacional do Itatiaia. **Ciência Florestal**, Santa Maria, v. 21, n. 1, p. 83–92, 2011.

BARLOW, J.; PARRY, L.; GARDNER, T. A.; FERREIRA, J.; ARAGÃO, L. E. O. C.; CARMENTA, R.; BERENGUER, E.; VIEIRA, I. C. G.; SOUZA, C.; COCHRANE, M. A. The critical importance of considering fire in REDD+ programs. **Biological Conservation**, London, v. 154, p. 1–8, 2012.

BARRETO, H. B. F.; SANTOS, W. de O.; CRUZ, C. M. da. Análise da distribuição da precipitação pluviométrica média anual no estado do Ceará. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, Pombal, v. 7, n. 2, p. 122–128, 2012.

BONTEMPO, G. C.; LIMA, G. S.; RIBEIRO, G. A.; DOULA, S. M.; SILVA, E.; JACOVINE, L. A. G. Registro de Ocorrência de Incêndio (ROI): evolução, desafios e recomendações. **Biodiversidade Brasileira**, Brasília, v. 1, n. 2, p. 247–263, 2011.

CAMARGO, A. C. L.; BARRIO, R. O. L.; CAMARGO, N. F. de; MENDONÇA, A. F.; RIBEIRO, J. F.; RODRIGUES, C. M. F.; VIEIRA, E. M. Fire affects the occurrence of small mammals at distinct spatial scales in a neotropical savanna. **European Journal of Wildlife Research**, Berlim, v. 64, n. 6, p. 63, 2018.

FERNANDES, M. do C.; COURA, P. H. F.; SOUSA, G. M. de; AVELAR, A. de S. Avaliação geoecológica de susceptibilidade à ocorrência de incêndios no estado do Rio de Janeiro, Brasil. **Floresta e Ambiente**, Seropédica, v. 18, n. 3, p. 299–309, 2011.

GANTEAUME, A.; JAPPIOT, M. What causes large fires in Southern France. **Forest Ecology and Management**, Amsterdam, v. 294, p. 76–85, 2013.

HANSEN, J.; RUEDY, R.; SATO, M.; LO, K. Global surface temperature change. **Reviews of Geophysics**, Washington, D.C., v. 48, n. 4, RG4004, 2010.

IBAMA – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. **Relatório de ocorrências de incêndios em unidades de conservação federais**: 2006. Brasília: IBAMA, 2007.

IEF/RJ – Instituto Estadual de Florestas do Rio de Janeiro. ASCOM (Assessoria de Comunicação). **Incêndios florestais colocam IEF em alerta máximo**. 2007. Available at: http://www.ief.rj.gov.br. Accessed on: 15 nov. 2016.

IRLAND, L. C. Extreme value analysis of forest fires from New York to Nova Scotia, 1950-2010. **Forest Ecology and Management**, Amsterdam, v. 294, p. 150–157, 2013.

JOLLY, W. M.; COCHRANE, M. A.; FREEBORN, P. H.; HOLDEN, Z. A.; BROWN, T. J.; WILLIAMSON, G. J.; BOWMAN, D. M. J. S. Climate-induced variations in global wildfire danger from 1979 to 2013. **Nature Communications**, London, v. 6, p. 7537, 2015.

LIMA, G. S.; RIBEIRO, G. A.; GONÇALVES, W. Avaliação da efetividade de manejo das unidades de conservação de proteção integral em Minas Gerais. **Revista Árvore**, Viçosa, v. 29, n. 4, p. 647–653, 2005.

MAGALHÃES, S. R. de; LIMA, G. S.; RIBEIRO, G. A. Avaliação dos incêndios florestais ocorridos no Parque Nacional da Serra da Canastra – Minas Gerais. **Cerne**, Lavras, v. 18, n. 1, p. 135–141, 2012.

MARCUZZO, S. B.; ARAÚJO, M. M.; GASPARIN, E. Plantio de espécies nativas para restauração de áreas em unidades de conservação: um estudo de caso no sul do Brasil. **Floresta**, Curitiba, v. 45, n. 1, p. 129–140, 2015.

MMA – Ministério do Meio Ambiente. **Cadastro Nacional de Unidades de Conservação**. 2019. Available at: http://www.mma.gov.br/areas-protegidas/cadastro-nacional-de-ucs. Accessed on: 29 apr. 2019.

PÉREZ-SÁNCHEZ, J.; JIMENO-SÁEZ, P.; SENENT-APARICIO, J.; DÍAZ-PALMERO, J. M.; CABEZAS-CEREZO, J. de D. Evolution of burned area in forest fires under climate change conditions in southern Spain using ANN. **Applied Sciences (Switzerland)**, Basel, v. 9, n. 19, p. 4155, 2019.

PEZZATTI, G. B.; ZUMBRUNNEN, T.; BÜRGI, M.; AMBROSETTI, P.; CONEDERA, M. Fire regime shifts as a consequence of fire policy and socio-economic development: an analysis based on the change point approach. **Forest Policy and Economics**, Amsterdam, v. 29, p. 7–18, 2013.

PIVELLO, V. R. The use of fire in the Cerrado and Amazonian rainforests of Brazil: past and present. **Fire Ecology**, Berna, v. 7, n. 1, p. 24–39, 2011.

RODRÍGUEZ, M. P. R.; SOARES, R. V.; BATISTA, A. C.; TETTO, A. F.; BECERRA, L. W. M. Comparação entre o perfil dos incêndios florestais de Monte Alegre, Brasil, e de Pinar Del Río, Cuba. **Floresta**, Curitiba, v. 43, n. 2, p. 231–240, 2013.

SANTOS, J. F.; SOARES, R. V.; BATISTA, A. C. Perfil dos incêndios florestais no Brasil em áreas protegidas no período de 1998 a 2002. **Floresta**, Curitiba, v. 36, n. 1, p. 93–100, 2006.

SEGER, C. D.; BATISTA, A. C.; TETTO, A. F.; SOARES, R. V.; BIONDI, D. Caracterização do material combustível fino da estepe gramíneo-lenhosa no estado do Paraná, Brasil. **Ciência Florestal**, Santa Maria, v. 28, n. 2, p. 863–874, 2018.

SETIANI, P.; DEVIANTO, L. A.; RAMDANI, F. Rapid estimation of CO_2 emissions from forest fire events using cloud-based computation of google earth engine. **Environmental Monitoring and Assessment**, Amsterdam, v. 193, v. 10, p. 669, 2021.

SILVA JUNIOR, C. A. da.; TEODORO, P. E.; DELGADO, R. C.; TEODORO, L. P. R.; LIMA, M.; PANTALEÃO, A. de A.; BAIO, F. H. R.; AZEVEDO, G. B. de; AZEVEDO, G. T. de O. S.; CAPRISTO-SILVA, G. F.; ARVOR, D.; FACCO, C. U. Persistent fire foci in all biomes undermine the Paris Agreement in Brazil. **Scientific Reports**, London, v. 10, n. 1, p. 16246, 2020.

SOARES, R. V. Perfil dos incêndios florestais no Brasil de 1984 a 1987. **Floresta**, Curitiba, v. 18, n. 1–2, p. 94–121, 1988.

SOARES, R. V.; SANTOS, J. F. Perfil dos incêndios florestais no Brasil de 1994 a 1997. **Floresta**, Curitiba, v. 32, n. 2, p. 219–232, 2002.

TEBALDI, A. L. C.; FIEDLER, N. C.; JUVANHOL, R. S.; DIAS, H. M. Ações de prevenção e combate aos incêndios florestais nas unidades de conservação estaduais do Espírito Santo. **Floresta e Ambiente**, Seropédica, v. 20, n. 4, p. 538–549, 2013.

TORRES, F. T. P.; RIBEIRO, G. A.; MARTINS, S. V.; LIMA, G. S. Perfil dos incêndios em vegetação nos municípios de Juiz de Fora e Ubá, MG, de 2001 a 2007. **Floresta e Ambiente**, Seropédica, v. 17, n. 2, p. 83–89, 2010.

TORRES, F. T. P.; LIMA, G. S.; COSTA, A. das G.; FÉLIX, G. de A.; SILVA JÚNIOR, M. R. da. Perfil dos incêndios florestais em unidades de conservação brasileiras no período de 2008 a 2012. **Floresta**, Curitiba, v. 46, n. 4, p. 531–542, 2016.

ZHANG, Y.; LIM, S.; SHARPLES, J. J. Modelling spatial patterns of wildfire occurrence in South-Eastern Australia. **Geomatics, Natural Hazards and Risk**, v. 7, n. 6, p. 1800–1815, 2016.

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4. ARTIGO 2: INFLUÊNCIA DO FOGO SOBRE A COMUNIDADE DE FORMIGAS EM AMBIENTES SAVÂNICOS E FLORESTAIS DO BIOMA CERRADO

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ORIGINAL ARTICLE – Conservation of Nature

Fire Influence on the Ants Community in Savanic and Forest Environments of the Cerrado Biome

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Abstract

The objective of this work is to evaluate the effect of fire on ant assemblages in savanna and forest typologies in the Reserva Natural da Serra do Tombador in Cavalcante – Goiás, Brazil. Ant pitfalls traps were installed and subdivided into Burnt Cerrado (BC), Unburnt Cerrado (UC), Burnt Forest (BF) and Unburnt Forest (UF), and the samples were sorted, assembled and identified. The constancy and abundance of individuals, and the frequency of distribution of the genera in the total area and by treatment were evaluated. The UF, BF, UC and BC had 19, 14, 8 and 15 genera, with Jackknife 1 index indicating 18.5, 24.4, 8.9 and 20.4 respectively. The Shannon diversity index for the genera was 0.8462, 0.7604, 0.6448 and 0.5992 for UF, BF, BC and UC respectively. The Cerrado showed greater abundance of individuals and greater ant diversity index in relation to Forest when in presence of fire.

Keywords: Wildfires, Insect, Formicidae, Bioindicator, Forestry.

1. INTRODUCTION AND OBJECTIVES

Wildfire is considered a phenomenon that causes major economic, environmental and social impacts (JAFARI GOLDARAG et al., 2016; KAYET et al., 2020), which could get worse in the next decades due to climate change that could trigger an increase of these fires (FLANNIGAN et al., 2013; JOLLY et al., 2015). Fire can shape the landscape and change the habitat, flora and fauna structures in a drastic way, reducing the area of forests and other natural environments (AXIMOFF & RODRIGUES, 2011; CAMARGO et al., 2018).

In the tropics, the Cerrado is the biome with the highest amount of forest fires and burnt areas (SCHMIDT & ELOY, 2020). Savannas can be characterized by continuous grass layers with scattered trees and shrubs, growing under dry seasonality and warm climatic conditions (ALVARADO et al., 2017). In Brazil, the Cerrado (Savanna) is a large fire-prone ecosystem, and it has evolved under the influence of fire (PIVELLO, 2011), covering about 2 million km², which represents about 25% of the country's area (DURIGAN & RATTER, 2016). Vegetation in the Cerrado consists of different landscapes along environmental gradients and fire disturbances, such as savanna physiognomies, in greater proportions, and campestral and forest formations (BUENO et al. 2018). The thick rhytidome, tubercles, bulbs, shoots, underground rhizomes, thick bark and the typical tortuous shape of tree species are characteristics of the savanna fire adaptation (GOTTSBERGER & SILBERBAUER, 2006; COSTA-MILANEZ et al., 2015). Moreover, fire is considered an important event for the maintenance of the biodiversity in the biome (MARAVALHAS & VASCONCELOS, 2014; KELLY & BROTONS, 2017), and it is considered an important evolutionary force once it resumes the savanna ecological succession stage, benefiting certain species and the dynamic environments (KEELEY et al., 2012). However, the increase in deforestation caused by pastures and agricultural crops using fire (PEREIRA JÚNIOR et al., 2014; DALLE LASTE et al., 2019) and the rise in global temperature (BEDIA et al., 2014; EUGENIO et al., 2016; JOLLY et al., 2015; STEPHENS et al., 2020) threaten the savanna integrity. It is estimated that more than half of the Cerrado vegetation coverage has already disappeared (BEUCHLE et al., 2015).

In the savanna, due to its heterogeneous vegetation (SANO et. al, 2019) with different formations and types of forests, the woody composition is different along the gradient, mainly where it is related to fire-adapted and fire-independent species (HAIDAR et al., 2013). In typical forest physiognomies, wildfires stunt the natural regeneration (SANTOS et al., 2018). Tropical forests are more fire-sensitive environments, where a single fire event can drastically change the vegetation structure (BARLOW et al., 2003). The flammability of savannas and tropical forests tends to increase due to factors such as fragmentation and land usage changes (VELDMAN, 2016), and alterations after a fire event and its effects in these environments can be monitored by bioindicators (SILVEIRA et al., 2013).

Ants are widely used as bioindicators (RIBAS et al., 2012) once they indicate degradation or conservation in different areas (SILVA et al., 2013; OBERPRIELER & ANDERSEN, 2020) and in fire disturbance (ARCUSA, 2019). Fire causes direct or indirect effects on ants, altering the structure of their habitats, harming species richness and the composition of their functional groups (ANDERSEN et al., 2012; SILVEIRA et al., 2012; PAOLUCCI et al., 2016).

The foraging and nesting of Formicinae colonies are extensive, however they may be restricted to some specific micro-habitat, once they can be affected by temperature variations, humidity and resources availability (HOLLDOBLER & WILSON, 1990; AGOSTI et al., 2000; FÉRNANDEZ & SHARKEY, 2006). The type and intensity of degradation or alteration in the environment can produce different responses, by benefiting or harming species (ROCHA et al., 2015). Wildfires damage the soil ecosystems and compromise their functionality, reducing the diversity of some of the organisms in it, although it can also favor fire-adapted flora and fauna (ZAITSEV et al., 2016).

The objective of this work is to evaluate the effect of fire on ant assemblages in savanna and forest typologies in Brazilian Central-West region. The occurrence, distribution and abundance of genera in unburned and post-fire areas were evaluated in these two typologies. Understanding the effects of disturbance on communities is important to direct conservation efforts and manage ecological resources (DORNELAS, 2010), and it is also necessary to know the effect of the heterogeneity provided by fire on the diversity of ant species in vulnerable environments (TAYLOR et al., 2012). Many works present the responses of ants after a fire event in Cerrado and Atlantic Forest biomes (HOFFMAN et al., 2009; PACHECO & VASCONCELOS, 2012; MARAVALHAS & VASCONCELOS, 2014; VASCONCELOS et al., 2017), however they do not compare these responses in different phytophysiognomies in the same area of study.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in a protected area (Reserva Particular de Patrimônio Natural - RPPN) called Reserva Natural da Serra do Tombador (RNST) located in the municipality of Cavalcante, in the north of Goiás state, in Brazil. The area has 8730 ha and was converted into a Protected Area in 2007, by Fundação Grupo Boticário de Proteção à Natureza, as contribution to the conservation of the Cerrado biome (FUNDAÇÃO GRUPO BOTICÁRIO, 2011) (Figure 1).

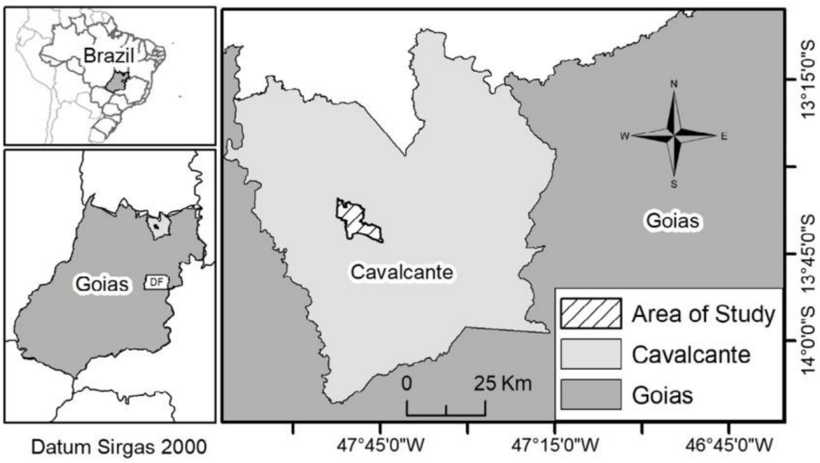

Figure 1. Localization of the Reserva Natural Serra do Tombador, Goiás, Brazil.

The RNST is located in a classic Cerrado vegetation area with distinct formations and it is covered by a mosaic of savanna vegetation that goes from open to closed ones, with grassland vegetation and forest formations. There are five predominant landscapes in the RNST: Savanna is dominant (78.0%), mostly represented by the Cerrado and Campo Rupestre; the forest landscape (20.0%) is represented by the Dense Ombrophilous Forest and Semideciduous Seasonal Forest and the other typologies are Anthropogenic formations (2.0%), Veredas (0.8%) and Rocky Outcrop (0.3%) (FUNDAÇÃO GRUPO BOTICÁRIO, 2011).

The region is located in the hydrographic basin of the Tocantins River with a warm and semi-humid Aw type climate (Koppen) with a dry season in winter (RIBEIRO et al., 2008). The temperature in 2017 ranged from 12ºC to 35ºC and precipitation from 7 to 319mm. June, July and August months are generally dry (00mm) and the rainy season occurs between November and March, with an average monthly rainfall of 132mm (INMET, 2018). In October 2017, anthropogenic originated fire affected more than 80% of the protected area.

2.2. Data collect

Ant traps were installed in the RNST savanna and forest formations. These typologies were subdivided into burnt areas (affected by the fire) and unburned areas (not affected) with the same ecological conditions as the areas were burned before the fire, totaling four treatments in forest formations: Burnt Forest (BF) and Unburnt Forest (UF) and in savanna formations: Burnt Cerrado (BC) and Unburnt Cerrado (UC).

Pitfalls traps were used to sample the ant fauna (adapted from BOSCARDIN et al., 2014). The traps were made from a 400mL plastic container with 100mL of alcohol and 100mL of water, and they were protected by plastic lids 10cm above the container. A linear 100m transect was made in each treatment and ten traps were placed 10m apart from each other in the transect, totaling 40 traps in the four above paragraph mentioned areas. The 100m transect arranged in 10 traps is a suggested methodology to standardize surveys with the Formicidae family, as there would be no variations in ant composition at distances of up to 100 meters within a forest area (SARMINENTO-M, 2003). The traps were left in the field for 48 hours. The traps were installed on February 22, 2018 and left in the field for 48 hours, being collected on February 24, 2018.

Then, the samples were sent to the Community Ecology Laboratory of the Universidade Federal de Viçosa (LabEcol/UFV) for sorting, assembly and identification of the species (BACCARO et al., 2015).

2.3. Statistical analysis

After identifying and quantifying the species (Annex), the constancy and abundance of individuals and the frequency of genera distribution in the total area were evaluated by treatment in R environment. The richness estimator indices of Jacknife 1st order, Sorensen similarity and Shannon diversity to identify the similarity and diversity between the genera of the areas were obtained.

The dataset was tabulated and analyzed using generalized linear modeling (GLM) in R statistical software and graphs were created by using the ggplot2 package (WICKHAM, 2016).

3. RESULTS

In the total grouping of data, 1,397 individuals of 72 species (Annex), distributed in 28 genera of seven subfamilies were collected. The richest subfamily in diversity was Myrmicinae, with 38 species and 11 genera (approximately 57% of individuals). The genus *Pheidole* (Myrmicinae) was the most representative in number (49.03%) followed by *Ectatomma* (Ectatomminae) (10.74%) (Table 1).

Table 1. Formicidae genera distribution by treatment in Cerrado vegetation types, Reserva Nacional Serra do Tombador, Goiás, Brazil.

Subfamily/*Genus*	UF	BF	UC	BC	Total
Dolichoderinae					20
Dolichoderus	2	-	-	-	2
Dorymyrmex	-	-	-	12	12
Forelius	-	-	-	1	1
Linepithema	3	-	-	2	5
Ectatomminae					287
Ectatomma	37	30	83	-	150
Gnamptogenys	16	16	-	105	137

Table 1. Continued...

Subfamily/*Genus*	UF	BF	UC	BC	Total
Formicinae					115
Brachymyrmex	3	-	3	2	8
Camponotus	3	13	9	75	100
Nylanderia	6	1	-	-	7
Myrmicinae					798
Acromyrmex	1	-	-	-	1
Atta	10	9	-	-	19
Cephalotes	-	1	-	-	1
Crematogaster	3	-	-	8	11
Mycocepurus	-	-	-	4	4
Ochetomyrmex	-	37	-	7	44
Pheidole	99	155	103	328	685
Sericomyrmex	4	16	-	-	20
Solenopsis	-	1	6	-	7
Trachymyrmex	1	-	-	3	4
Wasmannia	2	-	-	-	2
Non-Identified					1
Non-Identified	-	-	-	1	1
Ponerinae					86
Centromyrmex	-	-	1	-	1
Dinoponera	1	-	24	5	30
Hypoponera	-	1	-	-	1
Neoponera	3	26	9	-	38
Odontomachus	3	8	-	1	12
Pachycondyla	3	1	-	-	4
Pseudomyrmecinae					90
Pseudomyrmex	20	-	-	70	90
TOTAL	220	315	238	624	1397

Where: forest formations = Burnt Forest (BF) and Unburnt Forest (UF) savana formations = Burnt Cerrado (BC) e Unburnt Cerrado (UC)

The BC treatment was the most representative in number (44.67%), while the UF was the least one (15.75%). BF and UC represented 22.55% and 17.04% of the individual's abundance, respectively. According to Figure 2, the fire episode revealed no difference in abundance in the forest formation (BF x UF), unlike the treatments in the savanna formation (BC x UC), which showed greater abundance of ants in BC. The similarity of *Sorensen* by genus showed that the BC and UC treatments showed no similarity (0.35), while the BF and the UF showed it (0.61).

The distribution of genera types was different among treatments. Out of the 28 genera found, UF presented 19 and BF presented 14, with Jackknife 1 index indicating 18.5 and 24.4 respectively to these treatments. UC had a smaller number of genera (8) and BC presented 15, with 8.9 and 20.4 of Jackknife 1 index, respectively. In the savanna formation, *Gnamptogenys* and *Pseudomyrmex* stood out for appearing with a high representation of individuals in the burned area. On the other hand, the genus *Ectatomma*, which showed high distribution in the UC, was not represented in the savanna formation affected by fire. The genus *Ochetomyrmex*, not found in the UF, was highly representative in the BF. *Pseudomyrmex*, which was distributed in UF, was not found at BF. The genera *Pheidole* and *Camponotus* were the only ones present in all treatments. The *Atta* genus only occurred in forest treatment, before and after burning (Figure 3).

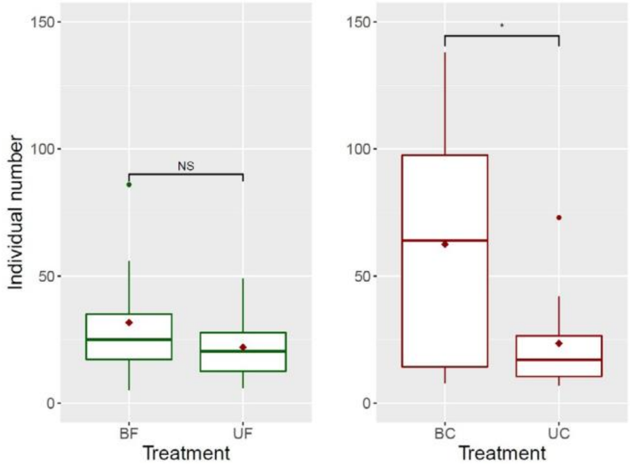

Figure 2. Distribution of Formicidae individuals by treatments in the Reserva Nacional Serra do Tombador, Goiás, Brazil.

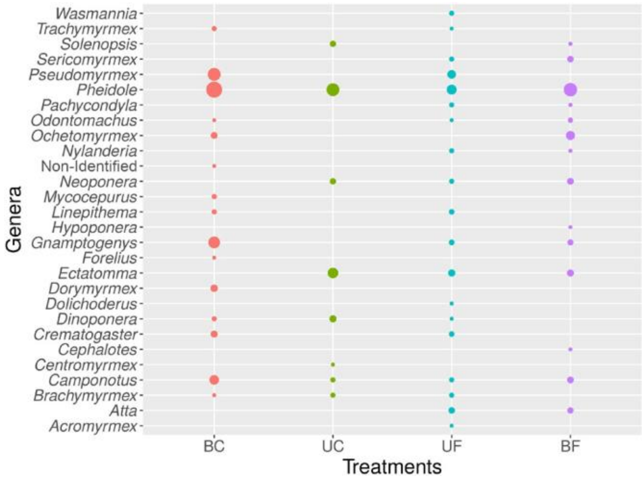

Figure 3. Distribution of Formicidae genera by treatment in the Reserva Nacional Serra do Tombador, Goiás.

The *Shannon* diversity index for the forest area genera was 0.8462 for the area not affected by fire and 0.7604 for the affected area. The index values for the savanna area were 0.6448 for the burned environment and 0.5992 for the unburned environment.

4. DISCUSSION

In several studies in Brazil central region, Myrmicinae was also the subfamily with the highest species richness (SOARES et al., 2010; MARAVALHAS & VASCONCELOS, 2014). In the entire Neotropical region, Myrmicinae is the largest and most diverse subfamily, with ease in adaptation to different ecological niches, high degree of social complexity (DORVAL et al., 2017) and presence in a wide variety of habitats, from tropical forests to savannas and deserts (WILSON, 2003). In the region of Uberlândia, Prata and Caldas Novas cities, located in the center of Brazil, in footpaths, thin savannah, dense savanna and savannah vegetation, 135 species of ants were recorded in pitfalls traps, being *Pheidole* the most diversified genus (20%), followed by *Camponotus* (16%) (PACHECO & VASCONCELOS, 2012). Collections in native cerrado and eucalyptus areas in Ivinhema city, Mato Grosso do Sul state, in midwest region of Brazil, registered the genus *Pheidole* with the highest number of species, followed by *Ectatomma* and *Camponotus*, with *Pheidole* being the most abundant genus both in the Cerrado and in the eucalyptus areas (SOARES et al., 2010). *Pheidole* is one of the largest genera, being generalists, occurring in different environments and having high numerical dominance and hyperdiversity, present in areas of tropical forests, savannas and deserts (WILSON, 2003; ECONOMO et al., 2014). *Ectatomma* is found in various environments, from forests to savannas, as they have nomadic life habits, are generalist predators and need a greater variety of habitats to forage in search of food resources (HOLLDOBLER & WILSON, 1990; BACCARO et al., 2015).

In general terms, both in forests and in the cerrado, fire may not significantly affect the abundance of ants, but it interferes in the diversity of genera (VASCONCELOS et al., 2017). However, ecosystems that depend on the maintenance of more dynamic ecological states may benefit from fire, unlike ecosystems characterized by a stable climatic condition, which can be harmed by fires (HOFFMAN et al., 2009; VASCONCELOS et al., 2017). Savannas are ecosystems considered dependent on fire, with a burning process that helps in their maintenance (HOFFMAN et al, 2009; VASCONCELOS et al., 2017).

Variable fire regimes can produce habitat heterogeneity, benefiting myrmecory (MARAVALHAS & VASCONCELOS, 2014). Besides the local variations in the incidence of fire in nutrient content and soil moisture that lead to large variations in plant cover, the mosaic of plant formations found in the Cerrado is an important factor for the maintenance of ant species (PACHECO & VASCONCELOS, 2012). Maravalhas & Vasconcelos (2014) support the pyrodiversity/biodiversity hypothesis for neotropical savanna ants, in which a fire regimes mosaic may be crucial for the maintenance of ant species (ARAÚJO et al., 2013).

In tropical forests, wildfires are rarer when comparing to Cerrado, as they do not have characteristics of adaptation to burning, such as resistant plants (HOFFMAN et al., 2009). Changes in the structure of vegetation caused by fire can cause changes in ant communities, reducing the abundance of forest specialist ants (PAOLUCCI et al., 2017), as well as the severity and frequency of fire influence on the constitution of invertebrates in general (GONGALSKY & PERSSON, 2013; BUCKINGHAM et al., al., 2019). Also, the time since disturbance can affect species biotic factors, such as dispersal, physiology and competition (HUEBNER et al., 2012; MALMSTRÖM, 2012; AUCLERC et al., 2019).

Fire significantly decreases the diversity of ants in tropical forests (VASCONCELOS et al., 2017). This decrease in diversity may be related to the complexity of the forest environment and changes in vegetation structure after fire (BARLOW et al., 2003; PILON et al., 2021). Forest areas present greater leaves litter production, less tree spacing and greater biomass per unit area than the cerrado, increasing the biome's production and heterogeneity (SILVA et al., 2013). In forests and other habitats with strong vertical stratification, species diversity is high, but the relative dominance may be lower (PANIZZI & PARRA, 1991). More heterogeneous environments present greater availability of resources for generalist ant species and greater variety for specialist ones (RIBAS et al., 2003). Pacheco & Vasconcelos (2012) found, on average, less species variety in the structurally least complex habitat, despite the low variation in species abundance among the remaining habitats, and the strong differences in vegetation structure among them. In deserts, pastures and savannas, this behavior does not occur, as fire may not significantly affect both the abundance and diversity of ants, due to the adaptation of the cerrado to fire (VASCONCELOS et al., 2017), in addition to the hypothesis that fire promotes the biodiversity of this phytophysiognomy (ARAÚJO et al., 2013; MARAVALHAS & VASCONCELOS, 2014).

Some soil arthropods abundancy may increase with the fire frequency, while others may be harmed or not change (CAUT et al., 2014; CANEDO-JÚNIOR et al., 2016; ANJOS et al., 2017; FAGUNDES et al., 2018). The diet of the Formicidae family is classified by genera (FERNÁNDEZ et al., 2006), being influenced by variations in temperature, humidity and resource availability (HOLLDOBLERET & WILSON, 1990; CURBANI et al., 2021). However, their eating habits are diversified, what facilitates the exploring of most terrestrial ecosystems (JAFFE, 2004). Fire can alter species richness, composition and dominance, harming or benefiting them (RIBAS et al., 2012; ROCHA et al., 2015). Its intensity, frequency and extension change the competitive balance among species and, consequently, the structure of communities, benefiting species with generalist habits (FRIZZO et al., 2011).

Gnamptogenys are generally found in humid forests, but they appear in savanna areas, once they have generalist habits and benefit from different environments (RICO-GRAY et al., 2007; BACCARO et al., 2015), even with fire disturbance. *Pseudomyrmex* have nesting habits, building nests in dead and hollow plant branches (WARD, 1990), which may have favored their presence in BC. The *Ectatommas* are known as army ants, with nomadic and predatory life habits, and with a huge variety of habitats requirements to forage and move to find new food resources (HOLLDOBLER & WILSON, 1990). They are also generalists, but oftenly appear in savanna areas in South America and in humid forests (RICO-GRAY et al., 2007).

The *Ochetomyrmex* genus stands out for its richness in species and in great morphological variety, which turns it into a large representative genus of species for obtaining food, reproduction and nesting (BACCARO et al., 2015). It is restricted to South America, ranging from lowland tropical forests to the east of the Andes and nesting in plant litter (FERNÁNDEZ, 2003). The occurrence of *Pseudomyrmex* in unburned forest is due to the genus' preference for native vegetation (WARD, 1990) and because they are food dependent on plant products (FERNÁNDEZ & SHARKEY, 2006).

Pheidole and *Camponotus* are the most numerous genera of species in the family, with most of these species being omnivorous (BACCARO et al., 2015). Ants of the genus *Atta* belong to the tribe Attini (Myrmicinae), and use plant material as a substrate of symbiotic fungus – the genus' main food source (FOWLER & CLAVE, 1991). They are known as leaf-cutting ants or saúvas, also important herbivores of neotropical forests, due to their cutting leaves habit (COSTA et al., 2009). They are considered fire resistant because they proliferate in altered habitats or in early succession stages (SANTOS et al., 2008).

In tropical forest environments, ants are considered organisms with high richness and abundance in variety, representing more than 60% of the arthropod fauna, with differentiated composition and foraging (ELLWOOD et al., 2004), being found in all forest strata, from canopy to the ground (VASCONCELOS et al., 2008). Diversity in UF is greater than in BF because of its heterogeneity as a result of the strong vertical stratification and increase in food and housing resources, as already mentioned (PANIZZI & PARRA, 1991; RIBAS et al., 2003). Both the richness and the composition of genera can be explained by environmental heterogeneity mediated through the complexity and variability of resources (TEWS et al., 2004; SANDERS & NICKEL, 2008), in addition to being an environment that does not have characteristics of adaptation to fire (HOFFMAN et al., 2009). The diversity index of the burnt savanna formation, on the other hand, is greater than the unburnt one, and it reinforces its adaptation (BOND et al., 2005; ARAÚJO et al., 2013), resistance (HOFFMAN, 2009; ANDERSEN et al., 2014; VASCONCELOS et al., 2017) and promotion of biodiversity through fire events (MARAVALHAS & VASCONCELOS et al., 2014; KELLY & BRONTONS, 2017).

The adaptation of savanna formations to fire is noticeable due to the greater abundance and diversity of the burnt phytophysiognomy when compared to the unburnt one. The Cerrado is an ecosystem considered adapted to fire due to its dynamic ecological states (HOFFMAN et al., 2009; VASCONCELOS et al., 2017), with thick and tortuous bark trees that characterize the arboreal adaptation to these events (GOTTSBERGER & SILBERBAUER, 2006), in which these characteristics of environmental heterogeneity can benefit ant communities (MARAVALHAS & VASCONCELOS, 2014). However, in the forest phytophysiognomy, this adaptation is not perceived when comparing burnt and unburnt forest environments. Forest biomes have high heterogeneity (PANIZZI & PARRA, 1991; RIBAS et al., 2003) with a more stable climate condition, nevertheless it can be disrupted by fire episodes (HOFFMAN et al., 2009; VASCONCELOS et al., 2017), affecting the fauna and flora diversity.

5. CONCLUSIONS

This study states, by using ants as fire impact bioindicators, that the savanna formation of the Cerrado is favored by fire as it demonstrates greater abundance of individuals and a greater diversity index when compared to not burnt savanna, in addition to emergence of new ant genera in the burned area.

The forest physiognomy of the Cerrado, on the other hand, by presenting a statistical difference in the abundance of individuals and similarity between burnt and unburnt forest formation, in addition to the smaller number of genera and lower diversity index in the forest affected by fire, leads to the conclusion that fire can negatively impact on the diversity of ant genera in this phytophysiognomy.

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Tiago Vinicius Fernandes: data curation (supporting); formal analysis (supporting); investigation (supporting).

SUPPLEMENTARY MATERIAL

The following online material is available for this article: Annex. Distribution of ant subfamilies and species by phytophysiognomies affected and not affected by the Cerrado fire at Reserva Nacional Serra do Tombador, Goiás, Brazil.

REFERENCES

AGOSTI D, MAJER J, ALONSO LE, SCHULTZ R. (Eds.). Ants: Standard methods for measuring and monitoring biodiversity. Washington, D. C.: Smithsonian Institution Press. 2000. 280p.

ALVARADO ST, FORNAZARI T, CÓSTOLA A, MORELLATO LPC, SILVA TSF. Drivers of fire occurrence in a mountainous Brazilian cerrado savanna: Tracking long-term fire regimes using remote sensing. Ecological Indicators 2017; 78: 270–281.

ANDERSEN AN, WOINARSKI JCZ, PARR CL. Savanna burning for biodiversity: fire management for faunal conservation in Australian tropical savannas. Austral Ecology 2012; 37: 658–667.

ANDERSEN AN, RIBBON RR, PETTIT M, PARR CL. Burning for biodiversity: highly resilient ant communities respond only to strongly contrasting fire regimes in Australia's seasonal tropics. Journal of Applied Ecology 2014; 51: 1006-1013.

ANJOS D, CAMPOS R, CAMPOS R, RIBEIRO S. Monitoring effect of fire on ant assemblages in brazilian rupestrian grasslands: Contrasting effects on ground and arboreal fauna. Insects 2017; 8(3): 1–12.

ARAÚJO GM, AMARAL AF, BRUNA EM, VASCONCELOS HL. Fire drives the reproductive responses of herbaceous plants in a Neotropical swamp. Plant ecology 2013 (214): 1479-1484.

ARCUSA JM. Fire effects on the ant community in areas of native and exotic vegetation. Sociobiology 2019; 66(1): 44–51.

AUCLERC A, LE MOINE JM, HATTON PJ, BIRD JA, NADELHOFFER KJ. Decadal post-fire succession of soil invertebrate communities is dependent on the soil surface properties in a northern temperate forest. Science of The Total Environment 2019; 647(10): 1058-1068.

AXIMOFF I, RODRIGUES RC. Histórico dos incêndios florestais do Parque Nacional do Itatiaia. Ciência Florestal 2011; 21(1): 83-92.

BACCARO FB, FEITOSA, RM, FERNÁNDEZ F, FERNANDES IO, IZZO TJ, SOUZA, JLP, SOLAR, RRC. Guia para os gêneros de formigas do Brasil. Manaus: Editora INPA, 2015. 388 p.

BARLOW J, PERES CA, LAGAN BO, HAUGAASEN T. Large tree mortality and the decline of forest biomass following Amazonian wildfires. Ecology Letter 2003; 6: 6–8.

BEDIA J, HERRERA S, CAMIA A, MORENO JM, GUTIÉRREZ JM. Forest fire danger projections in the Mediterranean using ENSEMBLES regional climate change scenarios. Climatic Change 2014; 122(1–2): 185–199.

BEUCHLE R, GRECCHI RC, SHIMABUKURO YE, SELIGER R, EVA HD, SANO E, ACHARD, F. Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach. Applied Geography 2015; 58: 116-127.

BOND WJ, WOODWARD FI, MIDGLEY GF. The global distribution of ecosystems in a world without fire. New Phytologist 2005, 165: 525-538.

BOSCARDIN, J, COSTA, E. C, DELABIE, J. H. C, GARLET, J. Efeito do fogo sobre a riqueza de formigas (Hymenoptera: Formicidae) associadas à Pinus elliottii Engelm. No sul do Brasil. Ciência Florestal 2014; 24: 1031-1040.

BUCKINGHAM S, MURPHY N, GIBB H. Effects of fire severity on the composition and functional traits of litter-dwelling macroinvertebrates in a temperate forest. Forest Ecology and Management 2019; 434(December 2018): 279–288.

BUENO LM, DEXTER KG, PENNINGTON, RT, PONTARA V, NEVES, DM, RATTER, JA, OLIVEIRA-FILHO AT. The environmental triangle of the Cerrado domain: ecological factors driving shifts in tree species composition between forests and savannas. Journal Ecology 2018; 106: 2109-2120.

CAMARGO ACL, BARRIO ROL, CAMARGO NF, MENDONÇA AF, RIBEIRO JF, RODRIGUES KMF et al. Fire affects the occurrence of small mammals at distinct spatial scales in a neotropical savanna. European Journal of Wildlife Research 2018. 64 (63).

CANEDO-JÚNIOR EO, GONÇALVES CUISSI R, DE ALMEIDA CURI NH, RAMOS DEMETRIO G, LASMAR CJ, MALVES K, et al. Can anthropic fires affect epigaeic and hypogaeic Cerrado ant (Hymenoptera: Formicidae) communities in the same way? Revista de Biología Tropical 2016; 64(1): 95 p.

CAUT S, JOWERS MJ, ARNAN X, PEARCE-DUVET J, RODRIGO A, CERDA X, et al. The effects of fire on ant trophic assemblage and sex allocation. Ecology and Evolution 2014; 4(1): 35–49.

Costa AN, Vasconcelos HL, Vieira-Neto EHM, Bruna EM. Do herbivores exert top-down effects in Neotropical savannas? Estimates of biomass consumption by leaf-cutter ants. Journal of Vegetation Science 2008; 19: 849-854.

COSTA-MILANEZ CB, RIBEIRO FF, CASTRO PTA, MAJER JD, RIBEIRO SP. Effect of fire on ant assemblages in brazilian cerrado in areas containing vereda wetlands. Sociobiology 2015; 62(4): 494–505.

CURBANI F, ZOCCA C, FERREIRA RB, WAICHERT C, SOBRINHO TG, SRBEK-ARAUJO AC. Litter surface temperature: A driving factor affecting foraging activity in Dinoponera lucida (Hymenoptera: Formicidae). Sociobiology 2021; 68(1): 1–9.

DALLE LASTE KC, DURIGAN G, ANDERSEN AN. Biodiversity responses to land-use and restoration in a global biodiversity hotspot: Ant communities in Brazilian Cerrado. Austral Ecology 2019; 44(2): 313–326.

DORNELAS M. Disturbance and change in biodiversity. Philosophical Transactions of the Royal Society B 2010; 365: 3719–3727.

DORVAL A, PERES FILHO O; JORGE VC; SOUZA MD DE; ROCHA WO. Diversity of ants in a savanna area in the city of Cuiabá, Mato Grosso, Brazil. Revista Espacios; 38(31): 3, 2017.

DURIGAN G, RATTER JA. The need for a consistent fire policy for Cerrado conservation. Journal of Applied Ecology 2016; 53(1): 11–15.

ECONOMO EP, KLIMOV P, SARNAT EM, GUÉNARD B, WEISER MD, LECROQ B, et al. Global phylogenetic structure of the hyperdiverse ant genus Pheidole reveals the repeated evolution of macroecological patterns. Proceedings of the Royal Society B: Biological Sciences 2014; 282(1798).

ELLWOOD, MDF; FOSTER, WA. Doubling the estimate of invertebrate biomass in a rainforest canopy. Nature 2004; 426: 549-551.

EUGENIO FC, DOS SANTOS AR, FIEDLER NC, RIBEIRO GA, DA SILVA AG, DOS SANTOS ÁB, et al. Applying GIS to develop a model for forest fire risk: A case study in Espírito Santo, Brazil. Journal of Environmental Management 2016; 173: 65–71.

FAGUNDES R, LANGE D, ANJOS DV, PAIXÃO DE LIMA F, NAHAS L, CORRO EJ, et al. Limited effects of fire disturbances on the species diversity and structure of ant-plant interaction networks in Brazilian Cerrado. Acta Oecologica 2018; 93(March): 65–73.

FERNÁNDEZ F. Subfamília Formicinae. In: Fernández, F. (Ed.). Introducción a las hormigas de la región Neotropical. Bogotá-COL: Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt 2003; 299-306.

FERNÁNDEZ F, SHARKEY MJ. Introducción a los Hymenoptera de la Región Neotropical. Univ. Nacional de Colombia, 2006.

FLANNIGAN M; CANTIN AS, GROOT WJ, WOTTON M, NEWBERY A, GOWMAN LM. Global wildland fire season severity in the 21st century. Forest Ecology and Management 2013; 294: 54–61.

FOWLER HG, CLAVE S. Leaf-cutter ant assemblies: effects of latitude, vegetation and behaviour. In: Huxley, C. R. & Cutler, D. F. (eds.). Ant-Plant Interaction 1991. Oxford University Press, Oxford.

FRIZZO TLM, BONIZÁRIO C, BORGES MP, VASCONCELOS HL. Revisão dos efeitos do fogo sobre a fauna de formações Savânicas do Brasil. Oecologia Australis 2011; 15: 365–379.

FUNDAÇÃO GRUPO BOTICÁRIO. Plano de Manejo da Reserva Natural Serra do Tombador. Supervisão: Gustavo Adolfo Gatti, 2011.

GONGALSKY KB, PERSSON T. Recovery of soil macrofauna after wildfires in boreal forests. Soil Biology and Biochemistry 2013; 57: 182–191.

GOTTSBERGER G, SILBERBAUER-GOTTSBERGER I. Life in the Cerrado: a south American tropical seasonal ecosystem. Reta Verlag, 2006.

HAIDAR RF, FAGG JMF, PINTO JRR, DIAS RR, DAMASCO G, SILVA LCR et al. Florestas estacionais e áreas de ecótono no estado do Tocantins, Brasil: Parâmetros estruturais, classificação das fitofisionomias florestais e subsídios para conservação. Acta Amzônica 2013; 43: 261–290.

HOFFMANN, WA, ADASME, R, HARIDASAN, M, DE CARVALHO, MT, GEIGER, EL, PEREIRA, MAB et al. Tree topkill, not mortality, governs the dynamics of savanna–forest boundaries under frequent fire in central Brazil. Ecology 2009; 90: 1326–133.

HOLLDOBLER B, WILSON EO. The ants. Cambridge: Havard University Press, 1990, 746p.

HUEBNER K, LINDO Z, LECHOWICZ MJ. Post-fire succession of collembolan communities in a northern hardwood forest. European Journal of Soil Biology; 48: 59–65, 2012.

INMET – INSTITUTO NACIONAL DE METEREOLOGIA. 2018. Brasília: INMET. [cited 2018 aug 16] Available from: <http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep>.

JAFFE K. Mundo de las Hormigas. Equinoccio, Ediciones de la Universidad Simón Bolívar, 2004, 148p.

JAFARI GOLDARAG Y, MOHAMMADZADEH A, ARDAKANI AS. Fire Risk Assessment Using Neural Network and Logistic Regression. Journal of the Indian Society of Remote Sensing 2016; 44(6): 885–894,

JOLLY WM, COCHRANE MA, FREEBORN PH, HOLDEN ZA, BROWN TJ, WILLIAMSON GJ et al. Climate-induced variations in global wildfire danger from 1979 to 2013. Nature Communications 2013, 6 (7537). doi: 10.1038/ncomms8537

KAYET N, CHAKRABARTY A, PATHAK K, SAHOO S, DUTTA T, HATAI BK. Comparative analysis of multi-criteria probabilistic FR and AHP models for forest fire risk (FFR) mapping in Melghat Tiger Reserve (MTR) forest. Journal of Forestry Research 2020; 31(2): 565–579.

KEELEY JE, BOND WJ, BRADSTOCK RA, PAUSAS JG, RUNDEL PW. Fire in Mediterranean Ecosystems: ecology, evolution and management, Cambridge University Press, 2012. 515 p.

KELLY LT, BROTONS L. Using fire to promote biodiversity. Science; 355 (6331): 1264-1265, 2017. Malmström, A. Life-history traits predict recovery patterns in Collembola species after fire: a 10-year study. Applied Soil Ecology 2012; 56: 35–42.

MMA - MINISTÉRIO DO MEIO AMBIENTE. Termo de Referência para a Elaboração do Plano Diretor de Recursos Hídricos da Bacia Hidrográfica do Rio Tocantins. Versão Preliminar. Brasília: 56. 2001.

MARAVALHAS J, VASCONCELOS HL. Revisiting the pyrodiversity/biodiversity hypothesis: long term fire regimes and the structure of ant communities in a Neotropical savanna hotspot. Journal of Applied Ecology 2014; 51: 1661-1668.

OBERPRIELER SK, ANDERSEN AN. The importance of sampling intensity when assessing ecosystem restoration: ants as bioindicators in northern Australia. Restoration Ecology 2020; 28(4): 737–741

PACHECO R, VASCONCELOS HL. Habitat diversity enhances ant diversity in a naturally heterogeneous Brazilian landscape. Biodiversity and Conservation 2012; 21(3): 797-809.

PANIZZI AR, PARRA JRP. Ecologia Nutricional de Insetos e suas Implicações no Manejo de Pragas. Manole LTDA, 1991, 359p.

PAOLUCCI LN, MAIA MLB, SOLAR RRC, CAMPOS RI, SCHOEREDER JH, ANDERSEN AN. Fire in the Amazon: impact of experimental fuel addition on responses of ants and their interactions with myrmecochorous seeds. Oecologia 2016; 182: 335–346.

PAOLUCCI LN, SCHOEREDER JH, BRANDO PM, ANDERSEN AN. Fire-induced forest transition to derived savannas: cascading effects on ant communities. Biological Conservation 2017; 214: 295–302.

PEREIRA JÚNIOR AC, OLIVEIRA SLJ, PEREIRA JMC, TURKMAN MAA. Modelling fire frequency in a Cerrado savanna protected area. PLoS ONE 2014; 9(7).

PIVELLO VR. The use of fire in Brazil: past and present. Fire Ecology 2011; 7: 24-39.

RIBAS CR, SCHOEREDER JH, PIC M; SOARES SM. Tree heterogeneity, resource availability, and larger scale processes regulating arboreal ant species richness. Austral Ecology; 28(3): 305-314, 2003.

RIBAS CR, CAMPOS RBF, SCHMIDT FA, SOLAR RRC. Ants as indicators in Brazil: a review with suggestions to improve the use of ants in environmental monitoring programs. A Journal of Entomology 2012; 2012: 1–23.

RIBEIRO JF, WALTER BMT. As principais fitofisionomias do bioma Cerrado. In: Cerrado: ecologia e flora. Embrapa Cerrados 2008; 10: 151-212.

RICO-GRAY V; OLIVEIRA PS. The ecology and evolution of ant-plant interactions. Chicago: University of Chicago Press, 2007. 320 p.

ROCHA WO, DORVAL A, PERES FILHO O, VAEZ CA, RIBEIRO ES. Formigas (Hymenoptera: Formicidae) Bioindicadoras de degradação ambiental em Poxoréu, Mato Grosso, Brasil. Floresta e Ambiente 2015; 22: 88–98.

SANDERS DH, NICKEL H, GRTUTZNER T, PLATNER C. Habitat structure mediates topdown effects of spiders and ants on herbivores. Applied Ecology 2008; 9: 152-160.

SANO EE, RODRIGUES AA, MARTINS ES, BETTIOL GM, BUSTAMANTE MMC, BEZERRA AS, et al. Cerrado ecoregions: A spatial framework to assess and prioritize Brazilian savanna environmental diversity for conservation. Journal of Environmental Management 2019; 232(July 2018): 818–828.

SANTOS BA, PERES CA, OLIVEIRA MA, GRILLOA, ALVES-COSTA CP, TABARELLI M. Drastic erosion in functional attributes of tree assemblages in Atlantic forest fragments of northeastern Brazil. Biological Conservation 2008; 141: 249-260.

SANTOS JFC, GLERIANI JM, VELLOSO SGS, SOUZA GCA, AMARAL CH, TORRES FTP et al. Wildfires as a major challenge for natural regeneration in Atlantic Forest. Science of The Total Environment 2018. v. 650. p.8019-821.

SCHMIDT IB, ELOY L. Fire regime in the Brazilian Savanna: Recent changes, policy and management. Flora: Morphology, Distribution, Functional Ecology of Plants 2020; 268(May).

SILVA FHO, DELABIE JHC, SANTOS GB, MEURER E, MARQUES MI. Mini-Winkler extractor and pitfall trap as complementary methods to sample Formicidae. Neotropical Entomology 2013; 42: 351–358.

SILVEIRA JM, BARLOW J, ANDRADE RB, MESTRE LA, LACAU S, COCHRANE MA. Responses of leaf-litter ant communities to tropical forest wildfires vary with season. Journal Tropical Ecology 2012; 28: 515–518.

SILVEIRA JM, BARLOW J, ANDRADE RB, LOUZADA J, MESTRE LA, LACAU S et al. The responses of leaf litter ant communities to wildfires in the Brazilian Amazon: a multi-region assessment. Biodiversity and Conservation 2013; 22: 513–529.

SOARES AS, ANTONIALLI-JUNIOR WF, LIMA-JUNIOR SE. Diversidade de formigas epigéicas (Hymenoptera, Formicidae) em dois ambientes no Centro-Oeste do Brasil. Revista Brasileira de Entomologia 2010; 54: 76-81.

STEPHENS SL, WESTERLING ALR, HURTEAU MD, PEERY MZ, SCHULTZ CA, THOMPSON S. Fire and climate change: conserving seasonally dry forests is still possible. Frontiers in Ecology and the Environment 2020; 18(6): 354 – 360.

TAYLOR RS, WATSON SJ, NIMMO DG, KELLY LT, BENNETT AF, CLARKE MF. Landscape-scale effects of fire on bird assemblages: does pyrodiversity beget biodiversity? Diversity and Distributions; 18: 519-529, 2012.

TEWS JU; BROSE V, GRIMM K, TIELBORGER MC; WICHMANN M, SCHWAGER FF. Animal species diversity driven by habitat heterogeneity/diversity: the importance of kerystone structures. Journal os Biogeography 2004; 31: 79-82.

VASCONCELOS HL, LEITE MF, VILHENA JMS; LIMA PA, MAGNUSSON WE. Ant diversity in Amazonian savana: Relationship with vegetation structure, disturbance by fire, and dominant ants. Austral Ecology 2008; 33: 221-23.

VASCONCELOS HL, MARAVALHA JB, CORNELISSEN T. Effects of fire disturbance on ant abundance and diversity: a global meta-analysis. Biodiversity and Conservation 2017; 26(1): 177-188.

VELDMAN JW. Clarifying the confusion: old-growth savannahs and tropical ecosystem degradation. Philosophical Transactions of the Royal Society 2016; 371.

WARD PS. The ant subfamility Pseudomyrmecinae (Hymenoptera: Formicidae): generic revision and relationship to other formicids. Systematic Entomology 1990; 15: 449–489.

WICKHAM H. Ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. 2016.

WILSON EO. La hiperdiversidad como fenómeno real: el caso de Pheidole: 363−370. In: F. Fernàndez, (eds). Introducción a las hormigas de la región Neotropical. Instituto Humboldt. Bogotá, v 26. 2003.

ZAITSEV AS, GONGALSKY KB, MALMSTRÖM A, PERSSON T, BENGTSSON J. Why are forest fires generally neglected in soil fauna research? A mini-review. Applied Soil Ecology 2016; 98: 261–271.

ZHANG Y, LIM S, SHARPLES JJ. Modelling spatial patterns of wildfire occurrence in South-Eastern Australia, Geomatics, Natural Hazards and Risk 2016; 7(6): 1800-1815.

5. ARTIGO 3: INFLUÊNCIA DO FOGO NA ESTRUTURA DE VEGETAÇÃO LENHOSA DE FORMAÇÕES SAVÂNICAS E FLORESTAIS DO BIOMA CERRADO

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ORIGINAL PAPER

Influence of fire on woody vegetation of savanna and forest formations in the Cerrado biome

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Abstract Wildfires have environmental, economic, and social impacts, and can shape the landscape and benefit ecosystems such as the Cerrado. This study evaluated the diversity, similarity, and floristic and structural differences of woody savanna and forest formations of the Cerrado, when affected and not affected by fire. Twenty-eight 25–400 m² plots were randomly allocated and divided into Burnt Cerrado and Unburnt Cerrado, Burnt Forest, and Unburnt Forest, and divided into three levels of inclusion according to diameter class (smaller than 2 cm, 2–5 cm and larger than 5 cm). Species were identified, DBH and height measured, and phytosociological parameters such as volume, diversity, and floristic similarity evaluated. Burnt Cerrado had lower diversity, density, and dominance at all inclusion levels compared to the Unburnt Cerrado, and showed similarities between treatments at the inclusion levels. Burnt Forest had smaller differences in diversity, density, and dominance than Unburnt Forest. Forest formation was similar at level 1 of inclusion and in the total area. However, it was dissimilar at lower levels. The lower density and diversity of species at the lowest levels of inclusion was associated with mortality from fire.

Keywords Biodiversity · Brazil · Burning · Floristic · Phytosociology

Introduction

Wildfires are natural and often anthropogenic events that result in severe, negative environmental, economic and social impacts (Jafari Goldarag et al. 2016; Zhang et al. 2016; Kayet et al. 2020). With vegetation, the impact of fire depends on factors such as season (Sato et al. 2010), vegetation type, rainfall regime, fire behavior (Miranda et al. 2010), and the response by the vegetation to fire (Camargos et al. 2015). Wildfires play an important role in the environment, responsible for high CO_2 emissions which may exceed 50% of emissions from world-wide fossil fuel combustion (Jolly

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et al. 2015). This increase in CO_2 emissions contributes to climate change and favors the spread of fire with climate variation related to the increase in global temperatures (Bedia et al. 2014; Stephens et al. 2020). With the intensification of climate change, fire occurrence is expected to increase worldwide. (Jolly et al. 2015).

Fire, climate, soil fertility, water availability, and herbivores are important determinants of the composition and structure of savanna environments (Lehmann et al. 2014; Bueno et al. 2018). However, fire acts more locally (Lehmann et al. 2014; Bueno et al. 2018), unlike climate, which is on a larger scale (Bueno et al. 2018).

The Cerrado is a neotropical savanna that covers 22% of Brazil's land area. The vegetation occurs in mosaics with different landscapes along areas with disturbance or absence of fire such as grasslands, savanna formations and, to a lesser extent, forest formations (Ribeiro and Walter 2008; Bueno et al. 2018). Ribeiro and Walter (2008) described 11 phytophysiognomies in three categories: forest formations (Ciliar Forest, Gallery Forest, Dry Forest and Cerradão); savanna formations (Cerrado stricto sensu; Parque de Cerrado, Palmeiral and Vereda), and campestral formations (Campo Limpo, Campo Sujo and Campo Rupestre). However, the Cerrado is the main area for agricultural and livestock production (Grecchi et al. 2014). Cattle livestock one of the main drivers of deforestation, which has been gradually increasing (Pereira Júnior et al. 2014; Dalle Laste et al. 2019), leading to a high frequency of fires due to the use of fire to open areas and renew pastures (Durigan and Ratter 2016).

Studies on vegetation structural changes over time have demonstrated the Cerrado's resilience to fire (Pivello 2011; Rios et al. 2018) due to the tortuous trunk shapes and thick bark that provide protection from high temperatures and allow regrowth after disturbance (Gottsberger and Silberbauer-Gottsberger 2006; Costa-Milanez et al. 2015), considered an important engine of the ecosystem to manage and maintain levels of biodiversity. Fire can be used to promote biodiversity, if adapted to local conditions, and its benefits are considered interdisciplinary (Kelly and Brotons 2017). Research has suggested that pyrodiversity, the variability of fire effects across a landscape, promotes biodiversity in savanna environments (Maravalhas and Vasconcelos 2014). Although the savanna ecosystem and its species are adapted to fire, the increasing frequency of high-intensity fires has a negative effect because of the rise in mortality of small woody plants and promotion of grasses (Oliveras et al. 2013). This is associated with the loss of biodiversity, soil degradation, erosion and water reduction, and suppression of vegetation (Schmerbeck and Fiener 2015; Sansevero et al. 2017; Santos et. al. 2019). However, due to the savanna's heterogeneous vegetation with different formations and forest types, the woody composition varies along the landscape, mainly related to fire-independent and adapted species (Ribeiro and Walter 2008; Haidar et al. 2013), including competition from savanna and forest species (Lehmann et al. 2014).

The influence of the abiotic environment on the vegetation determines the characteristics of the plant community and its floristic composition (Almeida et al. 2014). Impact mitigation practices may be supported by studies that analyze changes in the structure of the different Cerrado's phytophysiognomies (Elias et al. 2013). Although floristic comparisons in the Cerrado domain exist, most forest vegetation types were not covered by these studies and there is also no correlation between fire and a more specific floristic composition (Bueno et al. 2018). Therefore, it is important to know the effect of fire disturbances in forest formations of seasonal semideciduous and savanna forests in the Cerrado (Hoffmann et al. 2009).

Thus, it is essential to evaluate changes in vegetation dynamics due to disturbances such as fire, especially in biomes with great physiognomic heterogeneity such as the Cerrado, which may respond to disturbances in different ways. This study aimed to evaluate the influence of fire on the diversity, similarity, and floristic and structural differences of the woody communities in savanna and forest formations of the Cerrado in the Reserva Natural Serra do Tombador in Goiás state, Brazil. It also seeks to determine whether there are significant floristic differences between the burned and unburned areas of the savanna formation, and between the burned and unburned areas of the forest formation. The results will contribute to the development of strategies for conservation, sustainable use, and biome recovery.

Materials and methods

Study area

The Reserva Natural Serra do Tombador (RNST) is a nature reserve in the municipality of Cavalcante in northeast Goiás state, approximately 390 km north from Brasília and 22 km from the Parque Nacional Chapada dos Veadeiros (Fig. 1). The nature reserve was converted into a private natural heritage reserve (RPPN) in 2007 by Fundação Grupo Boticário de Proteção à Natureza to contribute to the conservation of the Cerrado biome (Fundação Grupo Boticário 2011; Françoso and Brandão 2013). The reserve is approximately 8730 hectares, one of the largest reserves in the Cerrado (ICMBIO 2018) and is located in the hydrographic basin of the Tocantins River.

The vegetation in the reserve is classic Cerrado with distinct formations, covered by a mosaic of savanna vegetation that varies from open to closed, interspersed with grasslands and forests. The vegetation structure

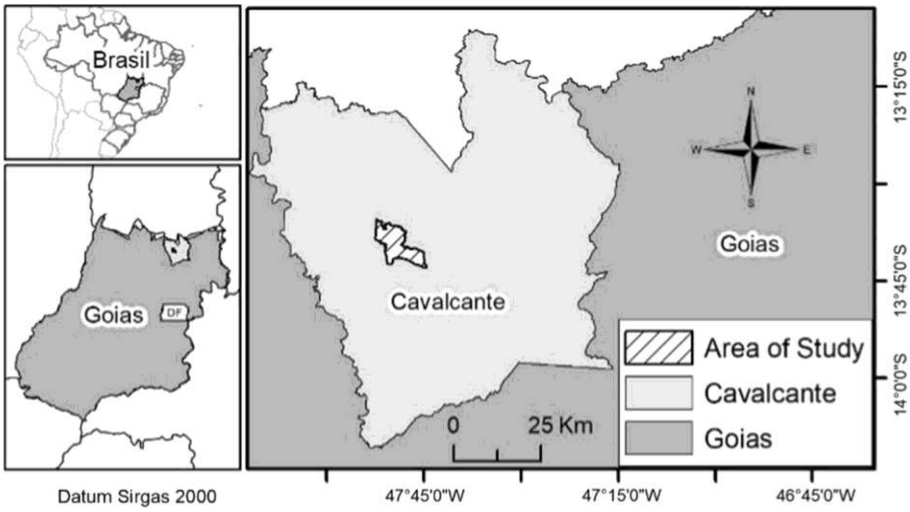


Fig. 1 Study Area, Reserva Natural Serra do Tombador (RNST), Goiás

is influenced by altitude, edaphic aspects, and water availability, thereby contributing to high physiognomic diversity. The predominant landscapes in the RNST are savanna (78.0%), represented mostly by the Cerrado and rupestrian grasslands; forest landscapes (20.0%), represented by dense ombrophilous forest and semideciduous seasonal forest; and other typologies such as anthropogenic formations (2.0%); veredas (0.8%) and rocky outcrops (0.3%) (Fundação Grupo Boticário 2011).

The predominant climate is Köppen's Aw type which is warm and semi-humid with a dry season in winter (Ribeiro and Walter 2008). Temperature variations in 2017 were from 12 to 35 °C and precipitation from 7 to 319 mm. June, July and August are the dry season without rain while the wet season is between November and March, with an average of 132 mm of rain per month (INMET 2018). In October of 2017, an anthropogenic fire burnt more than 80% of the Reserve.

Vegetation survey

Twenty-eight plots were randomly placed and allocated to the two main categories of vegetation (savanna and forest formations) with tree components. Campestral or open field formations were not included because of their small area and lack of trees (Bueno et al. 2018). These two categories were subdivided into burnt and unburnt areas, namely, Burnt Cerrado (BC) and Unburnt Cerrado (UC) and Burnt Forest (BF) and Unburnt Forest (UF). Each category recorded three levels per plot, family, genus, and species where possible, according to tree diameter class and area of the plot (Table 1). Diameter at breast height (DBH) at 1.30 m and height were measured.

Table 1 Sampling levels of forest inventory in the Reserva Nacional Serra do Tombador

Inclusion level	Area (m^2)	DBH (cm)
Level 1	400	≥ or 5
Level 2	100	5 > DBH < 2
Level 3	25	≤ 2

Data analysis

To verify the differences in the floristic structure between savanna and forest formations as a result of fire, the phytosociological parameters were determined, i.e., density, dominance and frequencies per hectare and their importance values, in addition to wood volume based on Miguel et al. (2017) and Rezende et al. (2006) for Cerrado forest and savanna formations, respectively.

$$TVWBc = 0,0000680 * DBH^{2,185900} * Ht^{0,697900} \quad (1)$$

where TVWBc = total volume of the stem with bark in m^3 in the savanna formation; DBH = diameter in cm; Ht = total height in meters (Miguel et al. 2017).

$$\mathrm{TVWB}f = 0.000085 * DAP^{2,122270} * H^{0,666217} \quad (2)$$

where TVWBf = total volume of the stem with bark in m^3 in the forest formation; DBH = diameter in cm; Ht = total height in meters (Rezende et al. 2006).

The diameter distribution was analyzed by category in diameter classes at 5 cm intervals.

Floristic diversities for categories were calculated using Shannon–Wiener diversity index (H′) or Shannon index, and the Pielou equability index (J′). The Shannon index expresses the floristic richness of a community, assuming that all species are represented in the sample. Its value usually ranges from 1.5 to 3.5, although, in exceptional cases, it may exceed 4.5. The higher the H′ value, the greater the floristic diversity of the population.

$$H' = \frac{(N * \ln(N) - \sum_{i=1}^{S} ni \ln(ni)}{N} \quad (3)$$

where H' = Shannon's diversity index; N = total number of individuals; ni = number of individuals in the i-th species; S = number of species sampled; ln = logarithm of the Naperian base (e).

The J′ index ranges from 0 to 1, where 1 demonstrates that all species are equally abundant.

$$J' = \frac{H'}{\ln(S)} \quad (4)$$

where J' = Pielou's equability index; H' = Shannon index; S = number of species.

The evaluation of floristic similarity between burnt and unburnt areas used qualitative data, presence and absence of species, based on the Sorensen index, which varies from 0 (dissimilarity) to 1 or 100% (total similarity), given by:

$$Ss = \frac{2a}{2a + b + c} \quad (5)$$

where Ss = Sorensen index; a = number of common species in burnt and unburnt areas; b = number of species in a burnt area and c = number of species in an unburnt area.

Results

Nine hundred and ninety-three plants of 155 species in 99 identified and 13 unidentified genera, and 48 families were recorded. The savanna formation had 264 individuals of 66 species in 30 families. The forest formation showed 729 individuals of 120 species in 43 families (Table S1).

The UC had a higher number of individuals, species, and families compared to the BC (Table 2). The Fabaceae family had the highest species richness, mainly in the unburnt area, followed by Myrtaceae (Table S2). The UF had higher number of individuals, species, and families (Table 2). The family with the highest species richness was Fabaceae in both categories (Table S3), followed by Myrtaceae, with two more species in the burnt area.

Table 2 Number of individuals, species, and families of tree components in unburnt and burnt savanna and forest formations

Parameter	UC	BC	UF	BF
Individual	193	71	440	289
Family	28	16	36	34
Species	55	24	92	78

BC, Burnt Cerrado; UC, Unburnt Cerrado; BF, Burnt Forest; UF, ,Unburnt Forest

Diameter distribution

In the savanna formations, both burnt and unburnt areas had a greater number of individuals in the 7.5 cm diameter class, considering individuals > 5 cm DBH at the level. 1 of inclusion. Both UC and the BC had an inverted-J DBH distribution. However, there was a large difference in the number of individual plants in the first DBH class between the areas, where the UC had 59% more individuals than in the burnt Cerrado (Fig. 2). The BC had two individuals in the largest DBH class (37.5 cm), both *Mauritia flexuosa* Lf. (Buriti).

In the forest formation, both burnt and unburnt areas had higher numbers of individuals in the smallest DBH class. The 7.5 cm class had 60% while the other DBH classes had fewer, leading to an inverted-J pattern. The UF had 21% more individual trees than the BF in the smallest diameter class. The largest class (77.5 cm) was represented by two trees (Fig. 3).

Horizontal structure

Savanna formation

At the species level in the unburnt Cerrado, In Level 1 of inclusion there were 129 individuals representing 48 species with a density of 537.5/ha, a basal area of 4.2 m^2/ha and a volume of 1.1 m^3/ha. The burnt Cerrado had 60 individuals of 19 species with a density of 250,000/ha (53.5% lower), a dominance of 3.1 m^2/ha (27.3% lower) and a volume of 0.7 m^3/ha (34.4% lower) (Table S4).

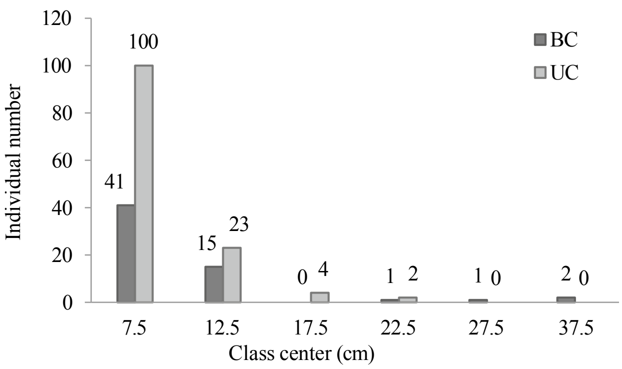
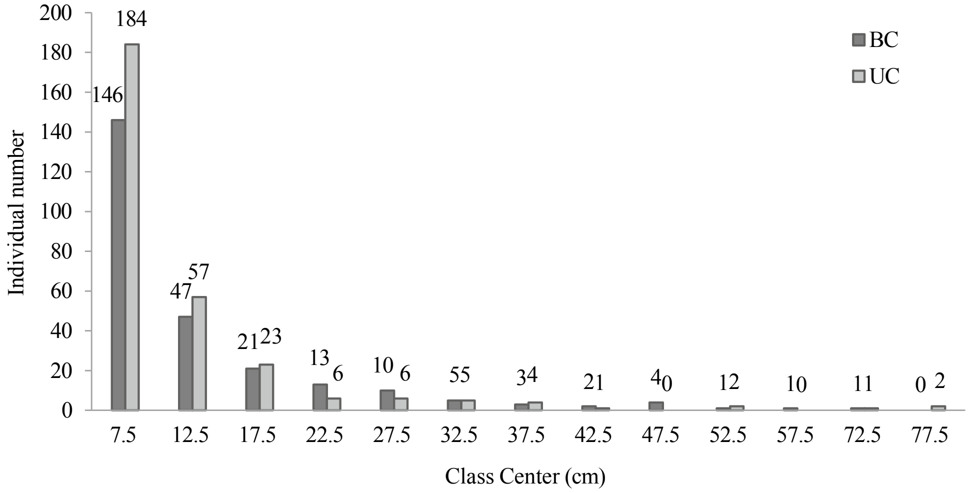


Fig. 2 Diameter distribution of trees in savanna formation (BC, Burnt Cerrado; UC, Unburnt Cerrado)

Fig. 3 Diameter distribution of trees in the forest formations in RPPN BF, Burnt Forest and UF, Unburnt Forest



Qualea multiflora Mart. had the highest importance value (IV) in both areas. *Qualea grandiflora* Mart. had the highest IV in the UC and was not found in the BC. *M. flexuosa* L.f. had one of the highest IV in the burnt Cerrado because of high basal area and was not found in the burnt Cerrado (Table S4). At inclusion level 2, unburnt Cerrado had 38 individuals in 18 species and the BC five individuals in five species. The UC had absolute density 85.9% higher than the burnt area and absolute dominance of 89.0% higher than the BC. *Myrcia* sp. 1 had the highest absolute density and dominance in both categories. Three species in the BC are not found in the UC (Table S5).

At Level 3 of inclusion, the unburnt Cerrado (UC) had 15 species and the burnt Cerrado (BC) only four. The BC had a density 76.9% lower than the UC, as well as the absolute dominance, 84.8% lower. Despite less dominance, the species in the UC were not present in the BC (Table S6).

Forest formation

At the species level, the unburnt forest (UF) had 291 individuals in 79 species and an absolute density of 909.4 trees/ha, absolute dominance of 18.1 m²/ha and volume of 19.8 m³/ha. These were slightly lower in the burnt forest (BF), with 254 individuals in 70 species, with an absolute density of 793.7 trees/ha (12.7% lower), absolute dominance of 17.7 m²/ha (1.8% lower) and a volume 17.5 m³/ha (3.37% lower) (Table S7).

Terminalia brasiliensis (Cambess. Ex. A. St.-Hil.) Eichler had the highest importance value (IV) and volume (3.1m³/ha) and *Aspidosperma parvifolium* A. DC. the highest absolute density (65.6 trees/ha) in the UF. In the burnt forest, *Hymenaea courbaril* L had the highest IV and volume (2.7 m³/ha) and *Myrcia* sp. 3 had the highest absolute density (793.7 trees/ha) (Table S7). *Copaifer langsdoffii* Desf. had one of the highest IV in the BF and was not found in the UF. At level 2 of inclusion, the unburnt forest had 101 individuals in 40 species, with an absolute density of 1683.3 trees/ha and absolute dominance of 1.6 m²/ha, a 70.3% higher absolute density (500,000 trees/ha) and 62.9% higher than the absolute dominance (0.6 m²/ha) of BF at the same level. The burnt forest (BF) at inclusion level 2 had 30 individuals representing 18 species (Table S8).

At level 3 of inclusion of the forest formation, the area not affected by fire had 48 individuals in 26 species and the formation affected by fire had 5 species in 5 individuals. The unburnt forest had a density per hectare 89.6% higher and absolute dominance 83.4% higher than the burnt forest (Table S9).

Table 3 Diversity of categories for burnt and unburnt Cerrado in the Serra do Tombador RPPN, Goiás

Índexes	Total		L1		L2		L3	
	BC	UC	BC	UC	BC	UC	BC	UC
H′	2.67	3.52	2.52	3.43	1.61	2.63	1.24	2.54
J′	0.84	0.88	0.86	0.89	1.00	0.91	0.90	0.94

H′, Shannon's diversity index; J′, Pielou's equability index; UC, Unburnt Cerrado; BC, Burnt Cerrado; L1, L2 and L3, plot inclusion levels

Table 4 Indexes for burnt and unburnt forests in the Serra do Tombador RPPN, Goiás

Indexes	Total		L1		L2		L3	
	BF	UF	BF	UF	BF	UF	BF	UF
H′	3.90	4.06	3.841	3.991	2.711	3.334	1.609	3.048
J′	0.90	0.90	0.904	0.913	0.938	0.904	1.000	0.935

H′ = Shannon's diversity index; J′ = Pielou's equability index; UF = Unburnt Forest; BF = Burnt Forest; L1, L2 and L3: plot inclusion levels

Diversity

Savanna formation

The BC diversity (2.7) was lower than the UC (3.5) and the diversity decreased as the sample level decreased. At all levels, the burnt area had lower values than the unburnt area. The formation with the greatest diversity was the UC at level 1 and the lowest was the BC at level 3 (Table 3).

Forest formation

The unburnt forest formation diversity (4.1) was higher than the burnt forest (3.9) and diversity decreased as the sampling level decreased. At all levels, the burnt area had a lower value than the unburnt area. The formation with the highest diversity was the UF at level 1 and the lowest the BF at level 3 (Table 4).

Similarity

The total similarity (0.33) and the similarity per level between the burnt and the unburnt savannas were low at 0.0 at level 3 (Table 5). In the forest formation, the total area and level 1 of inclusion showed a similarity between BF and UF (0.60 and 0.59, respectively), but similarity decreased with the decrease in the level of inclusion of the diameters (Table 5).

Discussion

Plant communities in regeneration and recruitment phases often show an inverted J distribution, where a majority of individuals are concentrated in the smaller diameter classes (Miranda et al. 2013). However, this study found a 59% difference of individuals in the lowest class between the burnt and unburnt savannas, and 21% between the burnt and unburnt forests at the same level. Mortality after fire is often pronounced in small diameter classes. Rios et al. (2018) found a 13% reduction of individuals in the smallest diameter classes of the Cerrado stricto sensu after a fire. In the same study, they found an increase in individuals in the smaller diameter classes after two years of fire protection. The same was reported in a 27-year study (1958–2012) in the Cerrado stricto sensu, where the smaller diameter classes ranged from 50 to 70%, with the highest values found between 2006 and 2012 when the area was protected from fire (Almeida et. al 2014). Fire, in addition to resulting in the death of small diameter plants, limits the development of vegetation (Sato et al. 2010).

In a monitoring study of the Cerrado stricto sensu in Brasília, the density and basal area of trees in the fire affected community fluctuated over time (Almeida et al. 2014). The lowest density (658 trees/ha) and basal area (5.5 m^2/ha) were in 1997, a year reflecting three earlier fires in previous years. In the same area, after 12 years without fires, the highest density (1419 trees/ha) and dominance (10.6 m^2/ha) were in 2009. The area also had a loss of 516 trees/ha and 1.4 m^2/ha of basal area because of a fire in 2011.

Table 5 Similarity between the burnt (BC) and unburnt (BC) Cerrado, and burnt (BF) and unburnt forest (UF)

Formation	Area	Level	Sorensen
Savanna	UC x BC	Total	0.33
		L1	0.30
		L2	0.19
		L3	0.00
Forest	UF x BF	Total	0.60
		L1	0.59
		L2	0.30
		L3	0.19

UC, Unburnt Cerrado; BC, = Burnt Cerrado; UF, Unburnt Forest; BF, Burnt Forest; L1, L2 and L3, plot inclusion levels

Absolute density and absolute dominance in this study, both in the burnt and in the unburnt areas, are within the range found in a study of the floristic and structural profile of the woody components in Cerradão areas (forest formation) along the Cerrado biome of six Brazilian states (Solórzano et al. 2012). The density ranged from 652 to 1732 trees/ha and basal area from 12.8 to 22.4 m^2/ha. They noted the difficulty of floristic and structural comparisons of forest formations in the Cerrado, mainly due to sampling standardization, sample unit sizes and inclusion criteria.

Imaña-Encinas et al. (2009) reported the difficulty of comparing wood volume from the Cerrado vegetation due to scarce information of volumetric parameters (Rezende et al. 2006). They also reported 16.2 m^3/ha volume, however, they did not address the phytophysiognomic subdivisions of the Cerrado as in this study. Information on volume of stocks and vegetation from different phytophysiognomies of the Cerrado biome are rare. However, this information is of importance for the sustainable management and conservation of the ecosystem as well as better targeting of degraded environment recovery projects (Miguel et al. 2017).

The species richness in the unburnt area at the lowest diameters reinforces the mortality of young plants after a fire (Almeida et al. 2014; Rios et al. 2018). At level 2 of the savanna formation, fire created a difference of approximately 86% in density and 89% in species dominance and, at level 3, a difference of 77% and 85% in density and dominance. In the forest formation, the lowest species richness affected by fire at levels 2 (lower 70.3%) and 3 (lower 89.6%) and dominance (62.9% lower) and (83.5% lower) in L2 and L3, respectively, reinforces the mortality of young plants after a fire (Almeida et al. 2014; Rios et al. 2018).

Although some species that were found both in the BC and in the BF, but not in areas not affected by fire, they were not abundant and had low species richness. The density of plants can change over time or due to disturbances (Mews et al. 2011). Rare species can appear or disappear in the same area as a result of dynamics and events in the floristic community (Aquino et al. 2007; Mews et al. 2011; Almeida et al. 2014), with fire being an event which can determine their presence or absence in an area.

The Fabaceae has been cited as one of the most important family in the Cerrado biome (Almeida et al. 2014; Rios et al. 2018), as well as the Myrtaceae. Most studies have recognized that the Fabaceae has the greatest species richness in the Cerrado stricto sensu, in burnt or unburnt areas, followed by the Vochysiaceae and Myrtaceae (Santos and Vieira 2005; Lima et al. 2009; Almeida et al. 2014; Rios et al. 2018). In the floristic survey of a seasonal semideciduous forest of the savanna-forest ecotone of São Paulo, the Myrtaceae family was second of families that showed the highest species richness (21), while Fabaceae was the fourth (12) (Pinheiro and Monteiro 2008). The species richness in the present forest formation study is in accordance with the findings of Solórzano et al. (2012) in six Brazilian states with Cerradão areas and ranged from 49 to 124 species.

Qualea multiflora, the species in the burnt and unburnt savannas in this study with the highest importance value, is among the most common species in the Brazilian Cerrado (Ratter et al. 2003). *Q. grandiflora*, with one of the highest importance values in the unburnt Cerrado and not found in the burnt Cerrado, is a species with wide distribution in the Cerrado (Ratter et al. 2003; Solórzano et al. 2012). Species of the Vochysiaceae family, such as *Q. multiflora*, are common in the Cerrado as they are typical aluminum accumulators, offering a competitive advantage in acidic soils (Lopes et al. 2009). *M. flexuosa* with its high basal area dominance, was among the five species with the highest importance value in the burnt Cerrado and not found in the UC. It is a common species in Veredas or along pathways, a dispersed phytophysiognomy within the category of savanna formations which has hydromorphic soils (Ribeiro and Walter 2008). These soils must be dry in order to permit fire to spread (Maillard et al. 2009), providing less moisture to combustible material (Busico et al. 2019). Therefore, soil moisture may have ensured the species survival from the spread of fire.

Solórzano et al. (2012) treats the Cerradão as a formation composed of species from both forest and savanna formations. *T. brasiliensis* was not recorded as a major species of forest formations in the Cerrado or in the Cerrado stricto sensu (Ratter et al. 2003; Solórzano et al. 2012). *A. parvifolium* was an uncommon Cerrado species (Ratter et al. 2003) and was not recorded in forest formations of the biome by Solórzano et al. (2012). *C. langsdoffii* is a species characteristic of forest formations in the Cerrado (Solórzano et al. 2012) and it was fire resistant, as it was among those species with the highest importance value in the burnt forest but not found in the unburnt forest.

In research of trees measured 30 cm above the ground and with DBH ≥ 5 cm in the Cerrado stricto sensu of several Brazilian states, diversity indices ranged from 3.0 to 3.8 (Lenza et al. 2011). In the study by Almeida et al. (2014), the Shannon diversity index was high, and the equability index showed little variation over 27 years of monitoring of the Cerrado stricto sensu areas. There was a small difference between the areas from 1997 after three fires ($H' = 3.27$ and $J' = 0.81$) and in 2009 after 12 years of fire protection ($H' = 3.49$ and $J' = 0.84$). In the present study, only level 1 of inclusion of the area not affected by fire is within the diversity values found in savanna areas, which reinforces the impact of fire on species diversity, especially in younger plants (Lima et al. 2009). In a Cerradão forest study in six Brazilian states, the Shannon index ranged from 3.1 to 4.0 and the evenness index from 0.79 to 0.83 (Solórzano et al. 2012). The indexes found in this study are within the ranges recorded in other studies, except for the lowest levels of inclusion of burnt areas where the younger plants were more susceptible to fire (Lima et al. 2009; Reis et al. 2017).

The limited similarity between the burnt and unburnt savannas by levels and, particularly at the lowest level of inclusion, illustrates the high mortality of plants, especially new regeneration and small diameter classes (Miranda et al. 2013; Almeida et al. 2014; Rios et al. 2018). In forests, in spite of the dissimilarity between the lower levels of inclusion due to low density and dominance of species of the burnt area, the similarity and higher level of inclusion between burnt and unburnt areas indicates that the greater availability of water and better soil fertility in forest formations can decrease the intensity of a fire (Silva et al. 2013; Pausas 2014; Bueno et al. 2018).

The woody vegetation of the Cerrado has adaptive and resilience characteristics to fire, such as crooked trees, thick bark (Gottsberger and Silberbauer-Gottsberger 2006) and low nutritional requirements (Lopes, et al. 2009). In addition to the fact that infrequent fires can favor the expansion of some subshrub and herbaceous species (Gottsberger and Silberbauer-Gottsberger 2006). However, frequent fires can cause impoverishment of the ecosystem by reducing total biomass, especially in the tree and shrub layers, leading to a progressive change in community diversity and structure (Fiedler et al. 2004; Lopes et al. 2009; Francos et al. 2018). The lower number of species in Cerrado formations in this study affected by fire compared to unaffected ones suggests that burning alters the structure and diversity of communities.,

Therefore, it is important to monitor the biome, especially with the subdivisions of its phytophysiognomies, to observe the development and resilience of the Cerrado after a fire disturbance (Silva et al. 2011; Rios et al. 2018). This is relevant because there may be a reduction in the diversity, frequency, density, and biomass of woody species immediately after the disturbance (Fiedler et al. 2004; Pilon et al. 2021), as well as a reduction in the recruitment of seedlings (Silva et al. 2020a, b). However, there may be a phase of species immigration following fire occurrence, with an increase in the number of individuals and in basal area, generating a phase of balance in the rates of recruitment and mortality (Rios et al. 2018).

The complexity in the biome's vegetation, which is highly heterogeneous, must be considered (Ribeiro and Walter 2008; Bueno et al. 2018) because, despite studies of savannas, these neither focused on the types of vegetation nor included all formations (Bueno et al. 2018). This may overestimate or underestimate the density and diversity of the biome, in addition to not including formal analyzes of how environmental factors and fire correlate with a broader floristic composition (Bueno et al. 2018).

Thus, the continuity of inventories in the biome is necessary to verify whether the results in this study will be maintained in the next monitoring period or if the community will change, especially with long-term fire suppression which could lead to changes in physiognomy (Almeida et al. 2014). With the increase in temperatures due to climate change and deforestation, a greater occurrence of fires is expected (Jolly et al. 2015) and the impact on regenerating species hinders the establishment of the forest in the RNST. Therefore, continuous conservation of the area must be maintained to reduce uncontrolled fires and balance the fire episodes and area recovery (Adamek et al. 2015).

Conclusion

The burnt savanna formation had lower plant diversity, density, and dominance at all levels compared with the unburnt one, in addition to showing dissimilarity between treatments. The burnt forest formation had smaller differences in diversity, density and dominance in inclusion levels compared with unburnt areas. The forest formation showed similarity in the total area; however, between the lower levels, it showed dissimilarity. Therefore, the physiognomy of the Cerrado had greater dissimilarity in its formation without fire compared to the forest physiognomy. The higher mortality of younger individuals was associated with fire since the areas of savanna and forest showed a difference in density at the lowest levels of inclusion, in volume, and in diameter class with the smallest diameter of level 1.

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References

Adámek M, Bobek P, Hadincová V, Wild J, Kopecký M (2015) Forest fires within a temperate landscape: adecadal and millennial perspective from a sandstone region in central Europe. For Ecol Manage 336:81–90

Almeida RF, Fagg CW, Oliveira MC, Munhoz CBR, Lima AS, Oliveira LSB (2014) Floristic and structural changes in the cerrado sensu stricto over 27 years (1985–2012) at Fazenda Água Limpa, Brasília DF. Rodriguésia 65(1):1–19

Aquino FG, Walter BMT, Ribeiro JF (2007) Woody community dynamics in two fragments of "Cerrado" stricto sensu over a seven-year period (1995–2002) MA Brazil. Revista Brasileira De Botânica 30:113–212

Bedia J, Herrera S, Camia A, Moreno JM, Gutiérrez JM (2014) Forest fire danger projections in the Mediterranean using ENSEMBLES regional climate change scenarios. Clim Change 122(1–2):185–199

Bueno LM, Dexter KG, Pennington RT, Pontara V, Neves DM, Ratter JA, Oliveira-Filho AT (2018) The environmental triangle of the Cerrado domain: ecological factors driving shifts in tree species composition between forests and savannas. J Ecol 106:2109–2120

Busico G, Guditta E, Kazakis N, Colombani N (2019) A hybrid GIS and AHP approach for modelling actual and future forest fire risk under climate change accounting water resources attenuation role. Sustainability 11(24):7166

Camargos VL, Ribeiro GA, Silva AF, Martins SV, Carmo FMS (2015) Study of fire behavior on a part of semideciduous seasonal forest in Viçosa Minas Gerais. Ciência Florestal 25(3):537–545

Costa-Milanez CB, Ribeiro FF, Castro PTA, Majer JD, Ribeiro SP (2015) Effect of fire on ant assemblages in brazilian cerrado in areas containing vereda wetlands. Sociobiology 62(4):494–505

Dalle Laste KC, Durigan G, Andersen AN (2019) Biodiversity responses to land-use and restoration in a global biodiversity hotspot: ant communities in Brazilian Cerrado. Austral Ecol 44(2):313–326

Durigan G, Ratter JA (2016) The need for a consistent fire poltey for Cerrado conservation. J Appl Ecol 53(1):11–15

Elias F, Marimon BS, Gomes L, Forsthofer M, Abreu MF, Reis SA, Lenza E, Franczak DD, Marimon Junior BH (2013) Resiliência de um cerradão submetido a perturbações intermediárias na transição Cerrado-Amazônia. Biotemas 26(3):49–62

Fiedler NC, Azevedo INC, Rezende AV, Medeiros MB, Venturoili F (2004) Effect of fire on the structure and floristic composition of a Cerrado sensu stricto area in fazenda Água Limpa-DF. Revista Árvore 28:129–138

Francos M, Pereira P, Alcañiz M, Úbeda X (2018) Post-wildfire management effects on short-term evolution of soil properties (Catalonia, Spain, SW-Europe). Sci Total Environ 633:285–292

Françoso RD, Brandão RA (2013) Landscape dynamic on neighboring of Serra do Tombador natural reserve, north Goiás. Caminhos De Geografia 14(45):284–293

Fundação GB (2011) Plano de manejo da reserva natural serra do tombador. Supervision Gustavo Adolfo Gatti

Gottsberger G, Silberbauer-Gottsberger I (2006) Life in the Cerrado: a South American tropical seasonal ecosystem. Reta Verlag, Ulm, p 277

Grecchi RC, Gwyn QHJ, Benie GB, Formaggio AR, Fahl FC (2014) Land use and land cover changes in the Brazilian Cerrado: a multidisciplinary approach to assess the impacts of agricultural expansion. Appl Geogr 55:300–312

Haidar RF, Fagg JMF, Pinto JRR, Dias RR, Damasco G, Silva LCR, Fagg CW (2013) Seasonal forests and ecotone areas in the state of Tocantins, Brazil: structure, classification, and guidelines for conservation. Acta Amazônica 43:261–290

Hoffmann WA, Adasme R, Haridasan M, Carvalho DE (2009) Tree topkill, not mortality, governs the dynamics of savanna–forest boundaries under frequent fire in Central Brazil. Ecology 90:1326–1337

ICMBIO–Instituto Chico Mendes de Biodiversidade (2018) Unidades de Conservação do Cerrado. http://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/cerrado/unidades-de-conservacao-cerrado/5427-rppn-serra-do-tombador. Acessed on 13 Aug 2018

Imaña-Encinas J, Santana OA, Paula JE, Rainier-Imaña C (2009) Wood volume equation for a cerrado at Planaltina. Goiás State Floresta 39(1):107–116

INMET (2018) Instituto Nacional de Meteorologia. https://portal.inmet.gov.br. Acessed on 13 Aug 2018

Jafari Goldarag Y, Mohammadzadeh A, Ardakani AS (2016) Fire risk assessment using neural network and logistic regression. J Indian Soc Remote 44(6):885–894

Jolly WM, Cochrane MA, Freeborn PH, Holden ZA, Brown TJ, Williamson GJ, Bowman DMJS (2015) Climate-induced variations in global wildfire danger from 1979 to 2013. Nat Commun. https://doi.org/10.1038/ncomms8537

Kayet N, Chakrabarty A, Pathak K, Sahoo S, Dutta T, Hatai BK (2020) Comparative analysis of multi-criteria probabilistic FR and AHP models for forest fire risk (FFR) mapping in Melghat tiger reserve (MTR) forest. J For Res 31(2):565–579

Kelly LT, Brotons L (2017) Using fire to promote biodiversity. Science 355(6331):1264–1265

Lehmann CER, Anderson TM, Sankaran M, Higgins SI, Archibald S, Hoffmann WA, Bond WJ (2014) Savanna vegetation-fire- climate relationships differ among continents. Science 343:548–552

Lenza E, Pinto JRR, Pinto AS, Maracahipes L, Bruziguessi EP (2011) Comparisons between a savanna on rocky soil tree-shrub community at Chapada dos Veadeiros, Goiás, and Cerrado sensu stricto areas of the Cerrado biome. Revista Brasileira De Botânica 34:247–259

Lima ES, Lima HS, Ratter JÁ (2009) Post fire changes in the structure and composition of the woody vegetation of a mesotrophic cerrado over a five-year period (1997–2002) in Nova Xavantina, MT Brazil. Cerne 15(4):448–480

Lopes SF, Vale VS, Schoavini I (2009) Effect of fire on the structure and floristic composition of a Cerrado sensu stricto area in Caldas Novas GO. Revista Árvore 33(4):695–704

Maillard P, Pereira DB, Souza CG (2009) Wildfires in Palm Swamps: concepts and case study in the Peruaçu. Rev Bras Cartogr 61:4–11

Maravalhas J, Vasconcelos HL (2014) Revisiting the pyrodiversity-biodiversity hypothesis: long-term fire regimes and the structure of ant communities in a Neotropical savanna hotspot. J Appl Ecol 51:1661–1668

Mews HA, Marion BS, Maracahipes L, Franczak DD, Marimon-Junior BH (2011) Dynamics of the woody community of a typical cerrado in Northeastearn Mato Grosso, Brazil. Biota Neotrópica 11:73–82

Miguel EP, Rezende AV, Pereira RS, Azevedo GB, Mota FCM, Souza AN, Joaquim MS (2017) Modeling and prediction of volume and aereal biomass of the tree vegetation in a Cerradão Area of Central Brazil. Interciencia 42(1):21–27

Miranda SC, Silva Junior MC, Carvalho OS (2013) The effect of fire protection in the structure of woody vegetation in an area of Cerrado censu stricto in Central Brazil. Heringeriana 7(1):61–72

Miranda HS, Nascimento Neto W, Neves BMC (2010) Caracterização das queimadas no Cerrado. In: Miranda HS (ed) Efeitos do fogo sobre a estrutura de comunidade de Cerrado: Projeto Fogo. IBAMA, Brasília, pp 66–84

Oliveras I, Meirelles ST, Hirakuri VL, Freitas CR, Miranda HS, Pivello VR (2013) Effects of fire regimes on herbaceous biomass and nutrient dynamics in the Brazilian savanna. Int J Wildland Fire 22:368–380

Pausas JG (2014) Alternative fire-driven vegetation states. J Veg Sci 26:4–6

Pereira Júnior AC, Oliveira SLJ, Pereira JMC, Turkman MAA (2014) Modelling fire frequency in a Cerrado savanna protected area. PLoS ONE. https://doi.org/10.1371/journal.pone.0102380

Pilon NAL, Cava MGB, Hoffmann WA, Abreu RCR, Fidelis A, Durigan G (2021) The diversity of post-fire regeneration strategies in the Cerrado ground layer. J Ecol 109(1):154–166

Pinheiro MHO, Monteiro R (2008) Floristics of a seasonal semideciduous forest from a forest-savanna ecotone in Bauru municipality, São Paulo State Brazil. Acta Botânica Brasilica 22(4):1085–1094

Pivello VR (2011) The use of fire in the Cerrado and Amazonian rainforests of Brazil: Past and present. Fire Ecol 7(1):24–39

Ratter JA, Bridgewater S, Ribeiro JF (2003) Analysis of the floristic composition of the Brazilian cerrado vegetation III: comparison of the woody vegetation of 376 areas. Edinb J Bot 60(1):57–109

Reis SM, de Oliveira EA, Elias F, Gomes L, Morandi PS, Marimon BS, Marimon Junior BH, Neves EC (2017) Resistance to fire and the resilience of the woody vegetation of the "Cerradão" in the "Cerrado"—Amazon transition zone. Revista Brasileira De Botanica 40(1):193–201
Rezende AV, Vale AT, Sanquetta CR, Figueiredo Filho A, Felfili JM (2006) Comparison of mathematical models to volume, biomass, and carbon stock estimation of the woody vegetation of a Cerrado sensu stricto in Brasília, DF. Scientia Foretalis 71:65–76
Ribeiro JF, Walter BMT (2008) Fitofisionomias do bioma Cerrado. In: Sano SM, Almeida SP (eds) Cerrado: ecologia e flora. EMBRAPA-CPAC, Planaltina-DF, pp 151–212
Rios MNS, Sousa-Silva JC, Malaquias JV (2018) Changings after fire in floristic and structure of tree arboreal and shrub vegetation in a Cerrado sensu stricto in Planaltina. DF Ciênc Florest 28(2):469–482
Sansevero JBB, Prieto PV, Sánchez-Tapia A, Braga JMA, Rodrigues PJFP (2017) Past land-use and ecological resilience in a lowland Brazilian Atlantic forest: implications for passive restoration. New For 48:573–586
Santos RM, Vieira FA (2005) Structural analysis of the arboreal component of three areas of Savannah in different stadiums of conservation, in Três Marias count, Minas Gerais state Brazil. Cerne 11(4):339–408
Santos JFC, Gleriani JM, Velloso SGS, Souza GCA, Amaral CH, Torres FTP, Medeiros NG, Reis M (2019) Wildfires as a major challenge for natural regeneration in Atlantic forest. Sci Total Environ 650:809–821
Sato MN, Miranda HS, Maia JMF (2010) O fogo e o estrato arbóreo do Cerrado: efeitos imediatos e de longo prazo. In: Miranda HS (ed) Efeitos do regime do fogo sobre a estrutura de comunidade de Cerrado: Projeto fogo. IBAMA, Brasília, pp 77–91
Schmerbeck J, Fiener P (2015) Wildfires, ecosystem services, and biodiversity in tropical dry forest in India. Environ Manage 56:355–372
Silva DM, de Loiola P, P, Rosatti NB, et al (2011) Fire regime effects on cerrado vegetation in the Emas national park: ideas for diversity conservation. Biodivers Bras 1:26–39
Silva LCR, Hoffmann WA, Rossatto DR, Haridasan M, Franco AC, Horwath WR (2013) Can savannas become forests? A coupled analysis nutrient stocks and fire thresholds in central Brazil. Plant Soil 373:829–842
Silva LS, Costa TR, Salomão NV, Otoni TJO, Machado ELM (2020a) After-fire variations in floristic composition at the Cerrado (Brazilian Savannah) phytophysiognomies in Curvelo, Minas Gerais Brazil. Floresta e Ambiente 27(3):1–9
Silva LS, Otoni TJO, Vieira AD, Gonzaga APD, Botezelli L, de Junior MS, M, Pereira IM, Machado ELM, (2020b) Temporary variations in the structure in phytophysiognomies of Cerrado and semi decidual state forest in Curvelo Minas Gerais State. Cienc Florest 30(3):730–742
Solórzano A, Pinto JRR, Felfili JM, Hay JDV (2012) Structural and floristic profile of the woody component of six Cerradão areas. Acta Bot Bras 26:328–341
Stephens SL, Westerling ALR, Hurteau MD, Peery MZ, Schultz CA, Thompson S (2020) Fire and climate change: conserving seasonally dry forests is still possible. Front Ecol Environ 18(6):354–360
Zhang Y, Lim S, Sharples JJ (2016) Modelling spatial patterns of wildfire occurrence in South-Eastern Australia. Geomat Nat Haz Risk 7(6):1800–1815

6. CONCLUSÕES GERAIS

As causas “Desconhecida”, “Queima para limpeza” e “Incendiários” foram as principais para a ocorrência de incêndios florestais em UCs federais do Brasil. O grande número de registros com causas “Desconhecidas” torna importante esta categoria e demonstra falhas na perícia dos incêndios de determinada UC. O período de maior ocorrência de incêndio foi de julho a outubro, representando o período normal do fogo no país. O estado de Minas Gerais foi o principal estado em ocorrência de incêndios.

O estudo afirma, através da utilização de formigas como bioindicadoras de impacto de incêndio, que a formação savânica é favorecida pelo fogo ao demonstrar maior abundancia de indivíduos e maior índice de diversidade quando comparado a formação não queimada com a queimada, além do surgimento de novos gêneros de formigas na área queimada. Já a fitofisionomia florestal, ao apresentar diferença estatística na abundância de indivíduos e similaridade entre a área florestal queimada e não queimada, além do menor número de gêneros e menor índice de diversidade na floresta atingida pelo fogo, demonstra que o fogo pode impactar na diversidade de gêneros de formiga nessa fitofisionomia.

Porém, a mortalidade de indivíduos arbóreos de menor porte está associada ao evento do fogo, visto que as áreas savânicas e florestais tiveram diferença de densidade nas áreas atingidas pelo fogo nos menores níveis e na classe de menor diâmetro. A formação savânica queimada se apresentou com diversidade, densidade e dominância inferior em todos os níveis de inclusão com a formação não queimada, além de não apresentar similaridade em nenhum nível de inclusão. A formação florestal também apresentou diferenças em diversidade, densidade e dominância nos níveis de inclusão. Apesar de apresentar similaridade na área total e no nível 1 de inclusão, houve dissimilaridade entre os menores níveis.

Espera-se um aumento das ocorrências de incêndios florestais em todo o mundo relacionados tanto ao aumento da temperatura global, devido às mudanças climáticas, quanto ao desmatamento, principalmente em regiões ameaçadas como o Cerrado. É necessário que haja planejamento de ações de educação ambiental, fiscalização e punição de incêndios que atinjam áreas de proteção ambiental e que os registros dos mesmos sejam feitos para que se conheçam as causas, áreas e os períodos críticos no Brasil. O aumento da frequência dos incêndios e o impacto do fogo em áreas de regeneração dificulta o estabelecimento de florestas adaptadas ou não ao fogo, sendo importante que a gestão de conservação de áreas de proteção, como a RNST, continue, evitando, principalmente, os incêndios criminosos e negligentes, para que o equilíbrio entre os episódios de fogo e recuperação possa ocorrer.

As versões publicadas na íntegra, estão disponíveis em https://periodicos.ufsm.br/cienciaflorestal/article/view/69028 (artigo 1); https://www.scielo.br/j/floram/a/9zn7gwYjTqPhFY3hzLw9y6v/?lang=en (artigo 2) e https://link.springer.com/article/10.1007/s11676-022-01573-3 (artigo 3).

APÊNDICES

APÊNDICE A - DISTRIBUIÇÃO DE SUBFAMÍLIAS E ESPÉCIES DE FORMIGAS POR FITOFISIONOMIAS ATINGIDAS E NÃO ATINGIDAS PELO FOGO DO CERRADO A RNST, GOIÁS

Subfamília / Espécies	CNQ	CQ	FNQ	FQ	Total
Dolichoderinae					
Dolichoderus sp 1			2		2
Dorymyrmex sp 1		12			12
Forelius sp 1		1			1
Linepithema sp 1			3		3
Linepithema sp 2		2			2
Ectatominae					
Ectatomma brunneum	45				45
Ectatomma edetatum	20		4		24
Ectatomma lugens	15		33	30	78
Ectatomma opaciventre	3				3
Gnamptogenys gp striatula sp 1		105	14	16	135
Gnamptogenys gp sulcata sp 1			2		2
Formicinae					
Brachymyrmex sp 1			3		3
Brachymyrmex sp 2	3	2			5
Camponotus sp 1	2	46			48
Camponotus sp 2				2	2
Camponotus sp 3	2		1		3
Camponotus sp 4	2			1	3
Camponotus sp 5		22		1	23
Camponotus sp 6	2				2
Camponotus sp 7			2		2
Camponotus sp 8	1			9	10
Camponotus sp 9		7			7
Nylanderia sp 1			6	1	7
Myrmicinae					
Acromyrmex coronatus			1		1
Atta sexdens			10	9	19
Cephalotes atratus				1	1
Crematogaster sp 1		8			8
Crematogaster sp 2			3		3
Mycocepurus goeldii		2			2
Mycocepurus smithii		2			2
Ochetomyrmex neopolitus				34	34
Ochetomyrmex semipolitus		7		3	10
Pheidole sp 1		40			40
Pheidole sp 2			8		8
Pheidole sp 3	12				12
Pheidole sp 4	2	54	36		92
Pheidole sp 5			18		18

Subfamília / Espécies	CNQ	CQ	FNQ	FQ	Total
Pheidole sp 6			15		15
Pheidole sp 7			1		1
Pheidole sp 8			13		13
Pheidole sp 9				4	4
Pheidole sp 10				1	1
Pheidole sp 11		148			148
Pheidole sp 12		38			38
Pheidole sp 13				10	10
Pheidole sp 14				24	24
Pheidole sp 15				4	4
Pheidole sp 16	1			2	3
Pheidole sp 17		22			22
Pheidole sp 18		16	2	103	121
Pheidole sp 19	86	3			89
Pheidole sp 20			5		5
Pheidole sp 21	1			1	2
Pheidole sp 22	1	7	1	6	15
Sericomyrmex sp 1			4	16	20
Solenopsis gp globularia sp 1	1				1
Solenopsis gp globularia sp 2	5				5
Solenopsis sp 1				1	1
Trachymyrmex sp 1			1		1
Trachymyrmex ufv-11		3			3
Wasmannia auropunctata			2		2
Ni					
Ni		1			1
Ponerinae					
Centromyrmex brachycola	1				1
Dinoponera quadriceps	24	5	1		30
Hipoponera sp 1				1	1
Neoponera commutata	1				1
Neoponera verenae	8		3	26	37
Odontomachus chelifer			3	8	11
Odontomachus sp 1		1			1
Pachycondyla harpax			3	1	4
Pseudomyrmecinae					
Pseudomyrmex sp 1			18		18
Pseudomyrmex termitarius		70	2		72
Total	238	624	220	315	1397

Legenda: formação savânica: CQ= Cerrado queimado e CNQ= Cerrado não queimadoe formação florestal: FQ= Floresta Queimadam e FNQ= Floresta não queimada

APÊNDICE B - COMPOSIÇÃO FLORÍSTICA POR FITOFISIONOMIAS ATINGIDAS E NÃO ATINGIDAS PELO FOGO DO CERRADO DA RNST, GOIÁS

Família/espécie	CQ	CNQ	FQ	FNQ	Total
Anacardiaceae					
Anacardium humile St. Hill		1			1
Anacardium occidentale L.		1			1
Astronium fraxinifolium Schott. ex Spreng			2		2
Astronium graveolens Jacq			1	2	3
Tapirira guianensis Aubl.			1		1
Annonaceae					
Annona sp 1			5	6	11
Annona sp 2				1	1
Duguetia lanceolata A.St.-Hil.		4		4	8
Guatteria sp				15	15
Ni (Annonaceae)			4		4
Xylopia aromatica (Lam.) Mart.	1				1
Xylopia sericea A.St.-Hil.		3	5	11	19
Apocynaceae					
Aspidosperma cylindrocarpon Müll.Arg. LC				4	4
Aspidosperma macrocarpon Mart. LC		1			1
Aspidosperma parvifolium A. DC.			11	23	34
*Aspidosperma s*p 1			5	1	6
Aspidosperma sp 2			1		1
Aspidosperma tomentosum Mart.	1				1
Hancornia speciosa Gomes		5			5
Himatanthus obovatus (Müll. Arg.) Woodson				2	2
Araliaceae					
Schefflera morototoni (Aubl.) Maguire et al.			2	3	5
Arecaceae					
Acrocomia aculeata (Jacq.) Lodd. Ex Mart			2		2
Attalea phalerata Mart. Ex Spreng.		1	6		7
Mauritia flexuosa L.f.	2				2
Syagrus oleracea (Mart.) Becc.				2	2
Asteraceae					
Ni (Asteraceae)	3	1			4
*Vernoni*a sp		1			1
Bignoniaceae					
Cybistax antisyphilitica Mart.			1		1
*Handroanthus impetiginosus (*Mart. ex DC.) Mattos		1	1	2	4
Handroanthus serratifolius (Vahl) S.Grose			2	1	3
Burseraceae					
Protium heptaphyllum (Aubl.) Marchand			6	15	21
Protium warmingianum Marchand				3	3
Trattinickia cf. rhoifolia Willd.			1	2	3
Caryocaraceae					
Caryocar brasiliense Cambess.	1	2			3

Família/espécie	CQ	CNQ	FQ	FNQ	Total
Celastraceae					
Austroplenckia populnea (Reissek)Lundell		1			1
Maytenus robusta Reissek				3	3
Chrysobalanaceae					
Licania kunthiana Hook.f.	1	1	1	7	10
Clusiaceae					
Garcinia gardneriana (Planch. & Triana) Zappi				1	1
Garcinia sp				2	2
Kielmeyera rubriflora Cambess.	2	1			3
Combretaceae					
Terminalia brasiliensis (Cambess.) Eichler			1	6	7
Terminalia fagifolia Mart.			2	1	3
Terminalia sp				1	1
Connaraceae					
Connarus suberosus Planch.		1			1
Dilleniaceae					
Curatella americana L.	4				4
Davilla elliptica St.-Hil.	6	6			12
Ealeocarpaceae					
Sloanea sp			1		1
Ebenaceae					
Diospyros hispida DC		1	1	5	7
Erythroxylaceae					
Erythroxylum deciduum A.St.-Hil.		1			1
Erythroxylum sp 1		1			1
Erythroxylum sp 2		1			1
Euphorbiaceae					
Croton sp				11	11
Maprounea guianensis Aubl.				1	1
Ni (Euphorbiaceae)			6		6
Sapium glandulatum (Vell.) Pax	2				2
Fabaceae					
Acosmium sp	1	2			3
Acosmium dasycarpum (Vogel) Yakovlev	2			2	4
Albizia polycephala (Benth.) Killip ex Record				1	1
Anadenanthera macrocarpa (Benth.) Brenan.			7	4	11
Apuleia leiocarpa (Vogel) J.F.Macbr.		3	1	7	11
Bauhinia cf. forficata Link.			4	1	5
Bauhinia rufa (Bong.) Steud.		1	2	5	8
Bowdichia virgilioides Kunth		7			7
Copaifera langsdoffii Desf.		1	5		6
Hymenaea courbaril L.			10	9	19
Hymenaea stigonocarpa Mart ex Hayne		6			6
Inga cylindrica (Vell.) Mart.		2	1	3	6
Inga sp			2	1	3

Família/espécie	CQ	CNQ	FQ	FNQ	Total
Lonchocarpus cultratus (Vell.)			1		1
Machaerium opacum Vogel			4		4
Machaerium sp	1				1
Platypodium elegans Vogel		1	11	6	18
Sclerolobium rugosum Mart.	3	3			6
Sclerolobium sp		8	5	4	17
Senna multijuga (Rich.) H.S.Irwin & Barneby				1	1
Senna sp		1			1
Stryphnodendron adstringens (Mart.) Coville		1			1
Swartzia flaemingii Raddi			5	1	6
Hypericaceae					
Vismia brasiliensis Choisy				7	7
Vismia guianensis (Aubl.) Choisy				1	1
Lamiaceae					
Vitex polygama Cham.		1	2	1	4
Lauraceae					
Nectandra oppositifolia Nees			1		1
Nectandra sp			5	7	12
Ni (Canela 2/Lauraceae)				1	1
Ocotea sp			1	6	7
Persea pyrifolia Nees & Mart.				3	3
Lythraceae					
Lafoensia pacari Saint-Hilaire			2	2	4
Malpighiaceae					
Byrsonima sericea DC			1	4	5
Byrsonima sp 1		1			1
Byrsonima sp 2		1			1
Byrsonima verbascifolia (L.) DC.	3	7			10
Malvaceae					
Apeiba tibourbou Aubl			1	2	3
Eriotheca gracilipes K.Schum.				2	2
Eriotheca pubescens (Mart. & Zucc.) Schott & Endl.		5	1		6
Guazuma ulmifolia Lam.			4	2	6
Luehea divaricata Mart. & Zucc.			8	4	12
Luehea grandiflora Mart. & Zucc				1	1
Pseudobombax longiflorum (Mart.) A.Robyns			5	1	6
Melastomataceae					
Miconia cinnamomifolia (DC.) Naudin	1			2	3
Miconia sp 1	2	5			7
Miconia sp 2	3				3
Meliaceae					
Guarea guidonia (L.) Sleumer				7	7
Moraceae					
Maclura tinctoria (L.) D.Don ex Steud.			1		1
Sorocea bonplandii (Baill.) W.C.Burger et al.			1		1

Família/espécie	CQ	CNQ	FQ	FNQ	Total
Myristicaceae					
Virola sebifera Aubl.		4		10	14
Myrtaceae					
Campomanesia sp 1			3	5	8
Campomanesia sp 2			9		9
Eugenia sp			1	4	5
Myrcia fallax (Rich.) DC.			3	14	17
Myrcia rostrata DC.			2		2
Myrcia sp 1	18	25			43
Myrcia sp 2		4	3	1	8
Myrcia sp 3		9	25	4	38
Myrcia tomentosa (Aubl.) DC.		1	1		2
Ni 1 (Myrtaceae)	1	1		1	3
Ni 2 (Myrtaceae)	2	2			4
Ni 3 (Myrtaceae)				2	2
Ni 4 (Myrtaceae)			2		2
Ni familia					
Ni (Ni familia)			1		1
Nyctaginaceae					
Guapira opposita (Vell.) Reitz		3		4	7
Ochnaceae					
Ouratea spectabilis (Mart.) Engl.		6	1	2	9
Piperaceae					
Piper sp			1	1	2
Primulaceae					
Rapanea guianensis Aubl.			2		2
Proteaceae					
Roupala montana Aubl.			2		2
Rhamnaceae					
Rhamnidium elaeocarpum Reissek			1		1
Rosaceae					
Prunus sellowii Koehne			3	4	7
Rubiaceae					
Alibertia macrophylla K.Schum.		5	16	29	50
Exora sp			1	4	5
Ferdinandusa sp 1			17	11	28
Ferdinandusa sp 2			2		2
Guettarda viburnoides Cham. & Schltdl.			2	1	3
Ni 1 (Rubiaceae)	1				1
Ni 2 (Rubiaceae)				2	2
Rutaceae					
Metrodorea stipularis Mart			2	9	11
Zanthoxylum rhoifolium Lam.				1	1
Salicaceae					
Casearia arborea (Rich.) Urb				1	1

Família/espécie	CQ	CNQ	FQ	FNQ	Total
Casearia sp		2		5	7
Casearia sylvestris Sw.		8	2		10
Sapindaceae					
Allophylus sericeus (Cambess.) Radlk				5	5
Cupania oblongifolia Mart.			2	6	8
Cupania sp 1				19	19
Cupania sp 2				1	1
Cupania sp 3				1	1
Dilodendron bipinnatum Radlk. LC				4	4
Magonia pubescens A.St.-Hil		2			2
Matayba elaeagnoides Radlk.			15	27	42
Sapotaceae					
Pouteria ramiflora (Mart.) Radlk.				1	1
Pouteria sp				10	10
Simaroubaceae					
Simarouba versicolor A.St.-Hil.		1		3	4
Siparunaceae					
Siparuna guianensis Aubl.	1		1	10	12
Verbenaceae					
Aegiphila lhotzkiana Cham.			1		1
Vochysiaceae					
Callisthene major Mart.		5	4	1	10
Qualea grandiflora Mart.		13		1	14
Qualea multiflora Mart.	13	20	7		40
Qualea parviflora Mart.			5	10	15
Total	75	202	296	447	1020

Legenda: formação savânica: CQ= Cerrado queimado e CNQ= Cerrado não queimadoe formação florestal: FQ= Floresta Queimadam e FNQ= Floresta não queimada

APÊNDICE C - NÚMERO DE ESPÉCIES POR FAMÍLIA EM FORMAÇÃO SAVÂNICA NÃO ATINGIDA E ATINGIDA PELO FOGO

Família	CQ	CNQ
Anacardiaceae	0	2
Annonaceae	1	2
Apocynaceae	1	2
Arecaceae	1	1
Asteraceae	1	2
Bignoniaceae	0	1
Caryocaraceae	1	1
Celastraceae	0	1
Chrysobalanaceae	1	1
Clusiaceae	1	1
Connaraceae	0	1
Dilleniaceae	2	1
Ebenaceae	0	1
Erythroxylaceae	0	3
Euphorbiaceae	1	0
Fabaceae	4	12
Lamiaceae	0	1
Malpighiaceae	1	3
Malvaceae	0	1
Melastomataceae	3	1
Myristicaceae	0	1
Myrtaceae	3	6
Ni familia	0	1
Nyctaginaceae	0	1
Ochnaceae	0	1
Rubiaceae	1	1
Salicaceae	0	2
Sapindaceae	0	1
Simaroubaceae	0	1
Siparunaceae	1	0
Vochysiaceae	1	3

Legenda: formações savânicas= CQ (Cerrado queimado) e CNQ (Cerrado não queimado)

APÊNDICE D - DENSIDADE ABSOLUTA E DOMINÂNCIA ABSOLUTA POR HECTARE EM NÍVEL 2 DE INCLUSÃO DA FORMAÇÃO SAVÂNICA NÃO ATINGIDA E ATINGIDA PELO FOGO NO NÍVEL 2 DE INCLUSÃO NA RPPN SERRA DO TOMBADOR, GOIÁS

Espécie	CNQ N2		CQ N2	
	DAi	DoA	DAi	DoA
Myrcia sp 1	133,3333	0,3223	16,6667	0,0300
Myrcia sp 3	66,6667	0,0463		
Ouratea spectabilis (Mart,) Engl,	66,6667	0,0841		
Hancornia speciosa Gomes	50,0000	0,0408		
Qualea multiflora Mart,	50,0000	0,0452		
Alibertia macrophylla K,Schum,	33,3333	0,0657		
Callisthene major Mart,	33,3333	0,0260		
Hymenaea stigonocarpa Mart ex Hayne	33,3333	0,0548		
Acosmium sp	16,6667	0,0287	16,6667	0,0175
Caryocar brasiliense Cambess,	16,6667	0,0135		
Casearia sylvestris Sw,	16,6667	0,0244		
Duguetia lanceolata A,St,-Hil,	16,6667	0,0112		
Eriotheca pubescens (Mart, & Zucc,) Schott & Endl,	16,6667	0,0107		
Myrcia sp 2	16,6667	0,0100		
Myrcia tomentosa (Aubl,) DC,	16,6667	0,0176		
Platypodium elegans Vogel	16,6667	0,0182		
Qualea grandiflora Mart,	16,6667	0,0103		
Sclerolobium sp	16,6667	0,0260		
Miconia cinnamomifolia (DC,) Naudin			16,6667	0,0098
Ni (Asteraceae)			16,6667	0,0178
Sclerolobium rugosum Mart,			16,6667	0,0191
Total	633,3333	0,8559	83,3333	0,0943

Legenda: CNQ= Cerrado não queimado (formação savânica); CQ= ccerrado queimado; N2: Nível de inclusão de parcela; DAi= densidade absoluta (ind/ha); DoA= dominância absoluta (m²/ha).

APÊNDICE E - DENSIDADE ABSOLUTA E DOMINÂNCIA ABSOLUTA POR HECTARE EM NÍVEL 3 DE INCLUSÃO DA FORMAÇÃO SAVÂNICA NÃO ATINGIDA E ATINGIDA PELO FOGO NO NÍVEL 2 DE INCLUSÃO NA RPPN SERRA DO TOMBADOR, GOIÁS

Espécies	CNQ N3		CQ N3	
	DAi	DoA	DAi	DoA
Miconia sp 1	333.3333	0.047853		
Byrsonima verbascifolia (L.) DC.	200,0000	0.075195		
Casearia sylvestris Sw.	200,0000	0.050914		
Hancornia speciosa Gomes	133.3333	0.062972		
Ouratea spectabilis (Mart.) Engl.	133.3333	0.056224		
Qualea grandiflora Mart.	133.3333	0.013077		
Myrcia sp 2	66.66667	0.025995		
Sclerolobium sp	66.66667	0.025258		
Qualea multiflora Mart.	66.66667	0.022414		
Eriotheca pubescens (Mart. & Zucc.) Schott & Endl.	66.66667	0.020393		
Xylopia sericea A.St.-Hil.	66.66667	0.019741		
Guapira opposita (Vell.) Reitz	66.66667	0.017236		
Callisthene major Mart.	66.66667	0.008069		
Stryphnodendron adstringens (Mart.) Coville	66.66667	0.007661		
Bauhinia rufa (Bong.) Steud.	66.66667	0.003316		
Myrcia sp 1			200,0000	0.015862
Licania kunthiana Hook.f.			66.66667	0.024531
Siparuna guianensis Aubl.			66.66667	0.012223
Xylopia aromatica (Lam.) Mart.			66.66667	0.016637
Total	1733.3333	0.4563	400.0000	0.0693

Legenda: CNQ= Cerrado não queimado (formação savânica); CQ= cerrado queimado; N2: Nível de inclusão de parcela; DAi= densidade absoluta (ind/ha); DoA= dominância absoluta (m²/ha).

APÊNDICE F - NÚMERO DE ESPÉCIES POR FAMÍLIA EM FORMAÇÃO SAVÂNICA NÃO ATINGIDA E ATINGIDA PELO FOGO

Família	FQ	FNQ
Anacardiaceae	3	1
Annonaceae	3	5
Apocynaceae	3	4
Araliaceae	1	1
Arecaceae	2	1
Bignoniaceae	3	2
Burseraceae	2	3
Celastraceae	0	1
Chrysobalanaceae	1	1
Clusiaceae	0	2
Combretaceae	2	3
Ealeocarpaceae	1	0
Ebenaceae	1	1
Euphorbiaceae	1	2
Fabaceae	12	13
Hypericaceae	0	2
Lamiaceae	1	1
Lauraceae	3	4
Lythraceae	1	1
Malpighiaceae	1	1
Malvaceae	5	6
Melastomataceae	0	1
Meliaceae	0	1
Moraceae	2	0
Myristicaceae	0	1
Myrtaceae	9	7
Nyctaginaceae	0	1
Ochnaceae	1	1
Piperaceae	1	1
Primulaceae	1	0
Proteaceae	1	0
Rhamnaceae	1	0
Rosaceae	1	1
Rubiaceae	5	5
Rutaceae	1	2
Salicaceae	1	2
Sapindaceae	2	7
Sapotaceae	0	2
Simaroubaceae	0	1
Siparunaceae	1	1
Verbenaceae	1	0
Vochysiaceae	3	3

Legenda: Formações florestais do cerrado: FNQ= Floresta não queimada; FQ= floresta queimada.

APÊNDICE G - DENSIDADE ABSOLUTA E DOMINÂNCIA ABSOLUTA POR HECTARE EM NÍVEL 2 DE INCLUSÃO DA FORMAÇÃO FLORESTAL NÃO ATINGIDA E ATINGIDA PELO FOGO NO NÍVEL 2 DE INCLUSÃO NA RPPN SERRA DO TOMBADOR, GOIÁS

Espécie	FNQ N2		FQ N2	
	Dai	DoA	Dai	DoA
Matayba elaeagnoides Radlk,	216,6667	0,1939	16,6667	0,0238
Alibertia macrophylla K,Schum,	183,3333	0,1647	16,6667	0,0204
Ferdinandusa sp	100,0000	0,0826	50,0000	0,0393
Metrodorea stipularis Mart	100,0000	0,0919		
Siparuna guianensis Aubl,	83,3333	0,0713		
Xylopia sericea A,St,-Hil,	83,3333	0,1017	16,6667	0,0278
Virola sebifera Aubl,	66,6667	0,0644		
Myrcia fallax (Rich,) DC,	50,0000	0,0453		
Protium heptaphyllum (Aubl,) Marchand	50,0000	0,0283	33,3333	0,0214
Qualea parviflora Mart,	50,0000	0,0520		
Apuleia leiocarpa (Vogel) J,F,Macbr,	33,3333	0,0461		
Aspidosperma parvifolium A, DC,	33,3333	0,0383	33,3333	0,0302
Bauhinia rufa (Bong,) Steud,	33,3333	0,0404		
Cupania oblongifolia Mart,	33,3333	0,0158		
Cupania sp 1	33,3333	0,0521		
Eugenia sp	33,3333	0,0222		
Garcinia sp	33,3333	0,0200		
Guatteria sp	33,3333	0,0347		
Maytenus robusta Reissek	33,3333	0,0402		
Ocotea sp	33,3333	0,0294		
Protium warmingianum Marchand	33,3333	0,0181		
Sclerolobium sp	33,3333	0,0219		
Allophylus sericeus (Cambess,) Radlk	16,6667	0,0211		
Casearia arborea (Rich,) Urb	16,6667	0,0264		
Exora sp	16,6667	0,0207		
Garcinia gardneriana (Planch, & Triana) Zappi	16,6667	0,0448		
Guapira opposita (Vell,) Reitz	16,6667	0,0110		
Guarea guidonia (L,) Sleumer	16,6667	0,0110		
Inga sp	16,6667	0,0120		
Licania kunthiana Hook,f,	16,6667	0,0235		
Luehea divaricata Mart, & Zucc,	16,6667	0,0235	16,6667	0,0194
Myrcia sp 3	16,6667	0,0214	50,0000	0,0503
Nectandra sp	16,6667	0,0120		
Ni 3 (Myrtaceae)	16,6667	0,0089		
Platypodium elegans Vogel	16,6667	0,0083		
Pouteria sp	16,6667	0,0185		
Prunus sellowii Koehne	16,6667	0,0264		
Qualea grandiflora Mart,	16,6667	0,0100		
Vismia brasiliensis Choisy	16,6667	0,0071		
Zanthoxylum rhoifolium Lam,	16,6667	0,0188		
Astronium fraxinifolium Schott, ex Spreng			16,6667	0,0169

Espécie	FNQ N2		FQ N2	
	Dai	DoA	Dai	DoA
Bauhinia cf, forficata Link,			16,6667	0,0138
Byrsonima sericea DC			16,6667	0,0294
Campomanesia sp 1			50,0000	0,0681
Campomanesia sp 2			83,3333	0,1411
Eriotheca pubescens (Mart, & Zucc,) Schott & Endl,			16,6667	0,0125
Machaerium opacum Vogel			16,6667	0,0231
Myrcia tomentosa (Aubl,) DC,			16,6667	0,0110
Ouratea spectabilis (Mart,) Engl,			16,6667	0,0229
Qualea multiflora Mart,			16,6667	0,0228
Total	1683,3333	1,6003	500,0000	0,5943

Legenda: FNQ= Floresta não queimada (formação florestal); FQ= floresta queimada; N2: Nível de inclusão de parcela; DAi= densidade absoluta (ind/ha); DoA= dominância absoluta (m²/ha).

APÊNDICE H - DENSIDADE ABSOLUTA E DOMINÂNCIA ABSOLUTA POR HECTARE EM NÍVEL 3 DE INCLUSÃO DA FORMAÇÃO FLORESTAL NÃO ATINGIDA E ATINGIDA PELO FOGO NO NÍVEL 2 DE INCLUSÃO NA RPPN SERRA DO TOMBADOR, GOIÁS

Espécies	FNQ N3		FQ N3	
	Dai	DoAi	Dai	DoAi
Matayba elaeagnoides Radlk,	533,3333	0,1064		
Alibertia macrophylla K,Schum,	200,0000	0,0306		
Bauhinia rufa (Bong,) Steud,	200,0000	0,0157		
Pouteria sp	200,0000	0,0562		
Siparuna guianensis Aubl,	200,0000	0,0435	66,6667	0,0253
Aspidosperma cylindrocarpon Müll,Arg, LC	133,3333	0,0487		
Croton sp	133,3333	0,0119		
Himatanthus obovatus (Müll, Arg,) Woodson	133,3333	0,0266		
Licania kunthiana Hook,f,	133,3333	0,0216		
Miconia cinnamomifolia (DC,) Naudin	133,3333	0,0131		
Prunus sellowii Koehne	133,3333	0,0166		
Virola sebifera Aubl,	133,3333	0,0204		
Allophylus sericeus (Cambess,) Radlk	66,6667	0,0217		
Annona sp 1	66,6667	0,0073	66,6667	0,0245
Cupania oblongifolia Mart,	66,6667	0,0160		
Eriotheca gracilipes K,Schum,	66,6667	0,0245		
Exora sp	66,6667	0,0054		
Ferdinandusa sp	66,6667	0,0054		
Guatteria sp	66,6667	0,0238		
Ni 1 (Myrtaceae)	66,6667	0,0172		
Ocotea sp	66,6667	0,0224		
Piper sp	66,6667	0,0021	66,6667	0,0089
Senna multijuga (Rich,) H,S,Irwin & Barneby	66,6667	0,0100		
Simarouba versicolor A,St,-Hil,	66,6667	0,0048		
Terminalia sp	66,6667	0,0026		
Vismia brasiliensis Choisy	66,6667	0,0026		
Casearia sylvestris Sw,			66,6667	0,0238
Swartzia flaemingii Raddi			66,6667	0,0127
Total	3200,0000	0,5774	333,3333	0,0953

Legenda: Formação florestal: FNQ= Floresta não queimada; FQ= floresta queimada; N3: Nível de inclusão de parcela; DAi= densidade absoluta (ind/ha); DoA= dominância absoluta (m²/ha).