Effect of different fire regimes on the *Caryocar brasiliense* Cambess. (pequizeiro) in a landscape scale

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Keywords: Integrated fire management; native fruits; natural resources; tropical savanna; Caryocaraceae.

ABSTRACT – An adequate fire regime for the management of natural resources is a key factor for environmental conservation in traditional and indigenous communities, especially when it involves species of great nutritional, cultural or economic importance. *Caryocar brasiliense* Cambess. (pequizeiro) is considered one of the most important species in Brazilian savannas (Cerrado biome). Its fruits are widely consumed by the population and generate one of the most important economic chains of native fruits in Brazil. Recently, federal environmental agencies have implemented integrated fire management in many protected areas in this biome. As a result, the predominant fire regime, exclusion of fire interspersed with large wildfires, was replaced by prescribed burning. The objective of this work was to verify the effects of these changes at the landscape scale, through the assessment of damage and fruiting in adult *C. brasiliense* trees. The methodology involved data collection by local indigenous brigade members and statistical analysis using the Tukey Test ($p < 0.05$). The results demonstrate that trees managed with prescribed burning had the lowest damage rates (mortality, severity and loss of reproductive structures), accompanied by the highest reproduction and fruit production rates. Trees affected by wildfires showed the highest rates of damage and prolonged fire exclusion led to reduced reproduction rates and fruit production. The results indicate that prescribed burning is the best fire management alternative in areas where *C. brasiliense* occurs.

Efeito de diferentes regimes de fogo em *Caryocar brasiliense* Cambess. (pequizeiro) na escala de paisagem

Palavras-chave: Frutas nativas, manejo integrado do fogo, recursos naturais; savanas tropicais.

RESUMO – Um regime de fogo adequado para o manejo dos recursos naturais é um fator-chave para a conservação ambiental em comunidades tradicionais e indígenas, principalmente quando envolve espécies de grande importância nutricional, cultural ou econômica. *Caryocar brasiliense* Cambess. (pequizeiro) é considerada uma das espécies mais importantes das savanas brasileiras (bioma Cerrado). Seus frutos são amplamente consumidos pela população e geram uma das mais importantes cadeias econômicas de frutas nativas do Brasil. Recentemente, os órgãos ambientais federais têm implementado o manejo integrado do fogo em muitas áreas protegidas deste bioma. Como resultado, o regime de fogo predominante, exclusão do fogo intercalado por grandes incêndios florestais, foi substituído pela queima prescrita. O objetivo deste trabalho foi verificar os efeitos dessas mudanças na escala de paisagem, através da avaliação de danos e frutificação em árvores adultas de *C. brasiliense*. A metodologia envolveu a coleta de dados pelos brigadistas indígenas locais e sua análise estatística pelo Teste de Tukey ($p < 0.05$). Os resultados demonstram que as árvores manejadas com queimas prescritas apresentaram os menores índices de danos (mortalidade, severidade e perda de estruturas reprodutivas), acompanhados das maiores taxas de reprodução e de produção de frutos. As árvores atingidas pelos incêndios florestais apresentaram os maiores índices de danos, e a exclusão prolongada do fogo levou à redução das taxas de reprodução e de produção de frutos. Os resultados indicam as queimas prescritas são a melhor alternativa de manejo do fogo nas áreas de ocorrência de *C. brasiliense*.

Efecto de diferentes regímenes del fuego en el *Caryocar brasiliense* Cambess. (pequizeiro) en la escala de paisaje

Palabras-clave: Frutas nativas, manejo integral del fuego, recursos naturales, sabana tropical.

RESUMEN – Un régimen del fuego adecuado para el manejo de los recursos naturales es un factor clave para la conservación ambiental en comunidades tradicionales e indígenas, especialmente cuando se trata de especies de gran importancia nutricional, cultural o económica. *Caryocar brasiliense* Cambess. (pequizeiro) es considerada una de las especies más importantes de las sabanas brasileñas (bioma Cerrado). Sus frutos son ampliamente consumidos por la población y generan una de las cadenas económicas de frutas nativas más importantes de Brasil. Recientemente, las agencias ambientales federales han implementado el manejo integrado de incendios en muchas áreas protegidas de este bioma. Como resultado, el régimen del fuego predominante, que consistía en la exclusión del fuego, intercalados con grandes incendios forestales, fue sustituido por la quema prescrita. El objetivo de este trabajo fue verificar los efectos de estos cambios a escala de paisaje, a través de la evaluación de daños y fructificación en árboles adultos de *C. brasiliense*. La metodología implicó la recolección de datos por parte de brigadistas indígenas locales y el análisis estadístico mediante la Prueba de Tukey ($p < 0,05$). Los resultados demuestran que los árboles manejados con quema prescrita tuvieron las tasas de daño más bajas (mortalidad, severidad y pérdida de estructuras reproductivas), acompañadas de las tasas más altas de reproducción y producción de frutos. Los árboles afectados por incendios forestales mostraron las mayores tasas de daño y la exclusión prolongada del fuego condujo a una reducción de las tasas de reproducción y de la producción de frutos. Los resultados indican que la quema prescrita es la mejor alternativa de manejo del fuego en áreas donde ocurre *C. brasiliense.*

Introduction

Fire is a central element for the conservation of fire-prone ecosystems such as tropical savannas [1][2][3]. In these regions, it is common for traditional and indigenous communities to use fire in different ways, including the production of natural resources [4][5]. Despite the already known benefits of traditional fire management, environmental protection policies often prohibit the use of fire, creating conflicts with local communities [6][7]. In this context, it is necessary to develop strategies that integrate the needs of people with the objectives of environmental conservation. Identifying key species and defining appropriate fire regimes is a fundamental step towards implementing more efficient and less conflictual protection strategies in these situations [8]. For populations living in the Brazilian Cerrado biome, *Caryocar brasiliense* Cambess. (known locally as pequizeiro) is considered one of the most important and valued species [9][10][11].

The main product of the pequizeiro is the fruit, which is responsible for one of the most important economic chains of native fruits in Brazil [12][13]. The annual production recorded in Brazil was 47,698 tons in 2022, which corresponded to R$ 50,618,000.0 in marketing, approximately USD 10,184,708.4 [12]. However, these values are quite underestimated, since its production is predominantly from native tree harvesting and its marketing is informal, promoted by local/regional arrangements [13].

The species occurs in areas with good light and low fertility, being common in almost all phytophysiognomies of the Cerrado biome. Adult trees can reach 10 meters in height, depending on the soil and genetic factors. The species is deciduous, and the leaves fall at the beginning of the dry season, regrowing simultaneously or shortly afterwards (9). Flowering accompanies the emergence of new leaves, towards the end of the dry season. The fruits develop at the beginning of the rainy season and the harvest can extend from October to February, depending on the region [9][13][14][15][16]. Due to their wide distribution, these intervals tend to have regional variations but, in the areas of the present study, these periods can well describe the phenology of the species. This phenological cycle is followed by both humans and animals, as it provides food for several species from flowering to fruit drop [11][13][17]. During this period, the trees are generally subject to frequent and high-intensity wildfires, especially in the protected areas of the Cerrado [18][19].

Although it is adapted to fire, like many plants in the biome, there are no specific studies on fire effects on the species [13]. Conversely, indigenous communities have vast traditional knowledge about the effects of fire on important natural resources [4][5][7][20][21][22][23][24]. According to indigenous peoples reports [25], Cerrado fruit trees need fire to stay healthy and productive. However, when fire occurs at the “wrong time”, in the reproductive period of many plants, the damage caused to the trees is higher and the flowers and unripe fruits get burned, reducing the fruit production. On the other hand, if fire occurs at the “right time”, the damage is lower, and the trees are stimulated to produce more fruits [25]. Fruit tree phenology is often an important temporal marker for fire use. The indigenous ethnic group Kayapó, for example, end the use of fire in the landscape as soon as *C. brasilense* begins to flower [26]. Traditional knowledge about fire is also present in traditional communities, and many fruit pickers reports indicate that the frequent occurrence of fire can harm trees and that burning flowers and fruits can reduce production [17][26]. Information like this is important, but it needs to be complemented so that communities adapt to the rapid changes in fire management policies [7][8].

Protection strategies based on fire exclusion are being abandoned, as they have debilitated several environmental services provided by tropical savannas [18][27][28][29][30]. In addition, the accumulation of cured fine fuel allows for the spreading of disastrous wildfires [6][18][19][27][28]. These wildfires, usually concentrated in the late-dry season, tend to have high intensity and, consequently, higher mortality rates and severity indexes [28][31][32][33][34][35]. On the other hand, fire regimes based on the application of prescribed burns tend to be less intense and to have lower flame height, resulting in lower severity and mortality rates [31][32][35][36]. These fires can be used to reduce the amount of fine fuel, avoiding wildfires of high intensity and magnitude, such as those that occur during the late-dry season [18][32][34][35][37].

In 2015, the main Brazilian federal environmental agencies, the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) and the Chico Mendes Institute for Biodiversity Conservation (ICMBio), began to implement management programs based on the principles of Integrated Fire Management (IFM) [6][8][25][38]. The Prevfogo, IBAMA's Fire National Center, chose to incorporate traditional knowledge to make management decisions in Indigenous Lands (ILs) and Quilombola (maroon) Territories (QTs) covered by the Federal Brigades Program-BRIFs [39]. Based on the objectives and fire regimes described in a work called "Recovering Traditional Knowledge Over the Use of Fire" [23], together with new technologies and technical/scientific recommendations, the prescribed burns were planned and executed in the savannas of 31 traditional territories, covering 10,462,418.9 hectares (ha) of the Cerrado, Pantanal and Amazonia biomes [39].

Since then, the prevailing fire regime in these areas, fire exclusion interspersed with wildfires [6][19][28], has been replaced by a frequent prescribed burnings regime [28][35][39]. Between 2015 and 2018, 3,386 prescribed burns were registered during the period between January and July, which resulted in a temporal and spatial mosaic of fire regimes and a unique opportunity to assess their effects in the ecosystems.

This work aimed to evaluate the results of different fire regimes in adult *C. brasiliense* trees, which are in full fruit production. This assessment, carried out in the field, can help to better understand what occurs when management is implemented on a large scale, forming an immense mosaic of fire behaviors and histories [35][39][40]. The work is part of a broader program to monitor the implementation of IFM by the BRIFs Program of IBAMA/Prevfogo in Brazilian ILs and QTs, that assessed the effects of different fire regimes on culturally important species of flora and fauna. Combined with other studies, this work can contribute to technical management recommendations, assess whether the environmental agency's decisions are being efficient for the ethnobiodiversity conservation, and the continuity of the environmental services provided by the traditional peoples.

Methodology

We developed a methodology to enable the monitoring of integrated fire management to be done locally. We participatorily developed protocols to allow indigenous and quilombola brigades to perform data collection and assessment of the effects of fire regimes in their territories, following the principles of Citizen Science [41].

Study area and fire regimes

Our study involved 18 traditional territories, 17 ILs and 01 QT, where prescribed burns were implemented and the species *C. brasiliense* occurred (Table 1 and Figure 1). All of them are located in the Cerrado biome, except the ILs Xingu and Pequizal do Naruvôtu, that are formally located in the Amazon biome but in a transitional zone between the biomes [42]. The average precipitation in the Cerrado biome varies between 1,200 and 1,800 millimeters, distributed throughout the year approximately as shown in Figure 2.

In the Cerrado biome, samples were also taken in some protected areas within stricter uses to assess some fire regimes that are difficult to find in traditional territories, such as fire exclusion for very long periods. In these cases, we collected samplings in Chapada dos Guimarães National Park, Serra das Araras Ecological Station, both from the state of Mato Grosso, and Contagem Biological Reserve and Brasília National Park, in the Federal District.

Table 1 – Name of the traditional territory, total area, number of burning plans registered and accumulated burnt area between 2015 and 2018, according to [39].

Nº	Traditional territory	Total area (ha)	Number of Burning plans	Burned area: average 2015-2018 (ha)	
				Prescribed burns[3]	Wildfires[3]
1	Kalunga[1]	261,827.4	106	4,359.4	15,281.4
2	Avá-Canoeiro[1]	38,000.0	11	4,271.5	65,631.1
3	Bakairi[1]	61,405.5	66	9,096.8	7,213.4
4	Juininha[1]	70,537.5	51	7,822.0	6,537.4
5	Paresi/Formoso[1]	583,336.0	140	216,225.7	50,409.5
6	Utiariti[1]	412,304.2	43	35,156.9	12,543.1
7	Xerente/Funil[1]	183,245.9	554	13,235.2	65,631.1
8	Kraholândia[1]	302,533.4	285	13,659.9	133,109.8
9	Apinajé[1]	82,432.5	104	5,629.5	161,036.5
10	Araguaia[2]	1,358,499.5	1,263	428,455.0	410,669.5
11	Xingu/Pequizal do Naruvôtu[2]	2,675,041.4	469	81,460.0	41,087.6
12	Porquinhos[2]	79,520.3	88	65,369.9	11,301.2
13	Governador/Krikati[2]	186,419.5	119	5,709.2	10,845.6
14	Araribóia[2]	413,288.0	87	13,602.5	46,684.2
	Total	**6,708,391.0**	**3386**	**904,053.5**	**1,037,981.4**

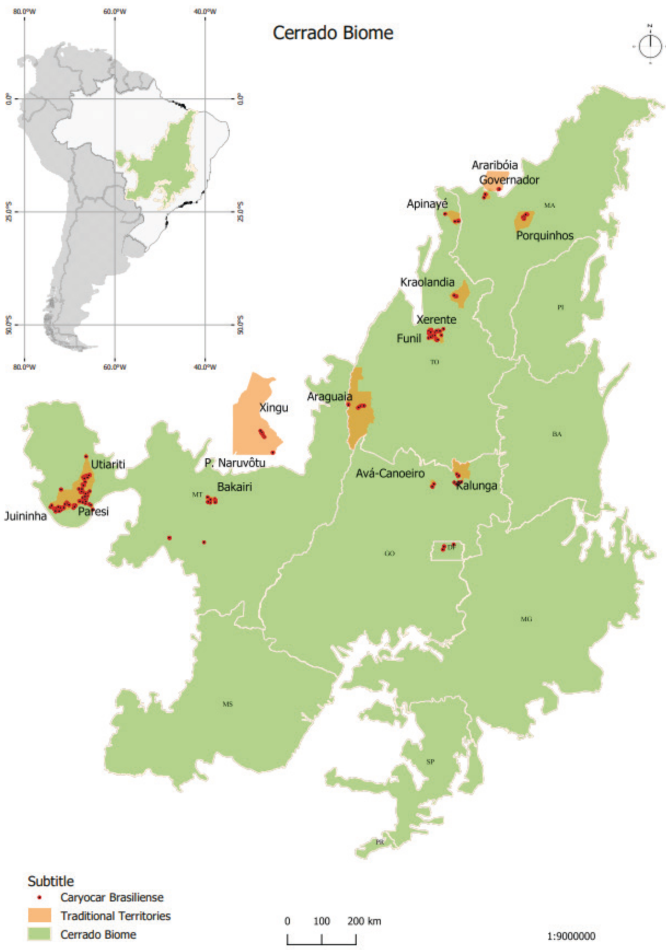

Figure 1 – Location of the Cerrado biome within South America (top left) and location of the 18 traditional territories and additional areas where *Caryocar brasiliense* populations were sampled under different fire regimes.

We separated the fire regimes, as described below (Figure 2):

- Prescribed burns (PB): any fire that occurred between the late-rainy season and mid-dry season, coinciding with the period recommended by the indigenous people for Cerrado fire management [25].
- Wildfires (WF): any fire that occurred between the late-dry season and the mid-rainy season, coinciding with the period that the indigenous people do not recommend Cerrado fire management [25].
- Fire Exclusion (FE): areas where fire did not occur for a period between 60 and 324 months.

Precipitation patterns vary across the study region and between years, but the dry season extends generally from April to September. Local fire practices also vary across the traditional territories, for that, we registered the periods that different ethnic groups recommended prescribed burns, in relation to the months of the year and the seasons (dry or rainy) (Figure 2). In communities located in the northeast of the Cerrado biome (Kanela, Gavião, Guajajara and Krikati) and in areas influenced by the flood pulse (Xingu and Araguaia), the periods of the year recommended for burning differ from the others.

The management objectives were divided into fruiting (stimulating flowering and fruit production of important species) and preventing wildfires, which include protection burns at forest edges, trail maintenance and fine fuel management (Figure 2). Fires that occurred outside the recommended period for the Cerrado management were considered as wildfires in the present study.

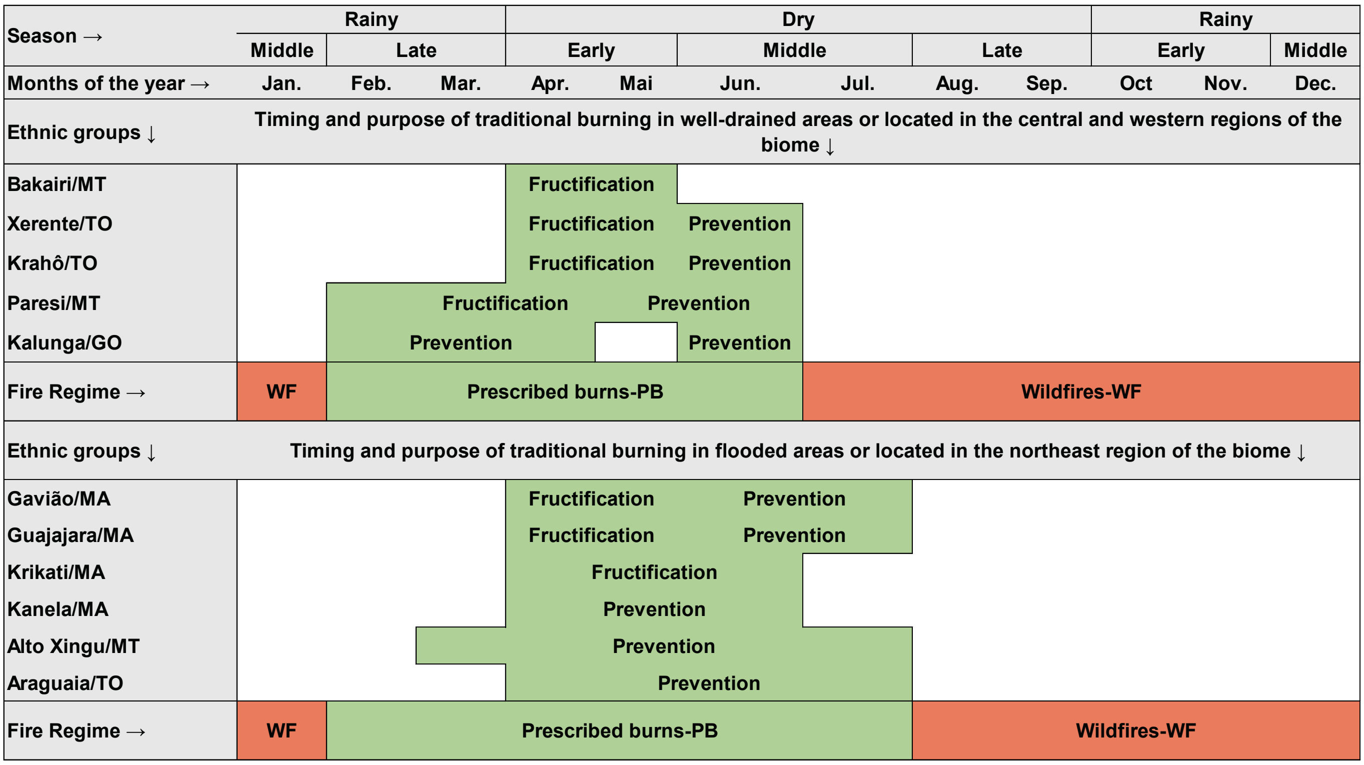

Figure 2 – Times of the year recommended by the communities for carrying out the fruiting fires for important species or for preventing wildfires, in addition to the period in which the prescribed burning and wildfire treatments were defined, depending on the seasons. Adapted from [39].

Field sampling and statistical analysis

The fire regimes and time since the last fire were identified through Prescribed Burn Plans, Wildfires Occurrence Reports and satellite images. The areas were selected and monitored to previously trained brigade members, who filled out a spreadsheet with general information, defined a sampling point with greater abundance of the target species and performed the data collection in a standardized way for 20 minutes. During the sampling period, all *C. brasiliense* adult trees were evaluated regarding flower and/or fruit production and canopy damage due to fire.

The loss of reproductive structures and the mortality rate were sampled only once, in the months following fire passage, while its impacts were still visible. The severity, the phenological stage and the fruit production per plant were sampled at intervals from 01 to 12, 13 to 24 and 25 to 36 months after the fire, to assess whether the effects of the fire persisted over the years. In the areas excluded from fire, all samplings were performed only once, randomly in relation to time since last fire.

The mortality rate was calculated from the comparison between the number of registered dead trees and the total number of sampled trees. To assess the severity index, all surviving trees were classified according to the damage observed in their crowns (% of dead branches), through the presence of regrowth and dead branches, as shown in Figure 3, based on the scientific literature [44][45][46].

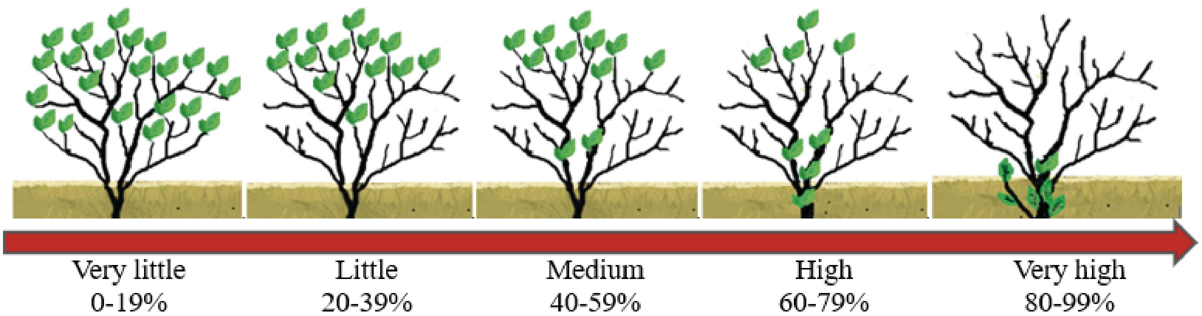

Figure 3 – Classes (indexes) of crown severity, according to the % of dead branches and regrowth.

To assess the loss of reproductive structures, all trees that lost flowers or fruit due to fire were accounted and compared with the total number of trees in the reproductive stage. To determine the proportion of plants in the reproductive stage, the number of trees that were in the reproductive phenophases (anthesis, flowering and fruiting) was compared with the total number of trees sampled. To evaluate the fruit production per plant, all the fruit trees were classified by the local brigade members as high or low production and compared with the total number of fruiting trees.

We evaluated 2,919 *C. brasiliense* individuals, distributed in the 18 protected areas (Figure 1). We used linear mixed effect models [47] to compare the effects of different fire regimes in each evaluated parameter. We considered fire regimes as the fixed variable and the sampling locations as a random effect variable. The intervals since the last fire were grouped with the respective fire regimes. From the results of the models, we performed the Tukey test to verify whether the response variables showed significant differences between fire regimes. We considered p values <0.05 as significant differences. We performed all statistical analyses in R software [48]. The mean values, standard error and n sample are shown from tables A.1 to A.8 in the Appendices.

Results

Mortality

No mature trees were found dead in the fire exclusion areas. In the other areas, there were significant differences, but the proportion of dead trees was low (PB 0.14 ± 0.09 and WF 1.72% ± 1.01) (Figure 4 and Table A.1 in the Appendices). During field sampling, it was possible to observe that the death of *C. brasiliense* caused by fire was a rare event. Even in areas hit by large wildfires, although they were often of high severity, trees sprouted from the ground.

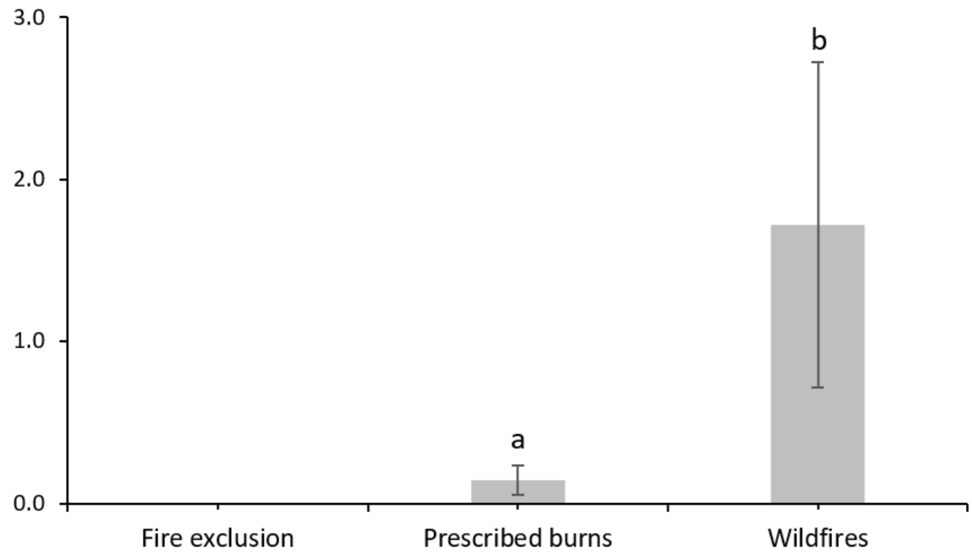

Figure 4 – Mortality rate of *C. brasiliense* trees subjected to different fire regimes in 18 protected areas across the Cerrado biome. The bars represent the mean values (%) for each fire regime and the lines that cross the bars show standard errors. Different letters indicate significant differences ($p < 0.05$), according to linear mixed models followed by Tukey tests.

Severity

Different fire regimes showed significant differences in severity index. *C. brasiliense* populations affected by wildfires had a higher proportion of trees classified high and very high severity (high 9.86% ± 2.56 and very high 2.60% ± 0.87), in relation to trees subject to fire exclusion (high 0.33% ± 0.31 and very high 0.33% ± 0.31) or managed with prescribed burns (high 0.47% ± 0.33 and very high 0.04% ± 0.04). Fire exclusion and prescribed burns showed significant difference in severity index (Figure 5 and Table A.2).

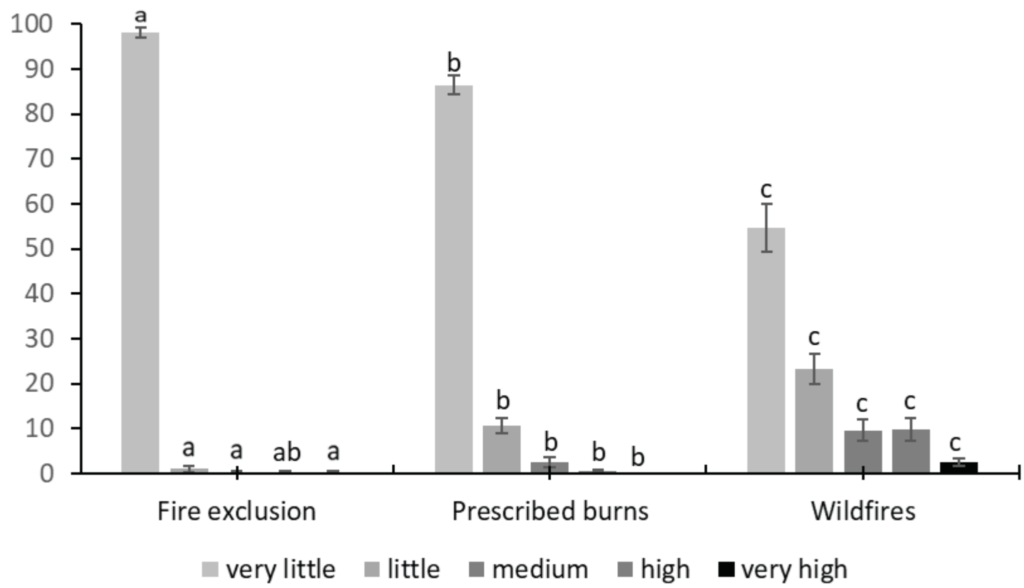

Figure 5 – Severity index for *C. brasiliense* trees subjected to different fire regimes in 18 protected areas across the Cerrado biome. The bars represent the mean values (%) for each fire regime, the lines that crosses the bars show standard errors, and the gradual shades indicate the degree of severity with the lighter shade being very little severity and darkest being very high severity. Different letters indicate significant differences between fire regimes ($p < 0.05$), according to linear mixed models followed by Tukey tests.

Caryocar brasiliense populations managed with prescribed burns had a low proportion of trees in the high (0.84 ± 0.59) and very high (0.07 ± 0.07) severity classes in the first year after fire. On the other hand, populations that were affected by wildfires had a higher proportion of trees in the high (5.93% ± 2.77) and very high (2.33% ± 1.65) severity classes in the first year after fire, a trend that remained constant in the second (high 9.45% ± 4.88 and very high 2.90% ± 1.39) and third (high 7.07% ± 3.29 and very high 2.47% ± 1.48) year after fire (Figures A.1 to A.3 and Tables A.3 to A.5 in the Appendices). This demonstrates that the most affected trees do not recover in the following years.

Phenological stage

The different fire regimes influenced the proportion of trees reproducing (Figure 6 and Table A.6 in the Appendices). The lowest reproduction rates were recorded in populations subjected to long fire exclusion (35.10% ± 9.40). In the first year after the fire, populations affected by wildfires had the lowest reproduction rate (37.53% ± 8.03), compared to populations managed with prescribed burns (49.93% ± 5.02). The following year, this behavior was reversed, with prescribed burning showing lower rates (47.10% ± 6.65) than wildfires (51.67% ± 7.22). The following year, this behavior was reversed again, with prescribed burning showing the highest rates in the study (64.59 ± 8.73).

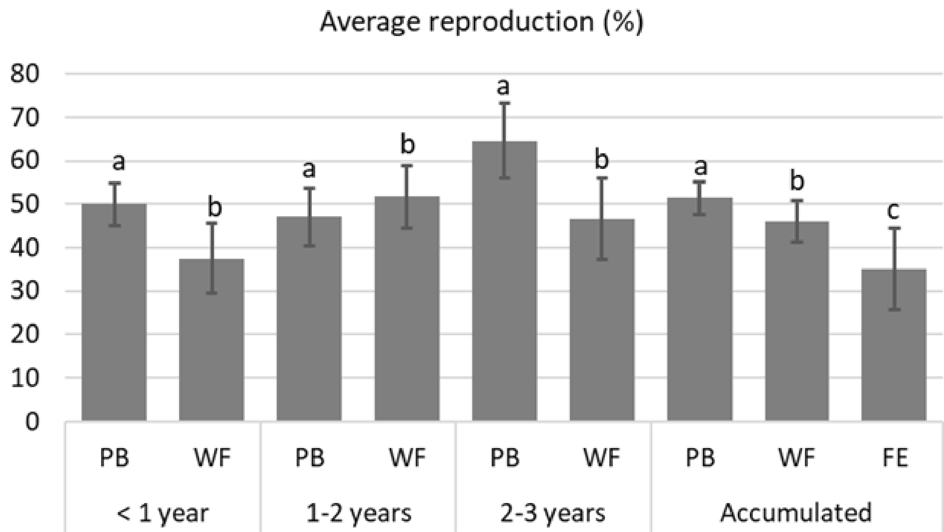

Figure 6 – Proportion of *C. brasiliense* trees in reproductive stage under prescribed burn-PB, wildfire-WF and fire exclusion-FE regimes in 18 protected areas across the Cerrado biome. The bars represent the mean values (%) for each fire regime, separated in three periods after fire passage (0-12 months, 13-24 months and 25-36 months) and the average of all periods together. The lines across the bars show standard errors and different lower-case letters indicate significant differences between fire regimes ($p < 0.05$).

Loss of reproductive structures due to fire

Caryocar *brasiliense* trees affected by wildfires showed significant higher losses of flowers and fruits (45.45% ± 15.01) than those managed with prescribed burns (5.53% ± 2.94) (Figure 7 and Table A.7 in the Appendices).

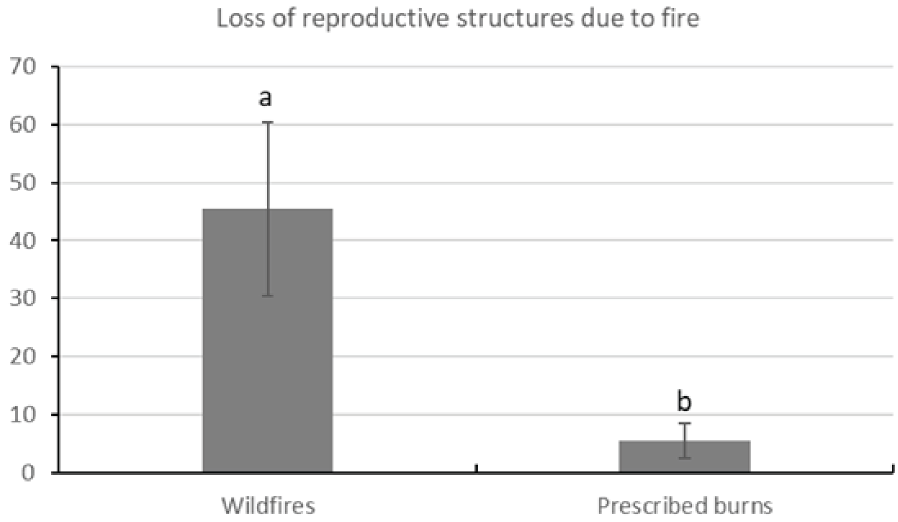

Figure 7 – Proportion (%) of *C. brasiliense* trees that showed losses of reproductive structures due to fire under prescribed burns-PB and wildfires-WF in 18 protected areas across the Cerrado biome. The bars represent the mean values (%) for each fire regime. The lines across the bars show standard errors and different lower-case letters indicate significant differences between fire regimes ($p < 0.05$).

Fruit production

The different fire regimes influenced the proportion of trees with high fruit productivity (Figure 8 and Table A.8 in the Appendices). The lowest high fruit productivity rates were recorded in populations subjected to long fire exclusion (19.80% ± 10.66). In the first year after the fire, populations affected by wildfires had the lowest high fruit productivity rate (29.87% ± 14.62), compared to populations managed with prescribed burns (63.64% ± 5.32). This trend continued in the second and third year after the fire.

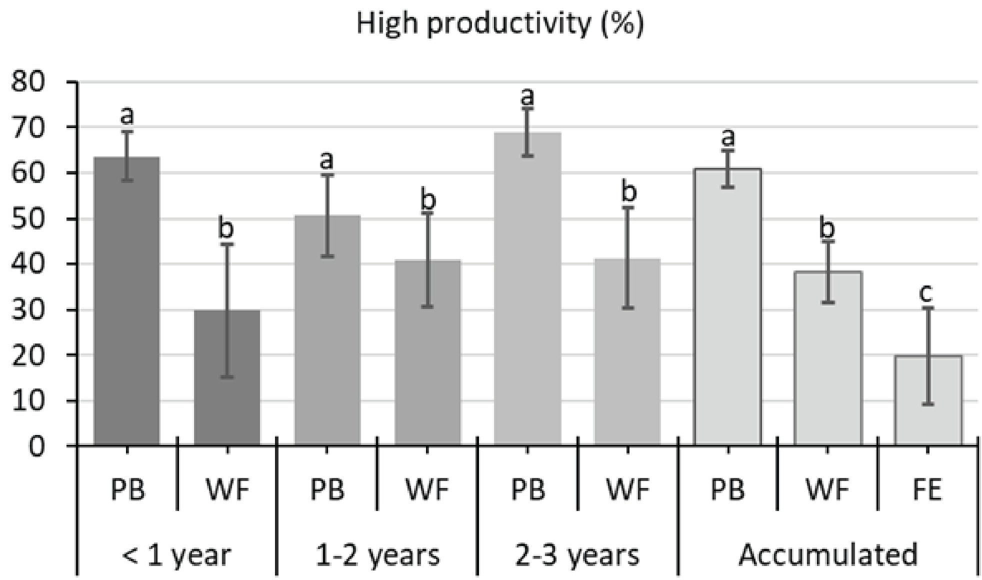

Figure 8 – Proportion of *C. brasiliense* trees with high fruit production under prescribed burn (PB), wildfire (WF) and fire exclusion (FE) regimes in 18 protected areas across the Cerrado biome. The bars represent the mean values (%) for each fire regime, separated in three periods after fire passage (01-12 months, 13-24 months and 25-36 months) and the aver-age of all periods together. The lines across the bars show standard errors and different lower-case letters indicate significant differences ($p < 0.05$) per sampled period, according to a posteriori contrast between fire regimes.

Discussion

The differentiated responses of *C. brasiliense* to fire regimes may be related to factors inherent to the species itself, such as the phenological stage, or external factors, such as fire behavior, during prescribed burns and wildfires. The species presents the typical morphological and physiological adaptations of Cerrado species [49][50]. Therefore, it is important to observe the positive and negative effects after its spreading or exclusion.

The mortality rates found in the present study were below those reported in several other studies that evaluated the effects of fire in Cerrado, even if the fire was applied during the wildfire season [51][52]. However, the present study evaluated fully mature trees, which tend to be more resistant to fire. During the sampling, we verified that the mortality of adult trees was indeed a rare event, associated with large, high-intensity wildfires, in some locations in the Rio Formoso, Xerente and Kraholândia Indigenous Lands. Unlike other species studied, such as *Hancornia speciosa* Gomes, mortality was not observed in areas under fire exclusion, due to the phenomenon of encroachment [30][53]. But in areas under long-term fire exclusion, *C. brasiliense* trees appeared to have more foliar diseases and, in some cases, intense infestation of agricultural pests, mainly from the Hemiptera family Pentatomidae.

The severity indices in the high and very high classes, verified in the present work, were also lower than those found in other studies for various Cerrado tree species [51][52] and in other tropical savannas [32] [33][54]. But again, it is important to highlight that the present work evaluated adult trees. Furthermore, one should not underestimate its consequences. In the areas affected by the wildfires, several of these trees showed high severity.

The greater severity of wildfires may be related to the phenological stage at the time of the fire, since prescribed burning coincides with leaf change and wildfires with regrowth and reproduction [14][15]. However, the predominant factor can be the greater intensity of the flames in the wildfires. The relationship between intensity, severity and fire regimes is well known [2][5][31][32][33][34][35][36][37[52]. There is a consensus that large late-dry season wildfires tend to have higher intensity and severity, even in tropical savanna trees [18][31][32][34]. In the case of the *C. brasiliense* populations in the present work, the trees that presented higher severity classes did not recover in the following years.

Although *C. brasiliense* has an aerial resprout, it takes a long time for the tree canopy to be restored. This could lead to an effect similar to that seen in other Cerrado species, which sacrifice sexual reproduction to invest in vegetative recovery [55][56]. But, although the trees affected by the fires showed a decline the following year, in the second year this rate already increased. This is probably due to trees that had low severity and reproduction rates in the previous year, since the species alternates years of greater and lesser reproductive activity [13][16].

Wildfires hit trees during the reproduction period [14][15], resulting in the loss of flowers and fruits. As a result, the productivity of trees affected by wildfires was much lower than that of trees managed with prescribed burns. This negative effect of fire during the wildfire season was reported by several indigenous and traditional populations [13][25][26]. However, the most surprising result was the low productivity of trees in areas under fire exclusion.

These results indicate that the use of prescribed burning in the management of indigenous and traditional territories increased the production of *C. brasiliense* fruits, benefiting the traditional and indigenous communities living in these places, as well as probably the fauna. This corroborates the various reports from indigenous people and brigades who claim that the amount of fruit from the Cerrado has greatly increased after the implementation of the IFM. There are still a few studies, and a large knowledge gap related to the effects of fire on this important species, which makes our research even more relevant. Thus, the study can help in the search for more suitable fire regimes, both for the management of this species and the Cerrado biome in general. However, it is important to emphasize that these results had a range of variations, since we evaluated trees from field samplings that were subjected to very different conditions.

Management considerations

There is a technical-scientific consensus that several phytophysiognomies in the Cerrado biome need to be managed with prescribed burning. However, these recommendations aim to protect biodiversity, reduce the risk of catastrophic wildfires and maintain landscapes. Little attention has been given to species of social, economic or cultural importance to the indigenous and traditional communities that inhabit these areas. The present study demonstrates that prescribed burning, in

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addition to not harming one of these most important species, also helps in its preservation and productivity. Therefore, depending on the location, management to increase *C. brasiliense* fruits production may be one of the fire prescription objectives.

Conclusions

Mortality rates of *C. brasiliense* was higher in areas affected by wildfires than in areas managed with prescribed burns or subject to fire exclusion.

C. brasiliense trees affected by wildfires showed greater severity in relation to areas managed with prescribed burning or subject to fire exclusion.

The proportion of trees in the reproductive phenological stages was higher in areas managed with prescribed burns, intermediate in wildfire areas and lower under fire exclusion.

The loss of *C. brasiliense* reproductive structures due to fire was higher in the wildfire treatments compared to the prescribed burn ones.

Fruit production per plant was highest in areas managed with prescribed burning, intermediate in areas affected by wildfires and lowest in areas subject to fire exclusion.

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Appendix

Table A.1 – Fire regimes, average, standard error and number of samples in Figure 4.

Fire regimes	Average (%)	Standard error	N Sample
Fire exclusion-FE	0.000	0.000	9
Prescribed burns-PB	0.143	0.089	105
Wildfires-WF	1.720	1.005	50

Table A.2 – Fire regimes, average (%), standard error and number of samples in Figure 5.

Severity class	Fire exclusion-FE			Prescribed burns-PB			Wildfires-WF		
	Average	Error	n	Average	Error	n	Average	Error	n
Very little	98.111	1.201	9	86.410	2.164	105	54.640	5.345	50
Little	1.000	0.737	9	10.667	1.650	105	23.240	3.476	50
Medium	0.222	0.210	9	2.438	1.074	105	9.640	2.338	50
High	0.333	0.314	9	0.467	0.329	105	9.860	2.560	50
Very high	0.333	0.314	9	0.038	0.038	105	2.600	0.871	50

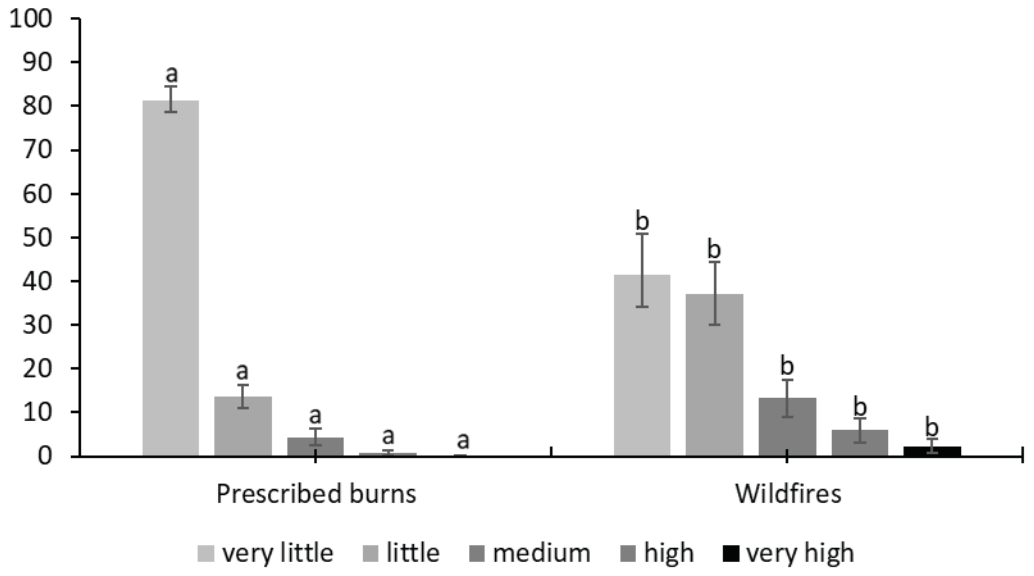

Figure A.1 – Fire severity indexes (mean % ± standard error) in C. *brasiliense* trees, between 1 and 12 months after the last fire. The letters indicate significant differences within the same index between fire regimes according to Tukey test. The data was collected in 18 study areas across the Brazilian savanna.

Table A.3 – Fire regimes, average, standard error and number of samples in Figure A.1.

Severity class	**Prescribed burns-PB**			**Wildfires-WF**		
	Average	**Error**	**n**	**Average**	**Error**	**n**
Very little	81.1724	3.47995	58	41.3333	9.55669	15
Little	13.5862	2.53712	58	37.2000	7.28176	15
Medium	4.32759	1.90802	58	13.2000	4.30008	15
High	0.84483	0.59116	58	5.93333	2.76722	15
Very high	0.06897	0.06837	58	2.33333	1.65373	15

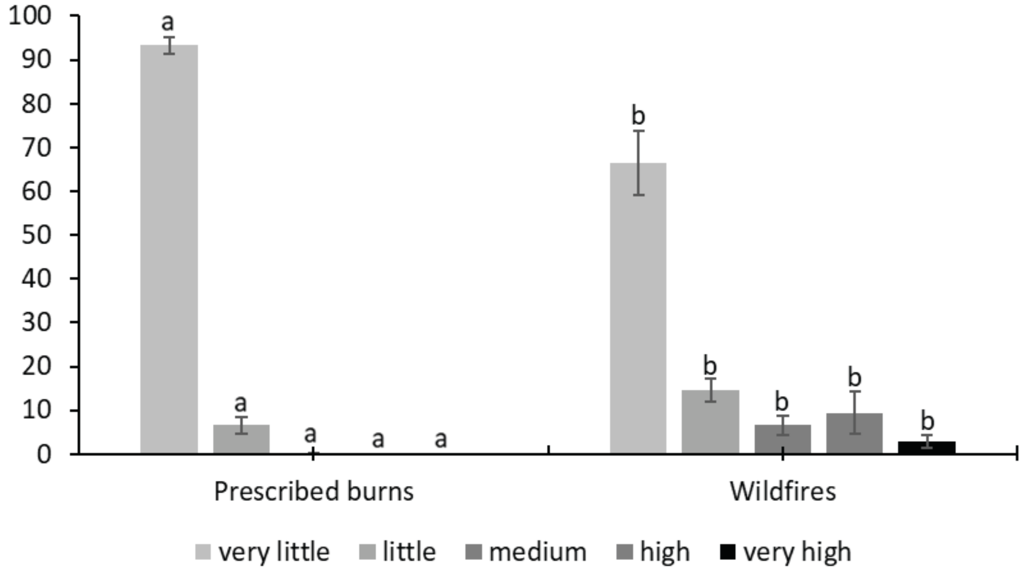

Figure A.2 – Fire severity indexes (mean % ± standard error) in C. *brasiliense* trees, between 13 and 24 months after the last fire. The letters indicate significant differences within the same index between fire regimes according to Tukey test. The data was collected in 18 study areas across the Brazilian savanna.

Table A.4 – Fire regimes, average, standard error and number of samples in Figure A.2.

Severity class	Prescribed burns-PB			Wildfires-WF		
	Average	Error	n	Average	Error	n
Very little	93.2581	1.92954	31	66.5500	7.28336	20
Little	6.61290	1.90168	31	14.55000	2.62152	20
Medium	0.16129	0.12981	31	6.60000	2.12415	20
High	0.00000	0.00000	31	9.45000	4.87467	20
Very high	0.00000	0.00000	31	2.90000	1.39803	20

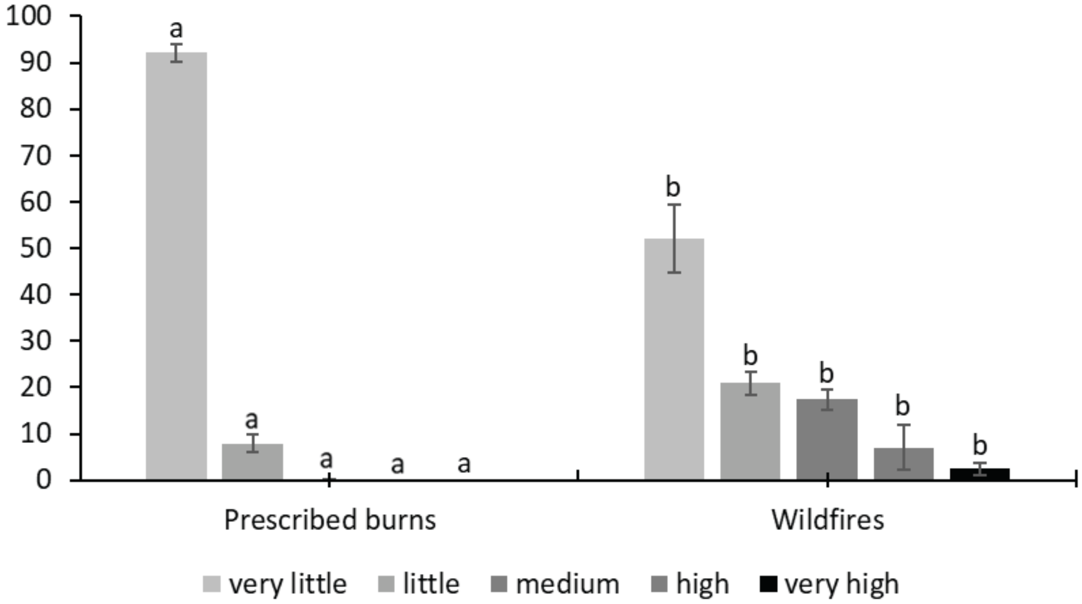

Figure A.3 – Fire severity indexes (mean % ± standard error) in C. *brasiliense* trees, between 25 and 36 months after the last fire. The letters indicate significant differences within the same index between fire regimes according to Tukey test. The data was collected in 18 study areas across the Brazilian savanna.

Table A.5 – Fire regimes, average, standard error and number of samples in Figure A.3.

Severity class	Prescribed burns-PB			Wildfires-WF		
	Average	Error	n	Average	Error	n
Very little	92.125	3.831	16	52.067	10.344	15
Little	7.938	3.836	16	20.867	6.993	15
Medium	0.000	0.000	16	17.400	6.270	15
High	0.000	0.000	16	7.067	3.288	15
Very high	0.000	0.000	16	2.467	1.484	15

Table A.6 – Sampling intervals, fire regime, average reproduction values, standard error and number of samples in Figure 6.

Sampling intervals	Fire regime	Average (%)	Standard error	n
01 to 12 months	Prescribed burns-PB	49.934	5.024	61
	Wildfires-WF	37.533	8.026	15
13 to 24 months	Prescribed burns-PB	47.100	6.646	30
	Wildfires-WF	51.667	7.224	21
25 to 36 months	Prescribed burns-PB	64.588	8.726	17
	Wildfires-WF	46.625	9.326	16
Average 3 years	Prescribed burns-PB	51.454	3.696	108
	Wildfires-WF	46.038	4.770	52
	Fire exclusion-FE	35.100	9.396	10

Table A.7 – Fire regime, average of trees with losses, standard error and number of samples in Figure 7.

Fire regime	Average (%)	Standard error	n
Prescribed burns-PB	45.45454545	15.01314225	11
Wildfires-WF	5.530612245	2.937088807	49

Table A.8 – Sampling intervals, fire regime, average, standard error and number of samples in Figure 8.

Sampling intervals	Fire regime	Average (%)	Standard error	n
01 to 12 months	Prescribed burns-PB	63.643	5.318	42
	Wildfires-WF	29.875	14.621	8
13 to 24 months	Prescribed burns-PB	50.714	8.900	21
	Wildfires-WF	41.000	10.204	13
25 to 36 months	Prescribed burns-PB	69.000	5.157	12
	Wildfires-WF	41.364	10.974	11
Average 3 years	Prescribed burns-PB	60.856	4.043	32
	Wildfires-WF	38.311	6.738	75
	Fire exclusion-FE	19.796	10.662	7

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