Fire Patterns in the Pantanal Biome

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Abstract.

The Pantanal biome, the largest continental wetland in the world, has been experiencing an increase in fire occurrence, culminating with 2020 widespread wildfires. The main goal of this work was to answer the following question: What burns and how are the fire patterns in the Pantanal biome characterized? Our results indicated that the year with the highest burned area was 2016, with 13069.68 km² fire-affected areas. The peak month occurred in September, similar to the entire time series studies. Forest and pastures were the most affected, with 7319.52 km² and 2733.96 km², respectively. Understanding these patterns is essential to the development of public policies and the preservation of biomes and ecosystems.

1. Introduction

Fire events have become one of the major global concerns in recent years, given the increased recurrence of these events and their contribution to CO_2 emissions in the atmosphere, contributing significantly to global climate change (Barlow et al., 2012). Every year, mainly during the dry season, thousands of hectares of biomes and ecosystems are burning and, consequently, subject to irreparable damage. The fire occurrence and intensity are influenced by some factors, for instance, land use and land cover changes, and climatic conditions. Among the factors that influence these events, we can cite the elements that compose the fire triangle: [1] weather conditions, which includes atmospheric stability, wind (controls the speed and direction of fires), air temperature, precipitation and relative humidity; [2] fuel and flammability, which are influenced by chemical composition, structure and arrangement, spatial continuity, density of fuel and type of vegetation; [3] topography, which includes slope, aspect and elevation, and controls the speed of fires (Pivello et al., 2021; Burton, et al., 2020; UNEP, 2022).

Historically, fire has been used as a tool for forest clearing to convert it to agriculture and pasture. Fire can pose a high potential for forest degradation and ecosystem destruction, and a danger to populations and climate (Anderson et al., 2020).

The disturbance caused by these events can result in a large range of destructive ecological and social negative socioecological impacts, causing tree mortality; changes in forest structure and composition; long-term reduction in carbon stocks; economic losses; harm to the health of the local populations; impact on air quality, clouds formation, precipitation, hydrological cycle, and moisture (Chuvieco et al., 2013). Also, these consequences of wildfires can in the long-term reverse the progress of the United Nations Sustainable Development Goals (SDGs) and cause damage to biodiversity conservation (Martin, 2019). In addition, an intense succession of wildfires can alter the infiltration and evapotranspiration rates, increasing, consequently, the susceptibility of the area to the erosion processes.

There are many uncertainties about how and when the changes related to the occurrence and intensification of fires will occur. According to Jolly et al. (2015) under 1ºC of global warming, the fire season has increased by an average of 33 days over the last 33 years in South America. According to a study developed by Burton et al. (2021), burned area is projected to increase in the future in all Shared Socioeconomic Pathways (SSP) scenarios, driven by an increase in temperature and a decrease in moisture. Understanding the factors that can alter the fire regime of an ecosystem is important and can help determine potential changes in fire behavior and, thus, their impacts of fire upon an ecosystem over a given period. The term fire regime includes the understanding of the role of fire in the structure and function of ecosystems and are described in terms of fire characteristics, e.g., fire extent, season, frequency, intensity and severity (Cochrane, 2009).

In this context, the Pantanal biome, the largest continental wetland in the world, which covers the countries of Brazil (80%), Bolivia (19%), and Paraguay (1%), was highlighted in the media for presenting a high number of fire events in the last years. The fire dynamics in the Pantanal are extremely complex and heterogeneous, mainly in the distinct portions of this biome (Brazil, Paraguay, and Bolivia). In 2020, for example, according to a study developed by Marques et al. (2021) was observed the largest quantity of burned area in the Brazilian Pantanal, about 50% higher than 2019. This shows changes in the predominant fire regime and a high-frequency of uncontrolled and unprecedented fire events. Moreover, Barbosa et al. (2022) found that climate variables in 2020 had an atypical behavior (hotter and drier than the historical average) and that burned areas in 2020 were 200% greater than the average. This result emphasizes that the increase in fire events was not only a result of extreme weather but also a consequence of human activities (Barbosa et al. 2022).

Pantanal has fire-prone vegetation composed of grasses and trees, which is characterized by a flood regime playing a vital role in structuring vegetation and is considered a World Natural Heritage Site and a Biosphere Reserve (UNESCO) (Abreu et al., 2022). However, few published studies still approached the patterns of fire in the biome (Marques et al., 2021), mainly in the portions of Bolivia and Paraguay. Furthermore, remote sensing techniques represent a particularly useful tool for mapping and quantifying the patterns, sizes, and assessing the impacts of fires on a range of natural and social systems. Thus, the main goal of this work was to answer the following question: What burns and how is characterized the patterns of fires in the Pantanal biome?

2. Materials and methods

2.1. Study Area

The study focuses on the Pantanal biome (Figure 1), one of the most biodiverse seasonal flood savannas in the world and the largest remaining wetland area of natural vegetation. This biome is located in the Upper Paraguay River Basin and includes two types of environments: lowlands (Pantanal biome) and highlands (Plateau). The Plateau is located outside the biome boundaries, but can influence the dynamics of the water cycle. The rainfall distribution is characterized by two well-defined seasons: rainy (October to March) and dry (April to September). This distribution controls the flooding cycles of the Pantanal. According to Schulz et al. (2019) these cycles are being changed, mainly due to deforestation for agriculture/pasture, the construction of waterways, which contribute to the intensification of drier conditions favorable to fire spread.

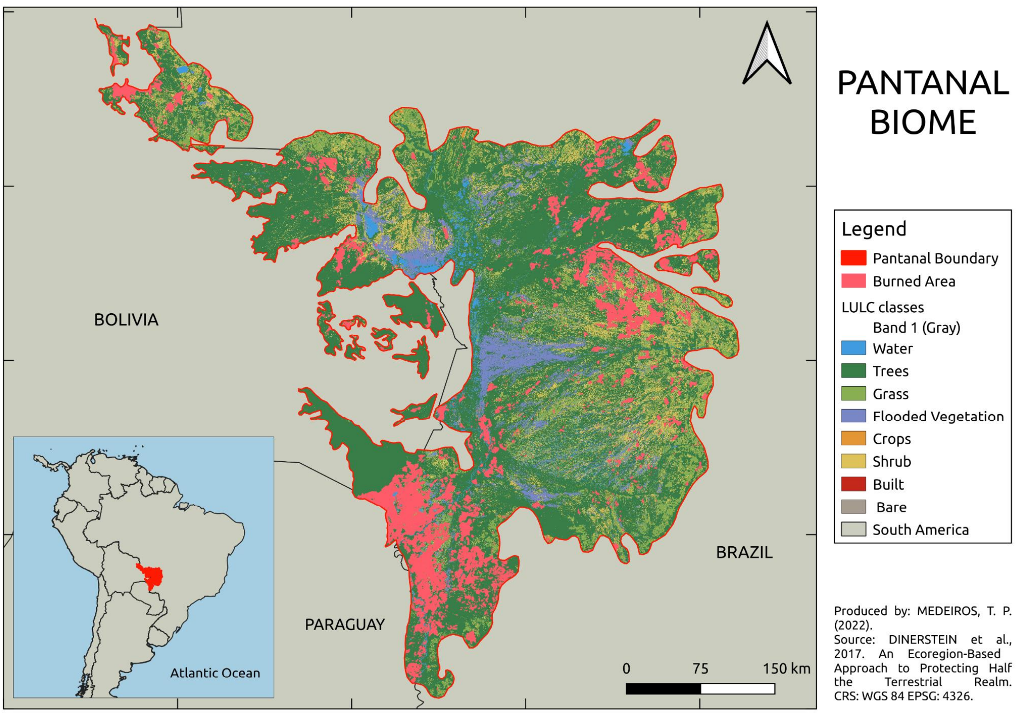


Figure 1. Study Area. Source: Dinerstein et al., 2017.

2.2. Data Collection

Aiming to understand the patterns of fires in the Pantanal biome, we collected the burned area dataset from the Global Fire Atlas (Andela et al., 2019). The Global Fire Atlas is a freely available global dataset that tracks the daily dynamics of individual fires to determine the timing and location of ignitions, fire size (km²), perimeter (km), duration (days), expansion (km²/days), fire line (fire line length, km), speed (km/day), and direction of spread (dominant direction of spread, north, northeast, east, southeast, south, southwest, west, and northwest). In addition, aiming to understand what burned, we selected the Dynamic World Land Use and Land Cover dataset, a near real-time global 10 m land use and land cover mapping. This LULC classification was processed using Sentinel-2 imagery and deep learning techniques (Brown et al., 2022).

2.3. Methodological Procedures

The work was carried out in three main steps (Figure 2). The first step [1] was the extraction of metrics arising from Global Fire Atlas for the three years of the available time series (2016, 2017, and 2018): total burned area (fire size, km²) on the annual and monthly scales; monthly percentage of fire, expressed as the percentage ratio between the fire size in each month and the total fire size accumulated in the respective year. This calculation was also performed on the perimeter of the fire and fire line, both measured in km. In addition, we calculated the mean of duration (days), speed (km/day), and expansion (km²/day) of fire per month, as well as, the standard deviation of these metrics (duration, speed, and expansion). The second step [2] focused on quantifying what burned in each year, by intersecting the individual burn scars with the land cover classes maps.

Finally, the third step performs data analysis, we applied the LOESS Regression (Locally Weighted Scatterplot Smoothing), a non-parametric approach created to adjust a smooth curve to the data, where the noisy data values, sparse data points, or weak interrelationships influence the ability of creating a line with better adjustment. All graphics generated in this work were developed within a Python environment, using the PLOTLY library (https://plotly.com/python/), which making possible the creation of interactive graphs.

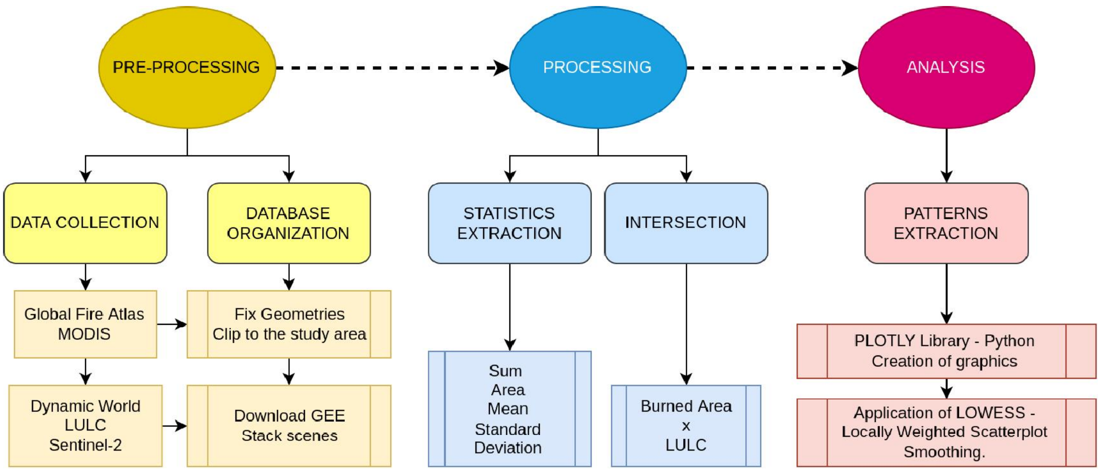


Figure 2. Flowchart of the methodological procedures developed in this work.

3. Results

The results are presented in two sections: [1] Monthly patterns of fires in the Pantanal biome according to metrics extracted from the Global Fire Atlas; [2] The identification of the most affected land use and land cover types.

The month and year with the largest burned area are September 2016 (~**6285 km²** burned), followed by September 2017 (~**5347 km²** burned) and October 2016 (~**3523 km²** burned). In addition, in 2016 we observed that September was responsible for **48%** of fire occurrences, followed by October, responsible for **27%** of fire occurrences, and finally, August, responsible for **14%**. In 2017, the month with the highest concentration of burn scars also occurred in September (**52%**), followed by August (**23%**), and July (**10%**). Finally, in 2018, the fire season is defined by two months: August (**48%**) and September (**44%**). The same fire pattern is visualized in graphics of Perimeter and Fire Line metrics (Figure 3). Therefore, 2016 was the year that burned the most and the fire season is mainly concentrated in July, August, September, and October.

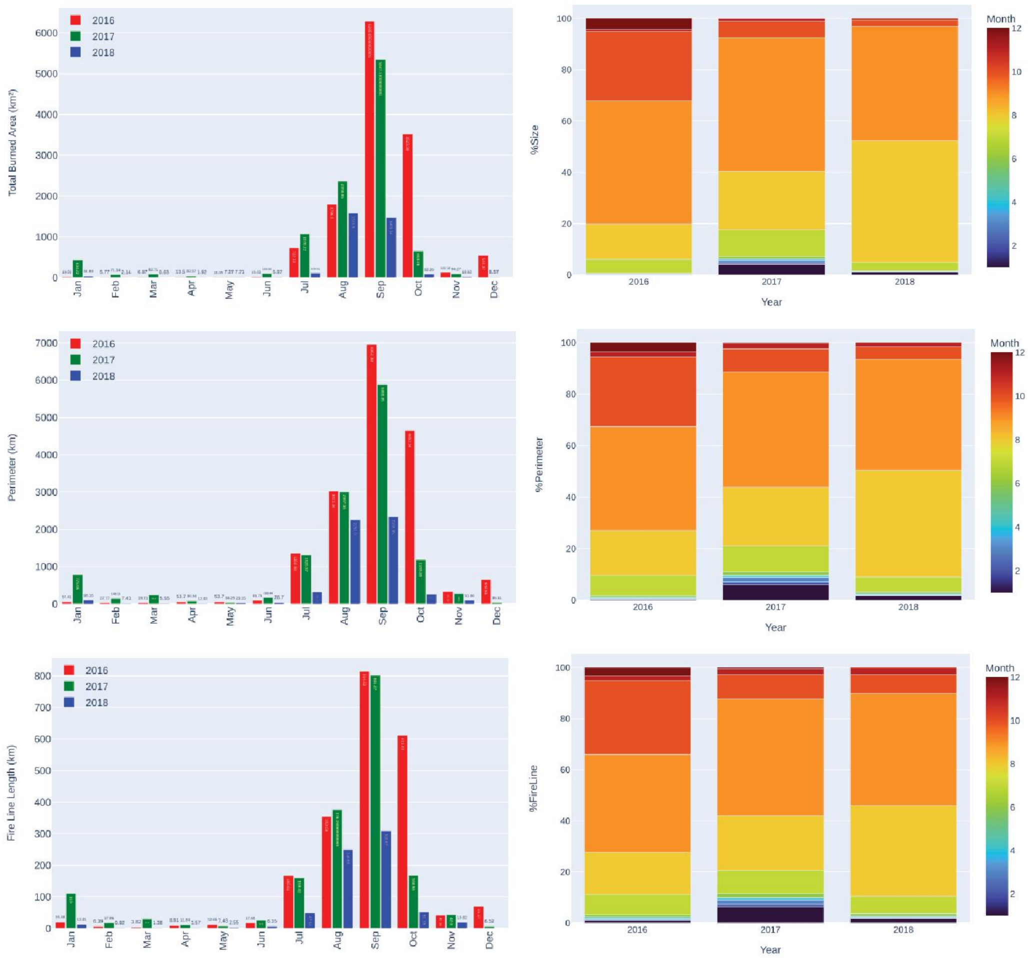


Figure 3. Total burned area per month and year - km² (upper left); Proportion of Burned Area per month - % (upper right); Total perimeter of the burn scars per

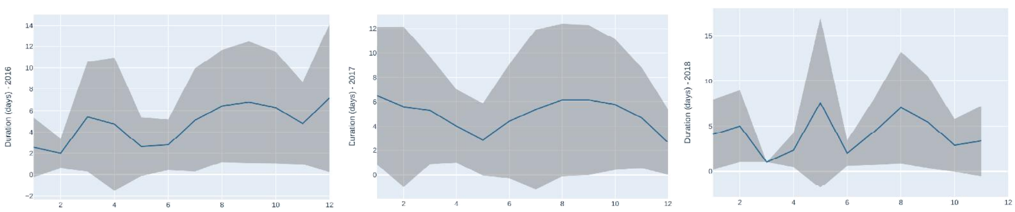
month and year - km (middle left); Proportion of Perimeter of the burn scars per month - % (middle right); Total length of the fire line per month and year - km (lower left); Proportion of Fire Line per month - % (lower right).

Other three metrics analyzed in this work are related to the duration of burn scars (days), speed of fire (km/day), and expansion of fire (km^2/day) (Figure 4). Through the analysis of LOESS method, we found a similar distribution in Expansion and Speed of fire, where the higher mean values are observed in September in all years and the higher variability also occurs in the September (Table 1). In Table 1 we observed that all mean values exceed the annual mean values and presents a high standard deviation, that is, a high variability.

Table 1: Expansion (km^2/day) and Speed (km/day) of fires over three years of time series (2016, 2017, 2018).

Fire metrics	**2016**	**2017**	**2018**
Mean | Expansion	1.33 km^2/day	1.29 km^2/day	0.93 km^2/day
Std | Expansion	5.08 km^2/day	5.08 km^2/day	2.52 km^2/day
Annual mean | Expansion	0.82 km^2/day	0.86 km^2/day	0.71 km^2/day
Mean | Speed	1.27 km/day	1.1 km/day	1.04 km/day
Std | Speed	2.44 km/day	2.01 km/day	1.9 km/day
Annual mean | Speed	0.71 km^2/day	0.71 km^2/day	0.44 km^2/day

However, the metric Duration of fire is more heterogeneous over the times series analyzed. For example, in 2016, the month with the highest mean days with fire was December, where each burn scar lasted an average of 7 days, while in 2017, the month with the highest value occurred in January (average duration of 6 days) and, finally, in 2018, the highlighted month was May (with an average duration of 8 days). Through this analysis, we can consider the month of September as the peak of fire in these years (2016, 2017, 2018) in the Pantanal biome, because the fire size, perimeter, fire line, speed, and expansion of fire, reached their maximum in this month.



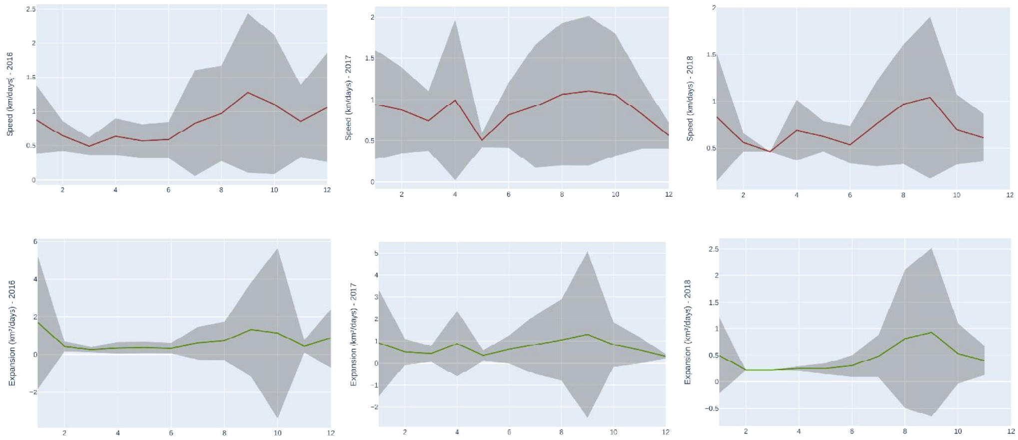


Figure 4. Average fire duration (days) over the months for the three years - 2016, 2017, 2018 (first row); Average fire speed (km/days) over the months for the three years - 2016, 2017, 2018 (second row); Average fire expansion (km^2/day) over the months for the three years - 2016, 2017, 2018 (third row).

Analyzing the intersection performed between burned area and LULC data, we observed that during 2016, the land cover type most affected were Trees (37%), Grass (31%) and Shrub (30%), in 2017 was Trees (56%), Shrub (35%) and Grass (8%), and finally, in 2018 was Trees (68%), Shrub (27%) and Grass (3%). It is observed an increase in the Trees burned over the years and a decrease in the Grass burned (Figure 5).

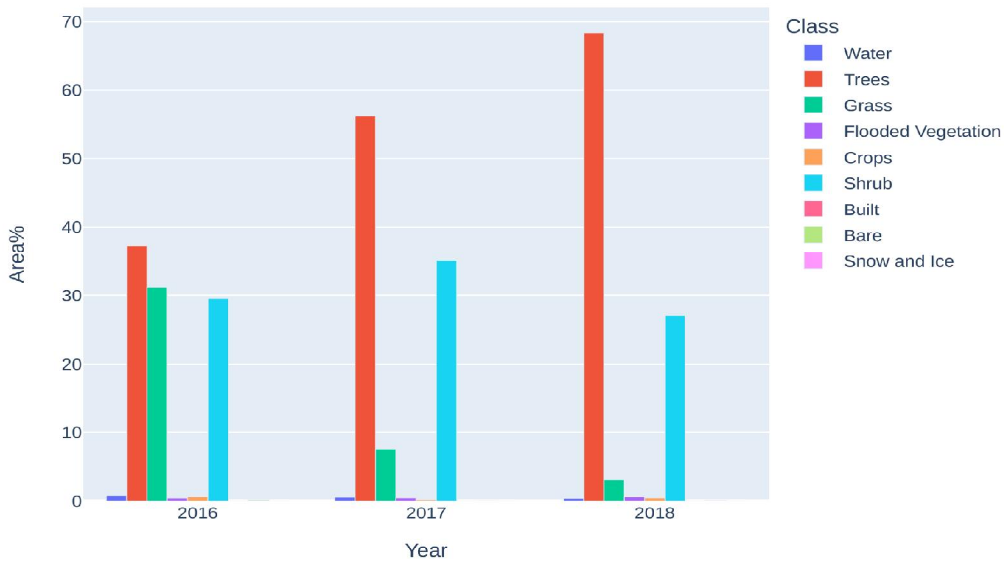


Figure 5. Percentage of burned area per Land Use and Land Cover (LULC) classes for the three years - 2016, 2017, 2018.

4. Discussion

Like the Brazilian savanna (Cerrado), a large portion of the Pantanal region is fire-prone, while the non-savanna portion of Pantanal is fire-sensitive, a region with no adaptation to fire events and susceptible to a plethora of disturbances (Hardesty et al., 2005). The fire pattern is defined in terms of size, frequency, or duration of burn scars, and their temporal variability is explained by rainfall seasonality, interannual variability and long-term droughts. Therefore, variations in precipitation rates along the seasons and the presence of droughts can affect the behavior of fires (Argibay et al., 2020).

The fire season in the Pantanal biome coincides with the dry period (April to September), extending until October (the first month of the wet season). Historically, fires in the Pantanal have been used as a low cost tool to convert natural vegetation into pasture and agriculture, bringing on exotic grasses, which can contribute to the alteration in the fire regime, this fact corroborates with one of the main causes of fires in the Pantanal, anthropogenic causes. Associated with anthropogenic causes, prolonged dry seasons and the intensification of extreme weather events, e.g., the 2016 drought, can influence the propagation of fire events (Barbosa et al., 2022).

In this context, it is possible to cite the ENSO (El Niño-Southern Oscillation) as a cause of 2016 drought, which is characterized by a Sea Surface Temperature (SST) anomaly, centered on the equatorial Pacific Ocean and divided between unusually warm SSTs (El Niño) or unusually cold SSTs (La Niña). These events can have a large impact on regular rainfall patterns and temperatures. The El Niño phase, for example, results in higher temperatures and reduced precipitation across the tropics, leading to increases in fire susceptibility. The increase in fire occurrence in the Pantanal during 2016 can be attributed to the peak of the last El Niño (Libonati et al., 2020; Burton et al., 2020).

According to Filho et al., (2021), many canals, called popularly "mouths", have been blocked by farmers aiming to avoid the flooding of fields used for grazing, causing the difficulty of water spread and runoff, which, in turn, increases exposure to droughts. The natural climate conditions (dry and hotter conditions), associated with human activities and inadequate agriculture practices have been influencing the water supply of rivers, reducing their sizes and, consequently, increasing the susceptibility to fire events. In addition, the lack of consolidated legislation to protect the ecosystems and the lack of respect for the Protected Areas increases the natural and humans pressures within this biome, and contributing with their degradation.

4. Conclusions

The Pantanal biome is controlled by the alternation of consecutive years of flood and drought, which constitutes one of the most important actors in the socio-economic and biodiversity of the region. Fire events put such a balance at risk, by resulting in a large range of destructive ecological and social impacts. Through the analysis of fire metrics (size, perimeter, duration of fires, speed and expansion) we observed that the year with the highest burned area was 2016, coinciding with the year of the El Niño event, proving that most drier and hotter years can lead to a more flammable landscape. In addition, we saw that the fire peak (the month with the highest percentage of burned area) occurred in September. These analyses were important because we could extract the main temporal patterns of fires, and identify what most burned, in this case, Forest (Trees) and Pasture (Grass). Identifying these patterns is essential for the development of public policies, aiming to the preservation of ecosystems and the reduction of impacts caused by fire events. Future works must be developed to understand the spatial patterns of fires and, thus, identify the areas most affected and susceptible to fire.

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