SPATIAL PATTERNS OF BURNED AREA IN THE PANTANAL BIOME AND THEIR RELATIONSHIP WITH LANDSCAPE STRUCTURE

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ABSTRACT

The Pantanal is the largest freshwater floodplain in the world, but its ecological equilibrium has been strongly impacted by human activities, which has caused an intensification in fires, an increase in landscape fragmentation and modification in the hydrological cycle. The goal of this study was to answer two main questions: 1. How are characterized the spatial patterns of fires, concerning total burned area (size) and duration of burn scars? 2. What is the relationship between fire and landscape fragmentation in the Pantanal biome? The following features were extracted from remote sensing products and analyzed: Size and Duration of fires and landscape metrics, Forest Proportion, Edge Density and Number of Patches. The spatial change observed in the fire patterns (southwest to northeast) can be explained by climate seasonality and by high level of fragmentation in the central portion of the biome.

***Keywords* —** Burned Area, Duration of fire, Pantanal Biome, Landscape Metrics, Land Use and Land Cover.

1. INTRODUCTION

Every year, mainly during the dry season, thousands of hectares of biomes and ecosystems are burned. It results in many ecological and social impacts, such as, tree mortality, changes in forest structure and composition, economic losses, harm to the health of local populations, impact on air quality, and many others [1]. 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 [2].

The Pantanal is the largest freshwater floodplain in the world, located in the central portion of South America (Brazilian states Mato Grosso and Mato Grosso do Sul ~80%, Bolivia ~19% and Paraguay ~1%). Despite being relatively well preserved, the ecological equilibrium has been strongly impacted by human activities (e.g. deforestation, agriculture, hydroelectric power stations and wildfires) [3]. These actions have a high potential to cause meaningful changes in the landscape structure and climate conditions.

Recently, Pantanal was highlighted for presenting a raise in the number of fire events [4, 5, 6]. The combination between the expansion of agriculture and livestock with fire use and droughts can increase wildfires leading to the intensification of landscape fragmentation. The landscape fragmentation is defined as a rupture in the landscape connectivity and can cause an increase in the edge effect and an intensification of outside factors [7]. This process affects the ecosystem dynamics, making the species more tolerant to fires more abundant and growing the probability of species more vulnerable to fire disappearing [8].

Remote sensing techniques are a useful tool for mapping and quantifying the patterns, size, and assessing the impacts of wildfires on a range of natural and social systems, and to understand the influence of landscape fragmentation in the Pantanal biome. In this sense, the goal of this work was to answer two main questions: 1. How are characterized the spatial patterns of fires, concerning total burned area (size) and duration of burn scars? 2. What is the relationship between fire and landscape fragmentation in the Pantanal biome?

2. MATERIAL AND METHODS

2.1. Study Area

The study covered the Pantanal biome (Fig. 1), located in the Upper Paraguay River Basin, and includes two distinct environments: lowlands (Pantanal biome) and highlands (Plateau).

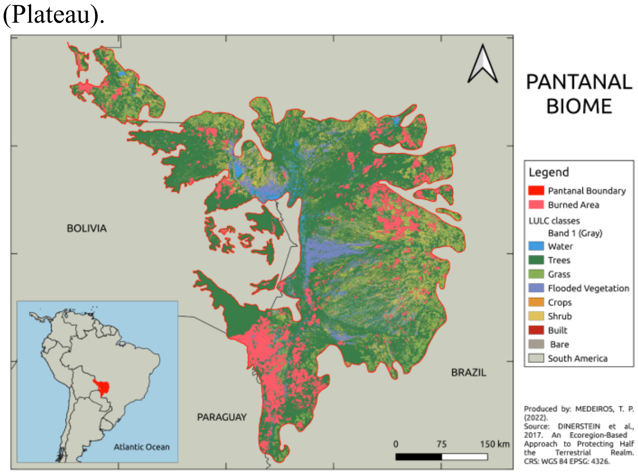

Figure 1: Study Area.

The Pantanal is a complex mosaic of different ecosystems shaped by climate, ecological and anthropogenic factors, which are closely interconnected. One of the defining characteristics is its flooding regime, characterized by a "flood pulse" and conditioned by the interaction between air masses. The climate is considered seasonal, marked by two well-defined seasons: dry (April to September) and rain cycles (October to March) [9, 10]. Due to the topography gradient, the Pantanal floods annually and presents a slow drain, resulting in the floodplain dynamics. This distribution controls the flooding cycles of the Pantanal. However, these cycles are being changed, mainly due to human activities, which contribute to the intensification of drier conditions favorable to fire spread [11].

2.2. Data Collection

Aiming to understand the spatial patterns of fire in the Pantanal biome, and their relationship with the landscape structure we used data from two different global products: 1. *Global Fire Atlas*, a global dataset that tracks day-to-day dynamics of individual fires to determine the timing and location of ignitions, fire size, duration, daily expansion, fire line length, speed, and direction of spread. [12]; 2. *Dynamic World LULC* (Land Use and Land Cover), a Sentinel-2 imagery, with 10m of spatial resolution, and deep learning techniques for globally LULC near real-time classification [13].

2.3. Methodological procedures

The work was developed in three main steps: 1. *Pre-processing*, which consisted of data collection and database organization; 2. *Processing*, first, we created a 10km² regular grid. After, we extracted the nine landscape metrics, Number of Patches (NP), Edge Density (ED), Total Edge (TE), PLAND (Percentage of Landscape), MPA (Mean Patch Area, mean and standard deviation), CA (Class Area, mean and standard deviation), and TCA (Total Core Area), using two packages in the RStudio, the *landscapemetrics* and *landscapetools*. All these landscape metrics were aggregated to the regular grid, as well as the fire metrics. It calculated the sum of total burned area in each cell (km²) and the mean of duration of fire (days); 3. *Statistical analysis*: we applied firstly a stepwise method to fit the better model to run a regression approach. This is an automatic search process, where at each step, the input and output of each independent variable are tested. Finally, we chose a non-parametric approach to fit curves using LOESS Regression (Locally Weighted Scatterplot Smoothing). We used the threshold 0.75 (default setting) in this analysis [14].

3. RESULTS

Through the application of stepwise method, we found which landscape metrics (independent variables) have a high correlation with fire metrics (size and duration, dependent variables) and fit the better model. Three landscape metrics stand out: PLAND; ED, and NP.

3.1. Spatial patterns of fire and landscape metrics

Concerning the spatialization of fire (duration and size) and landscape metrics (PLAND and ED) in the grid (Fig. 2), we observed, in 2016, a high concentration of burned area (4546 km² - 8006 km²) in the southwest portion of Pantanal biome, which coincides with the region that presents a low proportion of forest (0-20 %). In terms of fire duration, in the southwest, the burn scar lasts an average of one week to one month. Finally, in the case of edge density, we observed a high concentration of edges in the central portion of the Pantanal biome, covering the interval between 68 to 165 m/ha of edge density for this year (2016).

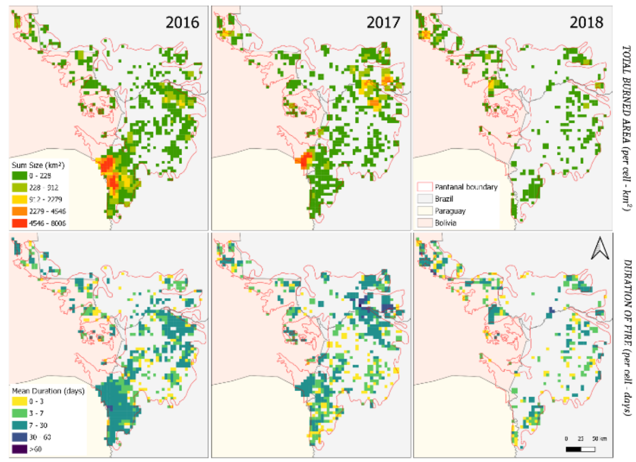

Figure 2: Spatial patterns of total burned area per cell (km²) and mean of duration of fire per cell (days).

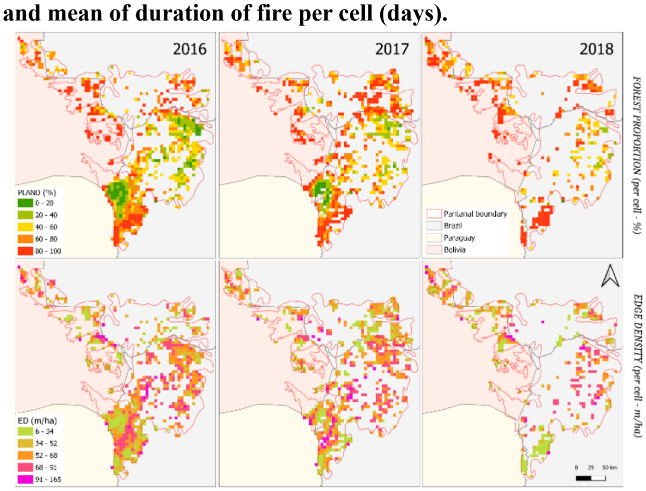

Figure 3: Spatial patterns forest proportion per cell (%) and edge density per cell (m/ha).

In 2017, the spatial patterns suffered a slight modification, we identified a reduction in the concentration of burned area in the southwest region, and the emergence of a new patch with high values of burned area, in the northeast (2279km² - 4546 km²). Also, we quantified in the northeast region one cell with a mean duration of fire of more than 60 days. In the northeast region a high proportion of forest, as well, is observed. In 2018, the concentration of burned area was much lower and we visualized some cells in the northwest region with a medium level of burned area (912km² - 2279 km²). Besides, we reached up to a maximum average of 30 days of fire duration. In the case of forest proportion and edge density the spatial pattern in 2017 and 2018 follows the same spatial pattern of 2016, that is, from one year to another no significant spatial changes are observed (Fig. 3).

3.2. Relationship between fire occurrence and landscape structure

In Fig. 4 we presented a boxplot for each metric analyzed in the work, and their respective histogram, accumulated for the three years (2016, 2017 and 2018). For the metric 'SIZE' (*graphics orange in Fig. 4*), we obtained a mean of ~347 km² burned area (dashed line), a minimum of 0.21 km², a maximum of 8.006 km² and a median of 27.86 km². The data distribution can be visualized in the histogram, where the data is skewed to the left and we have 1034 sample units (out of a total of 1799 cells) with values located in the first category (values in the range of 0 to 49.9 km² of burned area). In the case of the metric 'DURATION' (*graphics purple in Fig. 4*), we quantified a mean of ~9 days of fire duration, a minimum of 1 day, a maximum of 67 days and a median of 7.66 days. The data distribution is also skewed to the left, with most sample units (cells) located in the first categories of the histogram (0 to 10 days in duration of fire).

Concerning the landscape metrics (PLAND, ED, and NP), PLAND (*graphics green in Fig. 4*) presented a mean of 64% of forest proportion, a median of 66%, a minimum of 2.5%, and a maximum of 100% and is the unique metric with the distribution skewed slightly to the right, with a high concentration of cells located in the high values of forest proportions (80 - 100%). For metric ED (*graphics red in Fig. 4*), we observed a mean of 54.5 m/ha of edge density, a minimum of 5.7 m/ha, a maximum of 165 m/ha, and a median of 56.5 m/ha. Besides, we visualized a high amount of sample units (181 cells) located in the center of the distribution, in the category of 60 to 65 m/ha of edge density. Finally, NP (*graphics blue in Fig. 4*) presented a mean of 397 patches, a minimum of 1, a maximum of 2462, and a median of 354. Its distribution also is skewed to the left, in which a high number of cells is in the first category, ranging from 0 to 49 patches.

Regarding the graphics obtained through the smoothing process (LOESS regression) (Fig. 5), we observed a negative trend between Total Burned Area (Size, km²) and Forest Proportion (PLAND, %), where the highest values of the burned area are found in cells with a lower proportion of forest (*graphic A in Fig. 5*). Moreover, regarding the Total Burned Area and Number of Patches (NP) (*graphic B in Fig. 5*), we visualized a slight positive trend, where the size of the burned area tends to grow until it reaches the limit of 1250 patches. At the same time, analyzing the relation between the Duration of Fire and NP (*graphic C in Fig. 5*) we can conclude that the duration of fire (above 50 days of burning) reaches its maximum in cells with a low number of patches (until 500 patches), presenting a negative trend. Finally, regarding the Duration of Fire and ED we observed a positive trend, where the duration of fire reaches their maximum in the range of 25 to 75 m/ha (*graphic D in Fig. 5*).

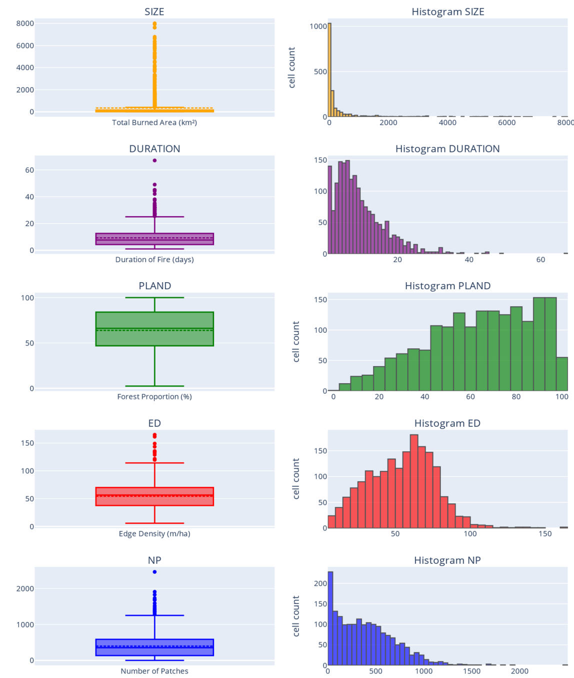

Figure 4: Boxplots and their respective histograms to each metric analyzed in the work: Size (orange), Duration (purple), PLAND (green), ED (red), NP (blue).

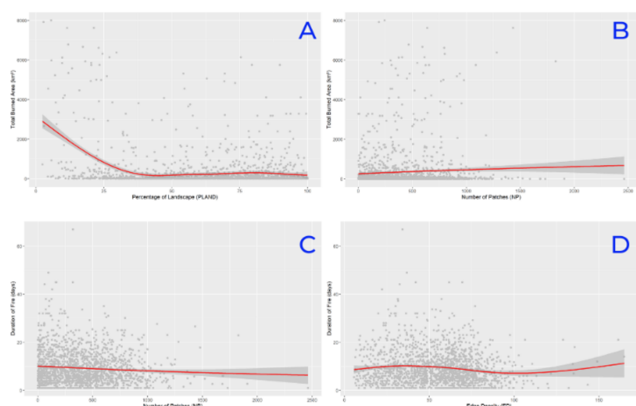

Figure 5: Graphics obtained through LOESS regression, showing the relationship between the variables: A. PLAND and Total Burned Area; B. NP and Total Burned Area; C. NP and Duration of Fire; D. ED and Duration of Fire.

4. DISCUSSION

Some elements can influence the fire regime: 1. Weather conditions, which includes atmospheric stability, wind (controls the speed and direction of fires), air temperature, precipitation, relative humidity, and its hydrodynamics - “flood pulse”; 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 [15].

The spatial change observed in the fire patterns (southwest to northeast) can be explained by climate seasonality (e.g. droughts, El Niño oscillation, flood pulse) and by high level of fragmentation in the central portion of the biome (high density of edges and low proportion of forest). The high concentration of burned in 2016 (a drought year) proves that the fire activity and climate are closely linked and, therefore, the 2016 Pantanal fires can be considered as a result arising from an interplay between extreme hot and dry conditions [3]. The 2016 drought can be attributed to the El Niño oscillation, resulting in the temperature increase and precipitation decrease, consequently, leading to increase in fire susceptibility [16, 17].

The presence of edges aligned with wind direction and biomass to burn (fuel) probably caused the change in the location of the burned area patch (northeast). In addition, in 2017, the duration of fire reaches its maximum, indicating a high susceptibility to fire in this region. This comproves that fires are also influenced by human activities, by burning the native vegetation through slash-and-burn practices for agriculture and livestock purposes, causing an increase in deforestation rates and an introduction of non-native grasses and shrubs [18].

We can see that fire reaches its highest intensity levels when we have medium levels of edge density, number of patches and forest proportions. This fact proves that if the region is very fragmented, there will be no more environmental conditions for the generation and propagation of fire. Above a certain threshold (75m/ha of edge density and 1250 patches) the burned area and its intensity (size and duration) presents a decrease.

The anthropic actions are responsible for growing the landscape fragmentation, which is one of the biggest threats to the ecosystem’s maintenance and biological diversity. The fragmentation process provides an increase in the edge effect, and, consequently, the intensification of the outside factors influence. In edge areas are observed an increase in luminosity and a decrease in humidity when compared to the core areas. The influence of external effects associated with microclimate changes makes the biomass more flammable, causing an increase in fires.

5. CONCLUSIONS

The fire dynamics in the Pantanal biome are complex and heterogeneous, where the spatial changes visualized can be attributed to climate seasonality and landscape fragmentation. Understanding the fire patterns and their relationship with landscape changes are very important, because when the fire becomes uncontrollable and spreads quickly the impacts and consequences are extremely dangerous, isolating populations, affecting ecosystems regeneration, making fire-tolerant species more abundant and increasing the probability that fire-vulnerable species may disappear.

6. REFERENCES

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