CHAPTER 80

Dynamics of forest fires about the types of usage and coverage of the earth in the Amazonian Forest of the state of Maranhão, Brazil.

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ABSTRACT
The Amazon in the state of Maranhão has recorded several types of degradation causing several damages to the environment and human health. The objective of this work was to understand the dynamics of the burned areas about the usage of the land and coverage in the period from 2001 to 2016 in Maranhão Amazon region. For this purpose we used the coverage and usage soil datas of MapBiomas Project in burned areas of the Fire_cci Burned product Area (BA) v5.0, of precipitation of the Climate Hazards Group InfraRed Precipitation with Station - CHIRPS, and Temperature MODIS LST data from the Global Climate Model Grid (CMG) version 6 (MOD11C3). The proportion of burned areas by land use and cover and the most critical years was identified, relating the area burned to rainfall and monthly temperature. In the studied period, 818,300 hectares were affected by fire. The biggest areas burned were recorded in 2007, 2012 and 2015. Soils with high proportion of pasture showed increasing burnings, compared to other classes. The months of September to November registered the highest occurrence of burned areas presenting precipitations below 50 mm and the highest temperatures in the period. These results indicate the need for actions to prevent, control and manage the usage of fire in the Maranhão Amazon.

Keywords: Burned area, Soil coverage, Amazon biome.

1 INTRODUCTION

Tropical forests play a crucial role in preserving biodiversity and providing essential ecosystem services to populations, such as: food supply; pollination; production support; water regulation; climate regulation and soil erosion control, which are important for the carbon balance in the ecosystem and therefore have been receiving increasing attention in control activities related to global warming (Le Clec'h et al., 2018; Brienen et al., 2015).

Local, regional and global processes affect the patterns and pace of deforestation that define land use change in the Brazilian Amazon (Gollnow et al., 2018). These processes are characterized by conversions of the forest into pasture and agriculture, driven by global food demand (Lewis at al., 2015).

A degraded forest is one that has undergone changes that have resulted in reduced capacity to provide goods and services, a consequence of events such as fires, predatory logging, and forest fragmentation (Thompson, 2012).

In the Amazon region, the process of agricultural production and expansion and the elimination of biomass in recently deforested areas occur mainly through the use of fire (Aragão et al., 2014). However, the risk of fire spread increases in years of extreme droughts turning these fires into uncontrolled fires (Aragão et al., 2007). Thus, climate, including short- and long-term droughts in conjunction with anthropogenic ignitor sources, influence fire regimes in wildfires (Alencar et al., 2015; Latorre et al., 2017).

The easternmost portion of the Amazon biome reaches the state of Maranhão. In this region that is located more than half of the center of endemism Belém, which houses great biological richness with endemic species of birds and mammals and also threatened with extinction, comprising areas of great ecological importance such as Environmental Protection Areas of the Baixada Maranhense and Reentrancias with contact zones between marine and fluvial waters that create unique environments of high productivity and very rich in species and endemisms of aquatic organisms, that are the important basis of sustaining local human populations (Oliveira, 2011).

The Maranhão Amazon has for years registered several types of degradation, such as deforestation, illegal timber removal, mining, coal production, excessive hunting and cattle ranching (Costa et al., 2016). causing various damages to the environment and human health (Castro et al, 2016). The Maranhão Amazon is also inserted in the region of the "Arc of Deforestation and Fire of the Amazon" of Brazil, which comprises the Cerrado-Amazon transition areas, constitutes the zone most frequently affected by fire in recent decades within the Brazilian territory (Alves and Pérez-Cabello, 2017).

Thus, to develop control, management and prevention policies, it is important to generate information about the spatial and temporal profile of fire. Remote sensing can help increase this information and contribute to monitoring strategies in the region of the Maranhão Amazon rainforest, which constitutes a public asset that generates benefits in terms of environmental services that are essential for the economy and food security for this region and for the whole society and, therefore, must be protected.

In this context, in order to understand the dynamics of the areas burned on different types of land use and cover in the Maranhão Amazon, in the period between 2001 and 2016, we sought to answer the following questions: what is the extent of the burned areas in the Maranhão Amazon? How did the temporal and spatial distribution of the burned areas occur for this period? was there recurrence of the burned areas? was there a relationship between precipitation and temperature with the occurrence of burned areas?

2 MATERIALS AND METHODS

2.1 AREA OF STUDY

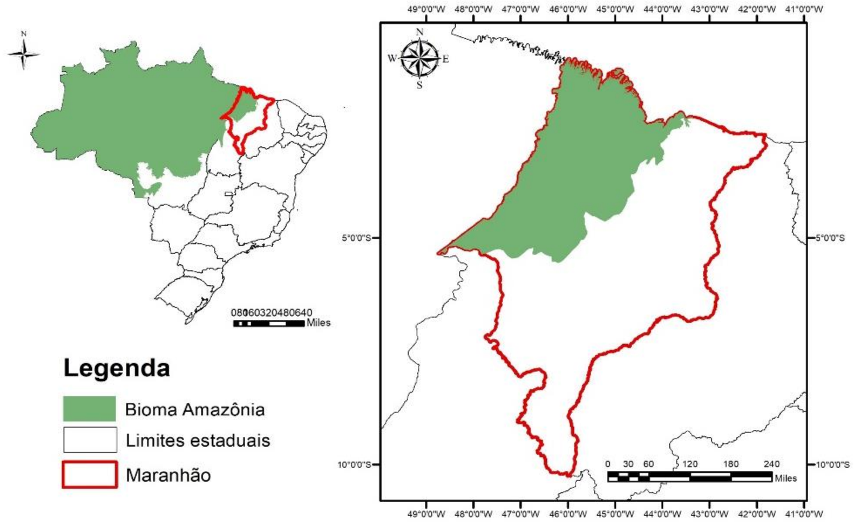
The state of Maranhão is one of the 27 states of Brazil, located west of the Northeast Region, is bordered to the north by the Atlantic Ocean, to the east by the State of Piauí, to the west by the state of Pará, and to the south and southwest by the State of Tocantins. Covering an area of 331,935.5 km2 and its current population is 6,574,789 inhabitants (IBGE, 2019).

The climate of the State of Maranhão is predominantly tropical, where average annual temperatures are higher than 26°C, with average annual rainfall totals ranging from 700 mm in the central region, where rainfall is scarcer, to more than 2200 mm in the northern region of the state, in the vicinity of the coast where rainfall is more abundant (NUGEO, 2015).

The State of Maranhão includes three different biomes, which contributes to a high diversity of landscapes: the Cerrado, the Amazon and a small portion of the Caatinga biome (EMBRAPA, 2016). For the analysis of this article, the delimitation of the Amazon biome for the state was adopted.

The Maranhense Amazon, figure 1, has rich biodiversity and is found in 62 municipalities of Maranhão and represents in terms of the biome, 34% of the state's territories (Costa et al., 2016).

Figure 1. Location of the state of Maranhão, with emphasis on the Amazon biome.



2.2 DATA COLLECTION AND PROCESSING

The information related to land cover and land use was extracted from the MapBiomas Project, data available in: www.mapbiomas.org, Collection 2.3 (Mapbiomas, 2018), in raster format with spatial resolution of 30 m.

For burned areas, we used the product Fire_cci Burned Area (BA) v5.0 (Roy et al., 2008) made available by the European Space Agency (ESA) with a spatial resolution of 250m. It has daily temporal resolution, being made available through a monthly temporal composition, the data were obtained from the websites of the European Space Agency (ESA) Fire CCI at the address: http://www.esa-fire-cci.org.

The precipitation data originated from the Climate Hazards Group InfraRed Precipitation with Station – CHIRPS (Funk et al., 2015), which is a product developed by the U.S. Geological Survey of the Earth Resources Observation and Science Center, in association with the Santa Barbara Climate Hazards Group at the University of California, with a spatial resolution (0.05 × 0.05∘). Access link: http://chg.geog.ucsb.edu/data/chirps.

For Earth Surface Temperature, we used the MODIS LST temperature dataset from the Grid Global Climate Model (CMG) version 6 (MOD11C3) (Wan et al., 2018). The product incorporates data collected with the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The monthly LST product data has a spatial resolution of 0.05° and was extracted in: https://lpdaac.usgs.gov, for the period studied.

Spatial and temporal analyses were performed to characterize the fire patterns in the study area, as well as to identify the types of land use and land cover most affected, the recurrence of fires and the most critical months and years. For the analysis of the main land uses in which burned areas occur, the study area was initially cut out, followed by the reclassification of the Mapbiomas classes to 5 classes: 0. Others = Other non-vegetated areas, urban infrastructure, water bodies, beach and dunes and not observed; 1. Forest = Natural Forest, Forest Formations, Mangrove and Planted Forests; 2. Natural Non-Forest Formations = Natural Non-Forest Wetlands, Grassland Vegetation, Other Non-Forest Formations; 3. Pasture = pasture, agriculture or pasture; 4. Agriculture = Agriculture. This reclassification aimed to group similar land uses and land cover into a single class and to group the classes that are not of interest to the study. Burned area data derived from CHIRPS precipitation Fire_cci Burned Area (BA) v5.0 were also cut to the study area. The period of data analysis comprised the years 2001 to 2016.

Then, the burned areas were grouped by month in order to determine the monthly and annual total. Spatially, the total of burned areas was quantified by proportion of the class of land use and cover, monthly temperature averages and average annual and monthly precipitation for the entire period 2001-2016, and for this the products of burned area, precipitation, temperature and use and coverage were grouped in a regular grid of 10 x10 km.

To quantify the extreme years of temperature, as well as the burned areas, monthly anomalies were calculated for each one in the study period, according to the methodology proposed by Aragão et al. (2007), (Equation 1).

$$X_{anomalias} = \frac{X-(\sum(2001-2016)/15}{\sigma_{2001-2016}} \qquad \text{(Eq. 1)}$$

Where, is the anomaly of temperature or burned areas, $X_{anomalia}$X is the value of the year to be evaluated, Σ(2001−2016)/15 is the mean of the series in question (from 2001 to 2016) and σ2001−2016 is the standard deviation of the adopted series.

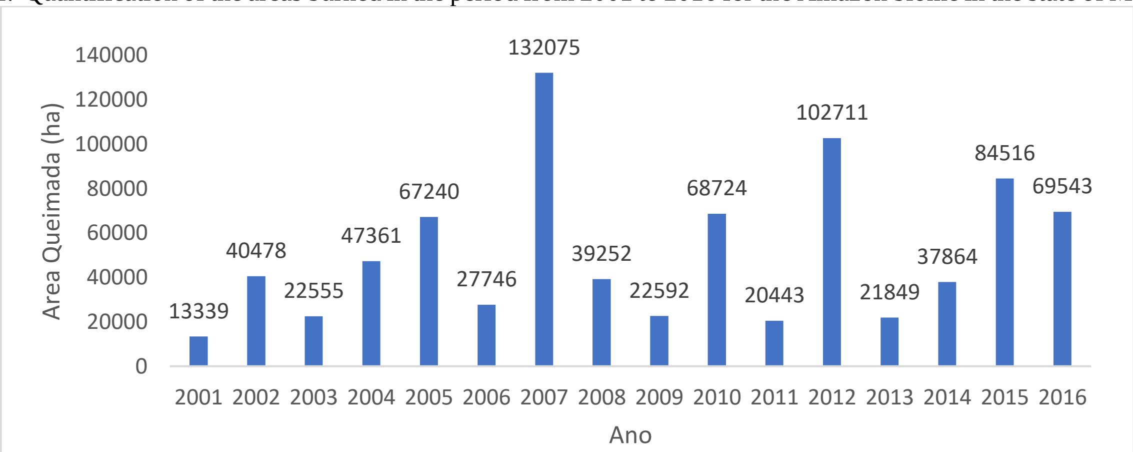
We also performed a trend analysis from the nonparametric Mann-Kendall test that was used to evaluate trend signals and the statistical significance of anomalies and Oceanic Niño index (ONI) (NOAA, 2019) for the study period.

3 RESULTS

3.1 SPATIAL AND TEMPORAL DYNAMICS OF THE BURNED AREAS ON THE DIFFERENT USES AND LAND COVER.

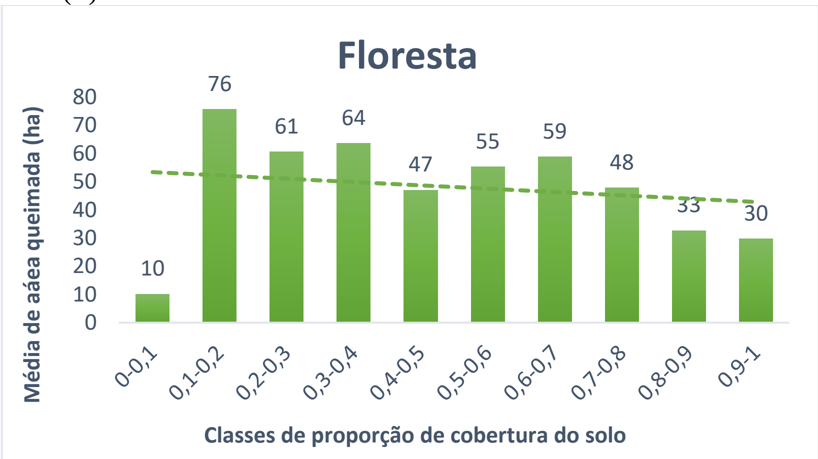
The accumulated burned area for the period between 2001 and 2016 in the Maranhão Amazon was 818,300 hectares, an area that corresponds to 43.57% of the territory of the biome in the state, however it is known that there are recurrences of fires in the same area over the years. The years with the largest burned areas were 2007, 2012 and 2015 with 132,075, 102,711 and 84,516 ha respectively, Figure 2. The lowest records of burned areas were for the years 2001, 2011, 2013 and 2009, with 13,339 hectares, 2011, with 20,443 hectares, 2013 with 21,849 and 2009, with 22,592 hectares burned.

Figure 2. Quantification of the areas burned in the period from 2001 to 2016 for the Amazon biome in the state of Maranhão.

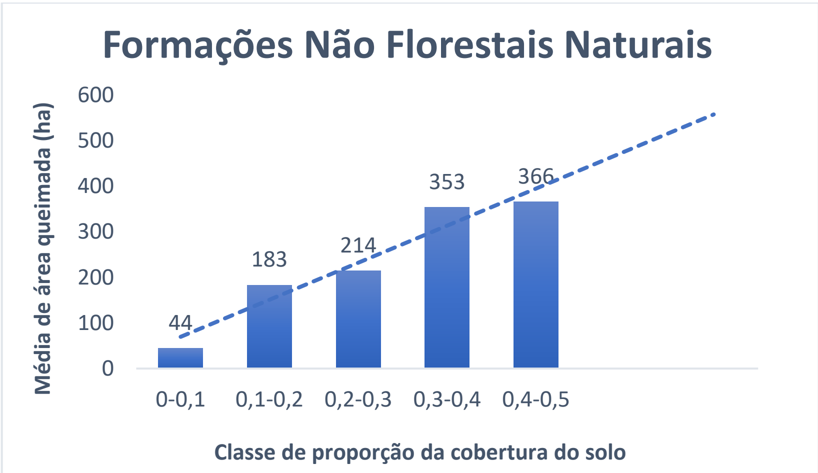


In the period evaluated, the averages of burned areas were observed according to the proportions of the classes of land use and cover, as shown in Figure 3. The results showed that as the proportion of forest in an area increases, there is a decrease in burned areas, where the lowest averages of burned areas were found in classes composed of 80 to 100% of forests, indicating that in preserved forest areas there is a smaller area the incidence of fires. The lowest value was found in the proportion of area with up to 10% of forest, which may be associated, mainly, with other forms of land use and cover. Regarding the coverage of Non-Natural Forest Formations, the analyzed areas did not present composition above 50% with these Forest Formations, indicating that they are formations of small extensions or more spatially fragmented, being composed mainly of vegetation of fields and savannahs, characteristics of the transition region with the cerrado. However, the highest averages of burned areas for the period were found in this type of plant formation, in the highest proportions found of this vegetation the averages were 366 ha of burned areas. For the pasture cover, it was possible to observe that the higher the proportion of an area with pasture, the higher the average of burned areas observed.

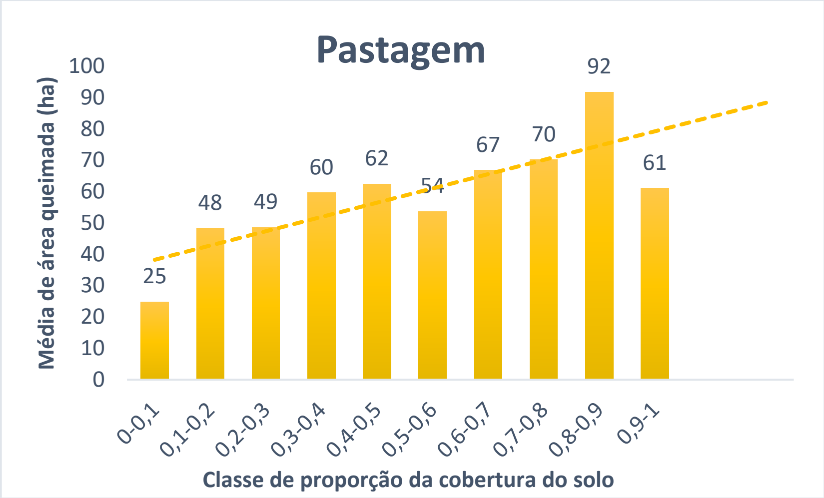
Figure 3. Averages of burned areas in the period from 2001 to 2016, by proportion class of Forest (A), Natural Non-Forest Formations (B) and Pasture (C) for the Amazon biome of the state of Maranhão..



(a)



(b)



(c)

The recurrence of forest fires ranged from two to eleven times in 15 years, concentrated mainly in the southwestern portions of the biome in the state, in transition with the cerrado. The areas that burned only once comprised the vast majority of cases, with 82% of the occurrences. Those that burned twice or more accounted for 18% of the recurrence areas. (Table 1). In total, 1,630 hectares showed recurrence of fires in the period of 15 years.

Table 1. Occurrence and recurrence of burned areas in the Amazon biome of the state of Maranhão, between 2001 and 2016.

NUMBER OF OCCURRENCES	AREA (ha)	%
1	7428,4	82,0
2	1060,3	11,7
3	338,0	3,7
4	151,2	1,7
5	57,7	< 1
6	13,0	< 1
7	4,6	< 1
8	4,0	< 1
9	0,9	< 1
10	0,4	< 1
Total	9058,3	100

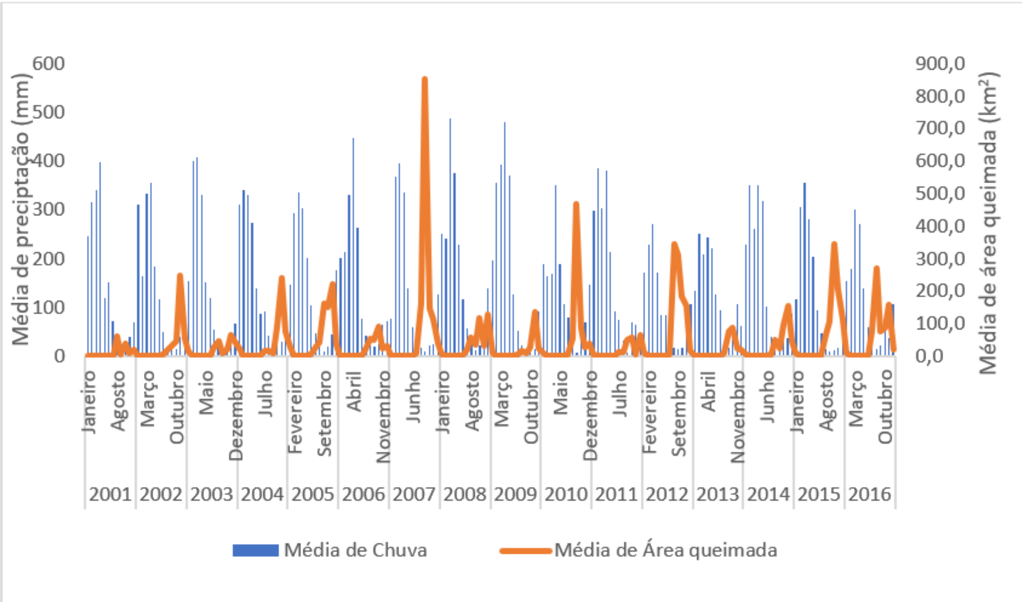
3.2 DYNAMICS OF BURNED AREAS AND THEIR RELATIONSHIP WITH PRECIPITATION AND TEMPERATURE.

The pattern of burned areas varied according to precipitation, in years when the accumulated precipitation was low the occurrence of burned areas was high. This pattern occurred for the years with the largest burned areas.

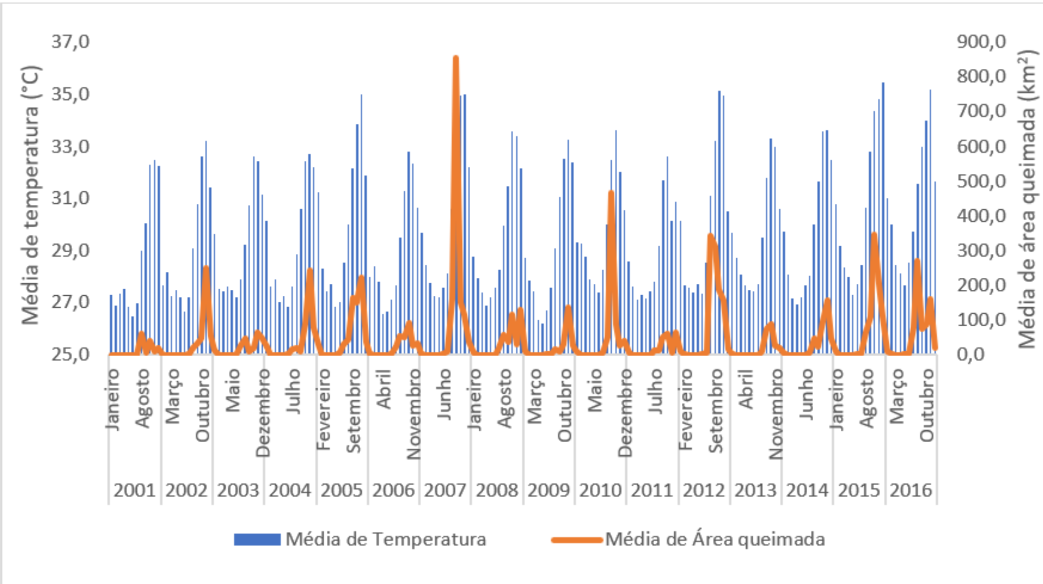
Relating the data of precipitation and burned area, from the period of 2001 to 2016, it was found that the months of September to November have the highest occurrence of burned areas, in this period the average rainfall was less than 50 mm. The month with the average rainfall of 10 mm or less was recorded in September of the years 2005, 2007, 2009, 2010, 2011 and 2015 and September 2007 and 2010 occurred the largest extensions of burned area (85,280 and 46,700 ha respectively), in which precipitation of approximately 09 mm and 07 mm was recorded, respectively. The highest temperature averages recorded for the period occurred in the months of October and November, around 35 ° in the years 2005, 2007, 2012, 2015 and 2016, in this same period the largest amounts of burned areas were recorded, figure 4.

Figure 4. Average rainfall and monthly burned areas (A) and average temperature and monthly burned areas (B) in the Amazon biome in the state of Maranhão between 2001 and 2016.

A



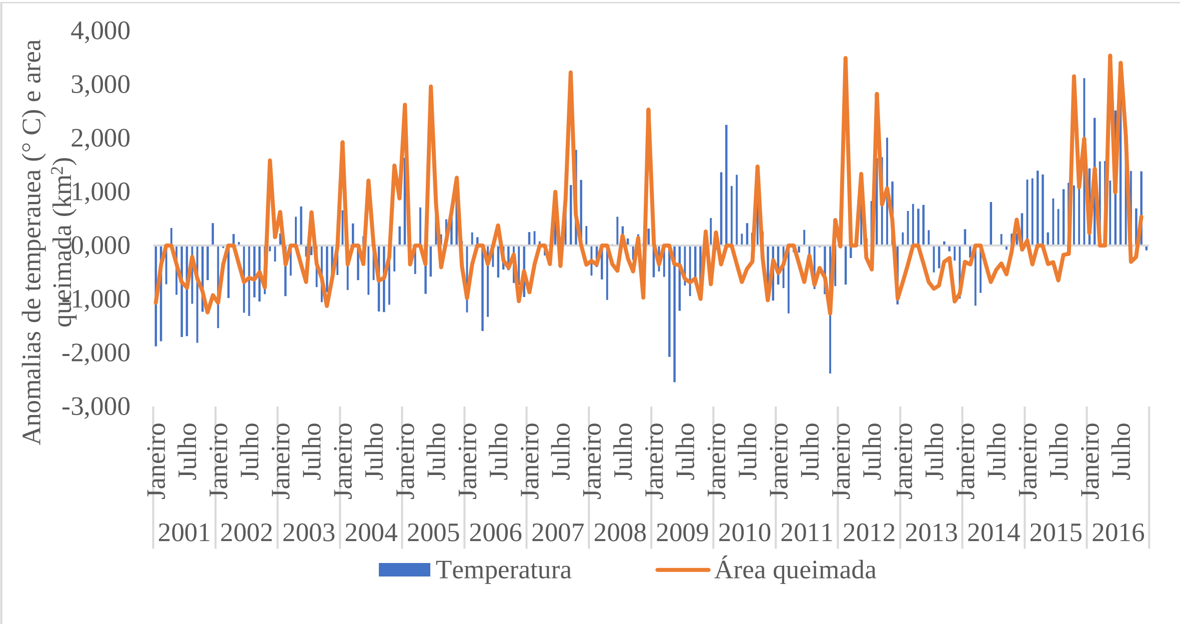
B



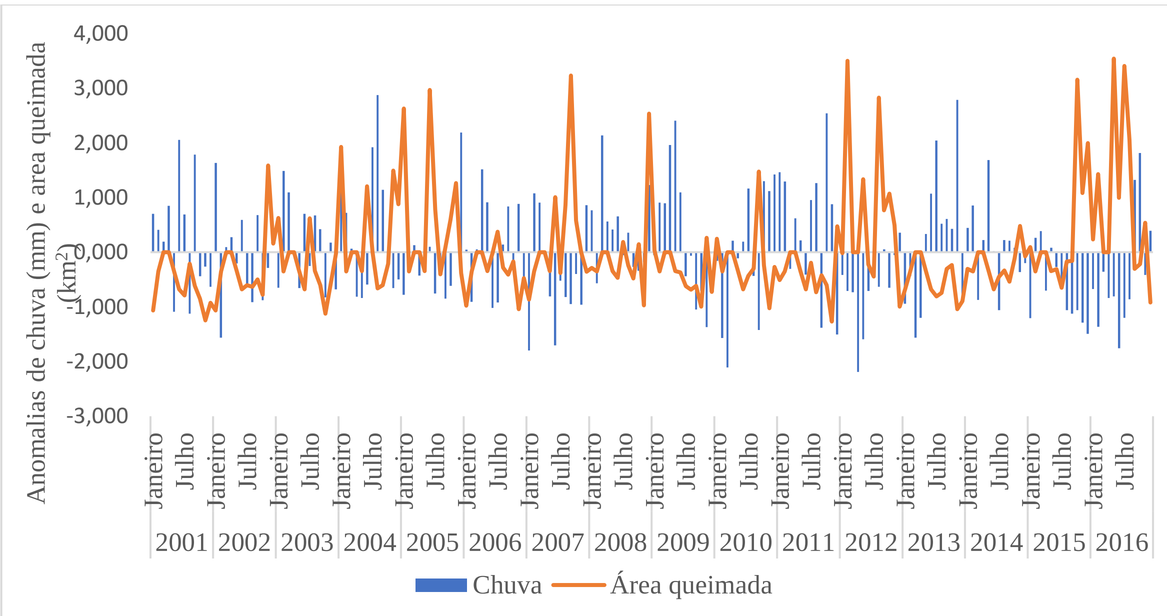
The largest negative fire anomalies occurred mostly in the months of November. Throughout 2007, 2012 and 2015 there were months with negative precipitation anomalies and positive for temperature, which correspond to the highest rates of burned areas recorded for the period studied. We can highlight that both temperature and precipitation remain anomalous for longer in recent years from 2014 to 2016, figure 5.

Figure 5. Anomaly of rainfall (A) and temperature (B) compared with anomalies of burned areas in the Amazon biome of the state of Maranhão between 2001 and 2016.

A

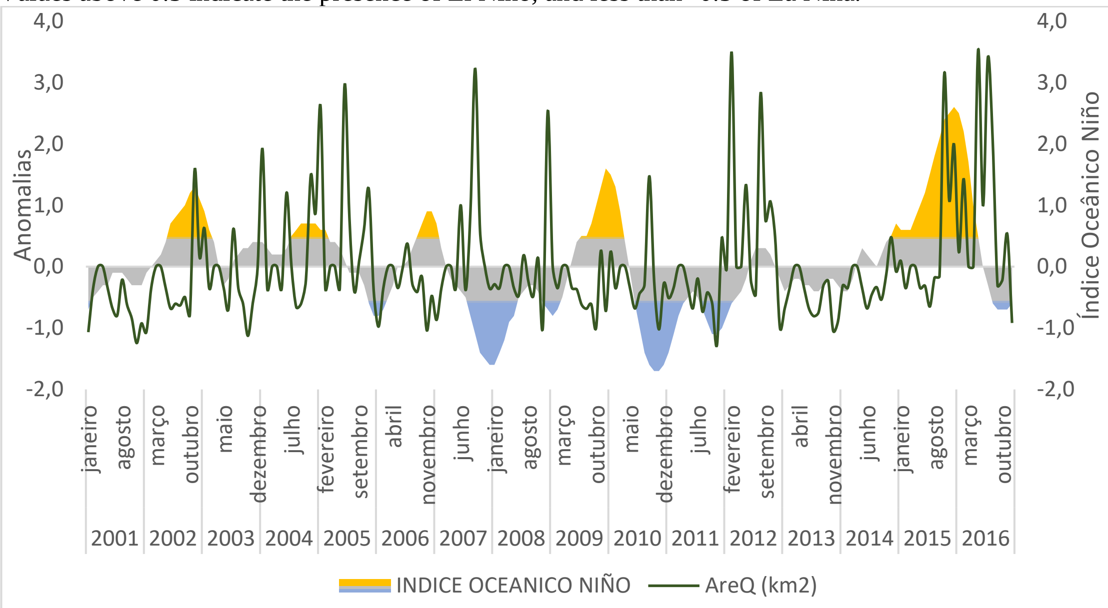


B



According to the niño ocean indices, figure 6, in the period from 2001 to 2016 we observed that the positive anomalies of burned areas are related to the presence of the El Niño phenomenon, especially in the years 2014 to 2016 in which the phenomenon occurred more intensely, maintaining the positive anomalies for the burned areas during this same period.

Figure 6. Niño Oceanic Index and anomalies of burned areas in the Amazon biome of the state of Maranhão between 2001 and 2016. Values above 0.5 indicate the presence of El Niño, and less than -0.5 of La Niña.



Performing the Mann Kendall analysis with the anomaly data for the total period, it was found that the oceanic index was constant during the period (p= 0.944). There was a slight trend of decrease in precipitation (p = 0.047) and increase for burned areas (p = 0.038), only the temperature had a high level of significance with a positive trend for the series (p <0.0001), this same trend for temperature occurred in the months of January and February and June to October, when analyzed separately throughout all years, The latter being considered months with drought for the biome, while the oceanic index niño, precipitation and burned areas remained constant (p>0.05) when the months were analyzed in isolation for the period.

4 DISCUSSION

In the period studied, the largest burned areas are associated with years that had adverse climatic events, such as the years of extreme droughts in the Amazon, which occurred in 2005, 2010 and 2015 (Lewis et al., 2011; Zeng et al., 2008; Jiménez-Muñoz et al., 2016) and in Northeast Brazil between 2012 and 2015 (Marengo et al., 2016). In this period the largest extensions of burned areas were found, this is related to the location of the Maranhão Amazon that receives influence both from the humid climate of the Amazon and the semi-arid Northeast. Cardozo et al., (2014) also found the largest areas burned in the years 2005 and 2010 in the Amazon. Neves et al., (2018) observed the highest rates in the years 2007, 2010 and 2012 in the Amazon-cerrado transition zone.

In addition, El Niño and La Niña have an influence on climate behavior, intensity of trade winds, precipitation, droughts, floods and cold fronts that reach the north-northeast of South America, with effects in the Amazon that may favor the occurrence of fire in this region (Marcuzzo and Romero, 2013).

The months of September to November recorded the largest extensions of burned areas, these being the months with the lowest rainfall for the region, indicating that the fires are modulated mainly by the pattern of seasonality of the precipitations. Similar results were indicated for the entire Amazon biome by Nogueira et al., (2017). The month of September presented the largest areas burned for several years, being the month with the lowest rainfall, below 50 mm and with the highest temperature averages, followed by the months of October and November. Aragão et al., (2007) observed that, when the monthly rainfall in the Amazon is less than 100 mm, the forest enters into water deficit, favoring the incidence of fires by the increase of combustible material in the vegetation. This relationship has also been observed in occurrences of extreme droughts in the Amazon (Anderson et al., 2018).

The areas with the greatest recurrence are mainly in the southern regions of the Maranhão Amazon, where there is greater anthropic activity in the region, which occurs through the occupation of the agricultural frontier, industrialization and the development driven by the Carajás Railroad (Almeida, 2016; Ribeiro Júnior and Sant'ana Júnior, 2011). Morton et al., (2013) also verified the relationship of recurrence with anthropic activities in the Amazon.

We observed that the increase in burned areas is associated with pasture areas, this is due to the lack of proper management in which the fire is used to clean the pasture in this region. In many cases, fire can escape to neighboring forests contributing to wildfires (Cano-Crespo et al., 2015; Rosan et al., 2017; Aragon and Shimabukuro, 2010). However, we observed that the greater the amount of forest in an area occurs a reduction of the burned areas.

Intense changes in land use and cover, and forest degradation in the Amazon threaten forest structure, biodiversity, and ecological functions (Coe et al., 2013). These changes caused by human activities generate a mosaic of land uses and increase degradation by deforestation, fragmentation, forest regeneration, selective extraction and forest fires (Aragão et al., 2014).

5 CONCLUSIONS

The analyses showed that the different classes of land use and land cover in the Maranhão Amazon have different behaviors for the occurrence of burned areas, reducing with the increase in the class of forest and with an increase in the class of pastures. In addition, we found that climatic conditions, such as high temperatures and low rainfall at certain times of the year favored the occurrence of fires, which can be increasingly aggravated by global climate change and may cause the increase and duration of these forest fire events. Thus, activities to fight forest fires and reduce the use of fire should be part of the prevention strategy for the Maranhão Amazon, since the management of fire-free land can reduce the incidence of fires in this area.

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