LARGE FIRES AND FIRE DANGER INDICES IN 'GOVERNADOR' INDIGENOUS TERRITORY, MARANHÃO STATE

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Received for publication: 24/11/2020 – Accepted for publication: 14/11/2021

Resumo

Grandes incêndios e Índices de perigo de incêndios na Terra Indígena Governador, Maranhão. Grandes incêndios são problemas ambientais globais, cada vez mais recorrentes em razão das mudanças climáticas, com perspectivas severas no futuro. O presente estudo caracterizou as condições edafoclimáticas da Terra Indígena (TI) Governador, Amarante do Maranhão - MA, assim como analisou a influência dessas condições em grandes cicatrizes de queimadas (acima de 50 ha) e índices de perigo de incêndios no período de 2001 e 2018. As cicatrizes foram mapeadas em imagens TM e OLI Landsat e os seguintes índices de perigo de incêndios foram avaliados: Índice Logarítmico de Telicyn; Índice de Nesterov; Fórmula de Monte Alegre (FMA) e Fórmula de Monte Alegre Alterada (FMA^+); e o índice canadense *Fire Weather Index* (FWI). Os resultados indicam que a região da TI Governador é uma área crítica em termos de incêndios florestais, com grandes áreas impactadas e com condições climáticas com elevado perigo de incêndio. Além disso, as formações savânicas apresentam grande propensão aos incêndios e predominam na região, assim com as pastagens no entorno. Destaca-se o índice da Fórmula de Monte Alegre com o melhor resultado, bem como a grande correlação com os dados climáticos e da vegetação, evidenciando o período de junho a agosto e as formações savânicas como as condições mais críticas.
Palavras-chave: Índice de perigo de incêndio, cicatriz de queimada, incêndios

Abstract

Large fires are global environmental problems, increasingly recurrent due to climate change, with severe perspectives for the future. The present study characterized the edaphoclimatic conditions of the Governador Indigenous Territory (TI), Amarante do Maranhão – MA state, and analyzed the influence of these conditions on large burn scars (over 50 ha) and fire danger indices in the period from 2001 to 2018. The scars were mapped on TM and OLI Landsat images and the following fire danger indices were assessed: Telicyn Logarithmic Index; Nesterov Index; Monte Alegre Formula (FMA) and Modified Monte Alegre Formula (FMA +); and the Canadian Fire Weather Index (FWI). The results indicate that the Governador TI region is a critical area in terms of wildfires, with large impacted areas and climatic conditions with great fire risks. In addition, savanna formations, which predominate in the region, are highly prone to fires, as well as pastures in the surroundings. The Monte Alegre Formula index stands out with the best result, as well as the great correlation with climate and vegetation data, highlighting the period from June to August and savanna formations as the most critical conditions.
Keywords: Fire risk, post-fire recovery, wildfire

INTRODUCTION

Large fires are global environmental problems which become increasingly more recurrent due to climate change and face alarming predictions in which fire management could not be enough to prevent future fire occurrences (Staal *et al.*, 2020). High-intensity fires and more severe fire regimes cause strong impacts on vegetation, with significant floristic and structural changes, that may lead to a process of secondary impact in part of the Amazon forest area, in the near future (Xaud *et al.*, 2013). Some studies point to a tipping point, in which a return would not be possible and the forest would lose its resilience (Staal *et al*., 2020). In addition to climate change, another factor that contributes to a tipping point is an inappropriate land management, in which there are no efficient policies for either suppressing fires or even for reducing fuel, allowing the accumulation of biomass, where the intensity of fire and its impacts on vegetation increase dramatically (Adams, 2013).

The occurrence and behavior of fires in native vegetation are directly related to factors such as combustible material, topographic aspects and climatic conditions, such as precipitation, relative humidity, temperature, wind speed and direction as well as other factors associated with human activity (Torres *et al*., 2008). Such factors influence the start, propagation, control of fires and the impacts on vegetation. Thus, the edaphoclimatic conditions, in which soil, climate and vegetation (combustible material) features are related, are essential for the development of more reliable vegetation assessment and fire prediction models. An analysis of the sensitivity of fire propagation models under different climatic conditions and combustible material can be very useful in assessing fire risk and in allocating and treating fuel to protect a vulnerable area as well as assessing how future fires can impact the communities and the wildlands (Ramirez *et al.*, 2019).

Meteorological data such as relative humidity, air temperature, precipitation and wind speed are commonly used to assess fire danger indices, which are the responsible for putting in number the danger of fire occurrence and spread (Torres *et al.*, 2017). In addition, historical records of fire occurrences obtained with orbital satellites have great potential to be used as ground truth, facilitating the monitoring and simulation of fires and, thus, supporting the decision making of the fire analysts. Hence, data from INPE/CPTEC (National Institute for Space Research/ Center for Weather Forecast and Climatic Studies) detection system can be used as fire validation (INPE, 2020).

Therefore, the use of geo-technologies, such as satellite images and geo-processing tools, as well as meteorological data is important for forest managers when assessing the impacts of fire scars in different geographical and climatic contexts. The present study aimed at carrying out a detailed characterization of the edaphoclimatic conditions present in Governador Indigenous Territory (TI) located in the municipality of Amarante do Maranhão – Maranhão state, as well as analyzing the influence of those conditions on large fire scars, greater than 50 hectares (ha), and on fire danger indices between 2001 and 2018 at this location. Our hypothesis is that the conditions of climate, land use and land cover are determinant for the occurrence of large fires, and also that some fire danger indices should be more appropriated for the studied region.

MATERIAL AND METHODS

Study Area

The Governador TI was demarcated by Decree 88,001, of December 29, 1982 and is located in the municipality of Amarante do Maranhão, in the state of Maranhão (Figure 1). The TI covers an area of 42,000 hectares, with a population of 655 indigenous people (https://terrasindigenas.org.br/es/terras-indigenas/3672#demografia). According to Alvarez *et al*. (2013), the Koppen classification for the region is defined as Aw, with a dry tropical winter climate, an average annual rainfall of 1300 to 1600 mm, and an average annual temperature greater than 26°C. The average monthly rainfall, temperature and relative humidity data for the studied stations are presented in Figure 2.

The Governador TI is located in an ecotonal region between the Amazon and Cerrado, therefore it presents phytophysiognomies of ‘dense tropical submontane rainforest’, ‘seasonal forest-savanna contact region’, ‘wooded savanna’, ‘park savanna’, as well ‘pasture lands’ (IBGE, 2019). About 80% of the TI is mapped as savanna vegetation and the surroundings are predominantly covered by pasture (livestock).

The distribution of the predominant soils, adapted from IBGE (2019), is red–yellow argisol which covers the greatest portion of the Governador TI, 36.4%, followed by the ortic quartzarenic neosol covering 28.6%, which are both associated with ‘savanna’ formations, while the red-yellow latosol is associated with ‘dense tropical submontane rainforest’.

Burn Scars

The analysis of the burn scars on the Governador TI and surroundings was carried out using the images from Landsat 5 and 8 series as a reference, as well as the heat signals obtained from the INPE website (BDQueimadas) for the period from 2001 to 2018, which was used to optimize the finding of the burned scars. According to some authors, fires can be considered as large fires when they are larger than 100 ha (Ferreira-Leite *et al*. 2017) or even 500 ha (Piñol *et al*., 1998). In our study, we considered a higher range of large fires, selecting all scars larger than 50 ha, identified through information of the heat signal in the probable date of fire occurrence. Furthermore, the number of mapped scars, individualized in different polygons, was correlated with the average annual precipitation data, and the data were processed using the ArcGIS 10 program.

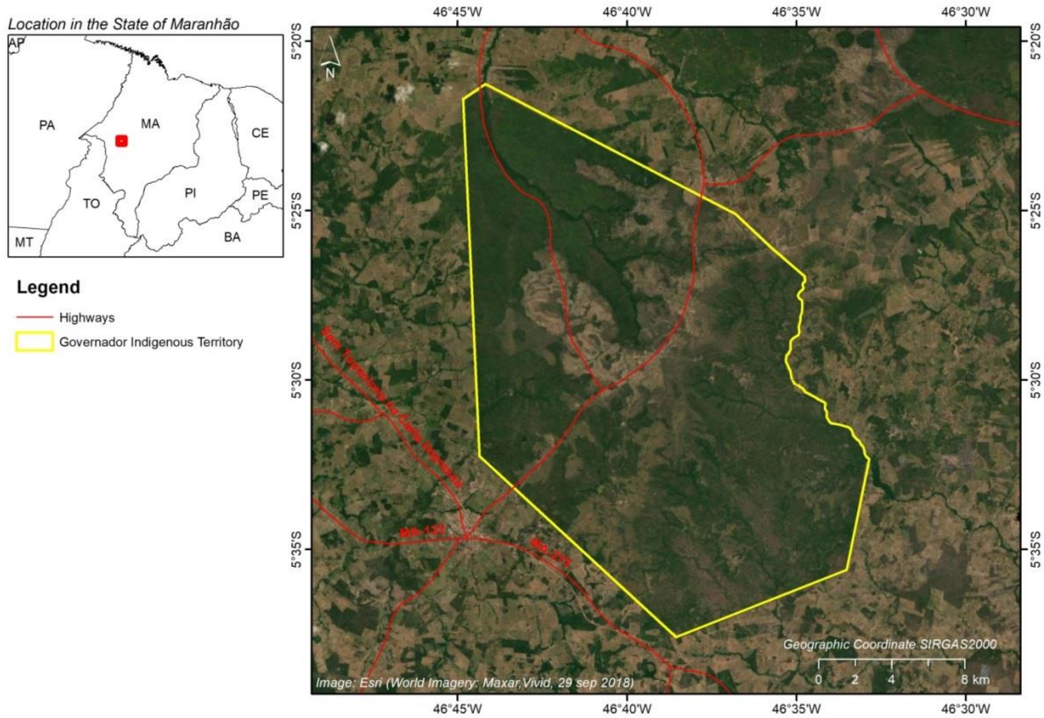

Figure 1. Location of the Governador Indigenous Territory in the state of Maranhão and its highways, with the satellite image visualization of the Vivid constellation of September 29, 2018 (Source: ESRI).

Figura 1. Localização da Terra Indígena no estado do Maranhão, rodovias e visualização de imagem de satélite da constelação Vivid de 29 de setembro de 2018 (Fonte: ESRI).

Calculation of fire danger indices

The data for the calculation of forest fire prediction indices were obtained from the meteorological stations closest to the study area, and due to the lack of data availability for the municipality of Amarante do Maranhão (MA state), the main station used was the station 82564, from the municipality of Imperatriz, 70 km away from the study site. Inaccuracies were detected in the years 2014, 2017 and 2018 in relative humidity and temperature data at the Imperatriz station, and for such situations, the data used were derived from the station 82765, in the municipality of Carolina, 155 km away from the TI.

From the probable date of fire occurrence and the information from the weather stations, the following fire danger indices were calculated for each burn scar, namely: Telicyn Logarithmic Index; Nesterov Index; Monte Alegre Formula (FMA) and Modified Monte Alegre Formula (FMA +); and the Canadian Forest Fire Weather Index (FWI). To calculate the Telicyn, Nesterov, FMA and FMA + indices, Excel spreadsheets were used, according to the equations presented in Torres *et al*. (2017). For the FWI, the *cffdrs* package (Wang *et al*., 2017) from the R program (R Core Team, 2020) was used. The intervals and degree of fire danger for each index studied are shown in Table 1. From all the data collected, it was producted crossings/intersections and interpretations of the environmental characterization data and afterwards graphs were generated along with basic statistics of the scars and their relationships with the edaphoclimatic conditions. The Shapiro Wilk test was applied to assess the normality of the data and then the Kruskal-Walli test was applied to assess whether there was a difference between the performance of each index through the R program (R Core Team, 2020). We considered as the best index related with large fires in this region the index with the higher percentage of number of burn scars in Very High class value days, showing a high success identification of fire risk.

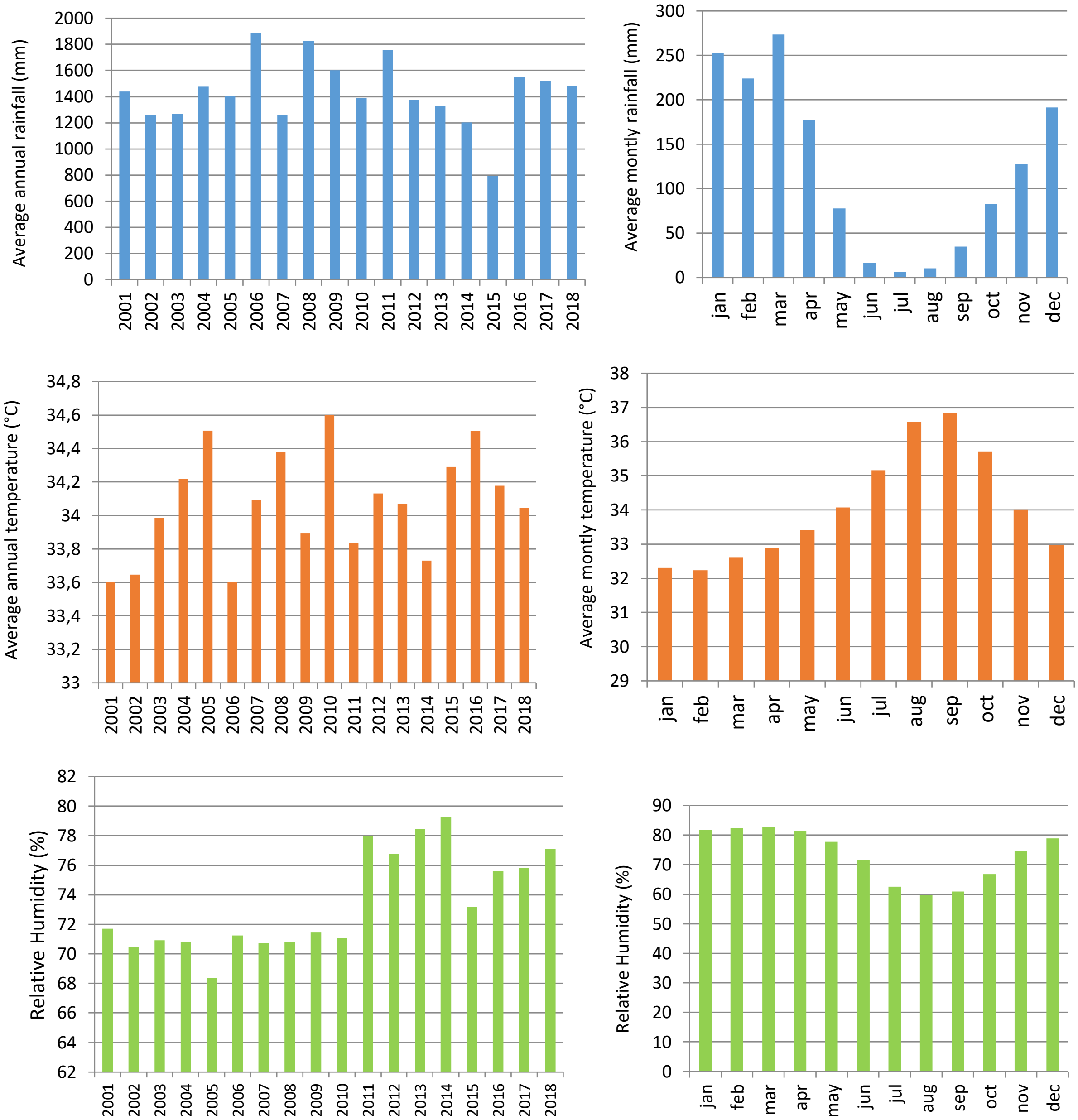

Figure 2. Average annual and monthly rainfall, temperature and relative humidity obtained from station 82564 and partially from station 82765 from the municipalities of Imperatriz and Carolina (MA state), respectively, from 2001 to 2018.

Figura 2. Precipitação, temperatura e umidade relativa média anual e méda mensal obtida das estações no. 82564 e partes da no. 82765 dos municípios de Imperatriz e Carolina (MA), respectivamente, durante o período de 2001 a 2018.

Table 1. Intervals and degree of fire danger, and climatic variables used for each index studied.
Tabela 1. Intervalos e grau de perigo de incêndio para cada índice estudado e as variáveis climáticas usadas em cada índice.

Index	None	Low	Medium	High	Very High	Climatic Variables	References
FMA	<1	1,1 a 3	3,1 a 8	8,1 a 20	>20	RH, P	Nunes *et al*. (2010) and Torres *et al*. (2017)
FMA+	<3	3,1 a 8	8,1 a 14	14,1 a 24	>24	RH, P, W	
Telicyn	<2	2,1 a 3,5	3,6 a 5	5 a 15	>15	T, RH, P	
Nesterov	<300	301 a 500	501 a 1000	1001 a 4000	>4000	T, RH, P	
FWI	0 a 1,9	2 a 4,9	5 a 8,9	9 a 16,9	>17	T, RH, P, W	Wang *et al*. (2017)

Legend: T: temperature (°C), RH: relative humidity (%), P: precipitation (mm/24 h),W: wind speed (m/s).

RESULTS

For the period studied (2001-2018), 107 burn scars larger than 50 ha were mapped. Figure 3 shows the scars mapped per each year and their areas in hectares. The years 2005 and 2010 were the ones with the largest burns (over 5,500 ha), while 2006 and 2018 were the years with smallest burned areas. 2006, 2008 and 2011 had the highest precipitation rates (Figure 2), approximately 1800 mm/year, and were also amongst the years with smallest burn scars. Meanwhile, 2005, 2010 and 2016 had the highest average annual temperatures (greater than 34.4 °C) (Figure 2) and presented large fire scars. The highest average annual relative humidity (RH) (above 76%) occurred from 2011 to 2014 (Figure 2) and from 2011 to 2013 no burn scar greater than 50 ha was recorded. On the other hand, 2005 had the lowest average annual RH (68.3%) and suffered one of the largest fire burns. Figure 4 illustrates the dispersion between the total number of scars and the average annual precipitation and RH with a negative correlation of R^2 0.37 and 0.11, respectively, and the average annual temperature with low positive correlation of R^2 0.12; indicating the higher importance of the rainfall variable.

Figure 5 shows the results of variation of the fire danger degree for all calculated indices (Table 1) for each burn scar studied. FMA obtained the greatest number of Very High Fire Danger predictions, followed by FMA+, Telicyn and FWI. Considering the large fires, associated with very high risks and greater than 50 ha, the FMA proved to be the most successful index.

The 107 mapped burn scars, larger than 50 ha, took place only in the months of June (27 scars), July (47 scars) and August (33 scars) in all years from 2001 to 2018 and coincide with the months presenting the lowest rate of monthly precipitation, less than 20 mm (Table 2 and Figure 2). From July to August, the relative humidity and the average monthly temperature also present low values and contribute to the greatest burn scars (Figure 2). Table 2 shows the number of scars separated by class of area and distributed in the months of June, July and August, where it can be noted that 50% of the mapped scars have between 50 to 100 ha, as well as the largest scars (> 300 ha) and number of scars occur in July.

Throughout the studied period (2001 to 2018), within Governador TI, 96% of the fire scars mapped were over the vegetation ‘park savanna’ with no gallery forest, the rest being in the other formations of ‘wooded savanna’ and only 0.1% in ‘rainforest’. When it comes to the soils, 89% of burn scars happened in ‘quartzarenic neosol’ while 5.5% of the scars took place in ‘red-yellow argisol’, and 4% happened in ‘red-yellow latosol’.

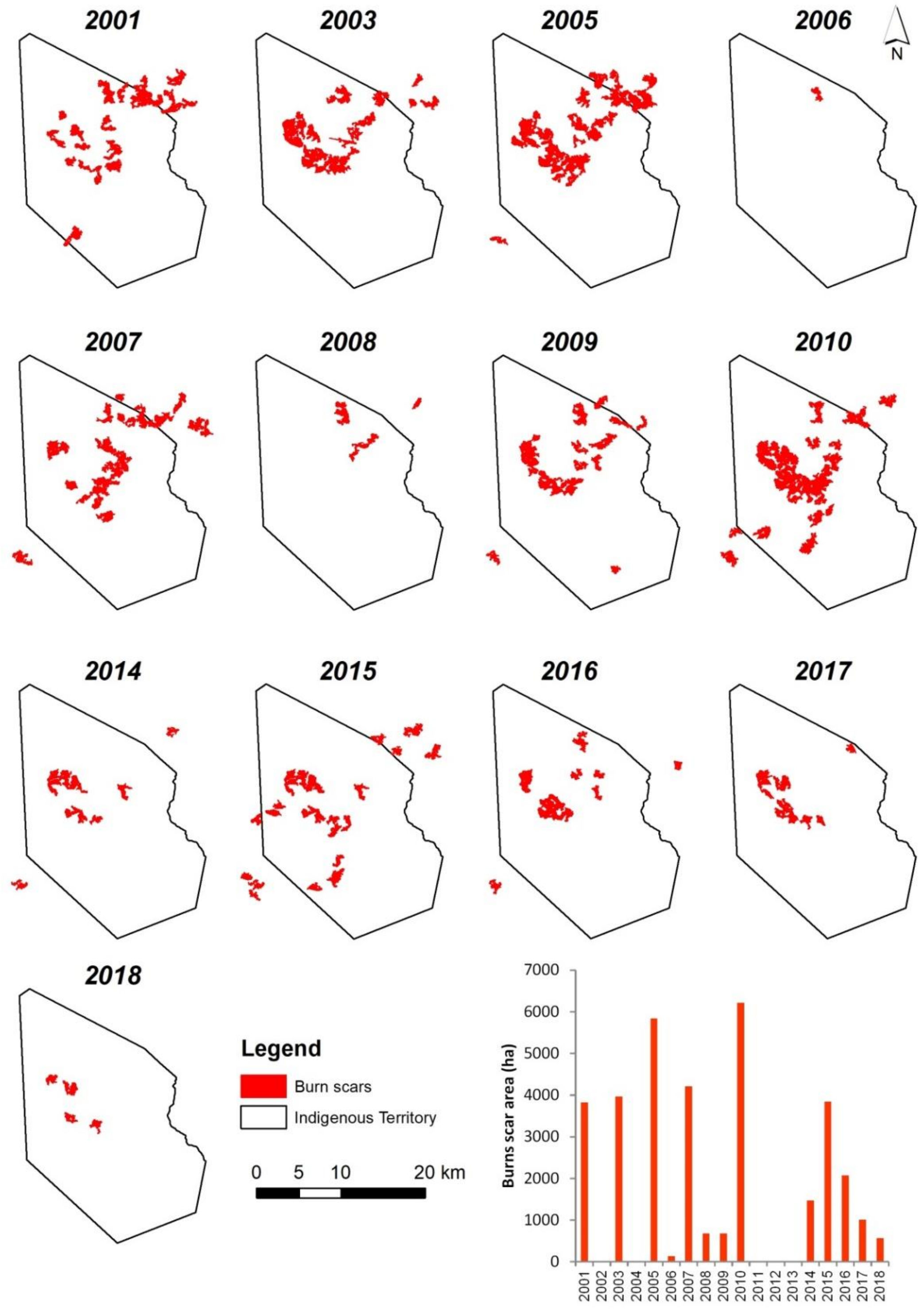

Figure 3. Burn scars larger than 50 ha for the period from 2001-2018 and their respective areas in hectares, at Governador TI.

Figura 3. Cicatrizes maiores que 50 ha para o período estudado (2001-2018) e a respectiva área em hectare, mapeadas na TI Governador.

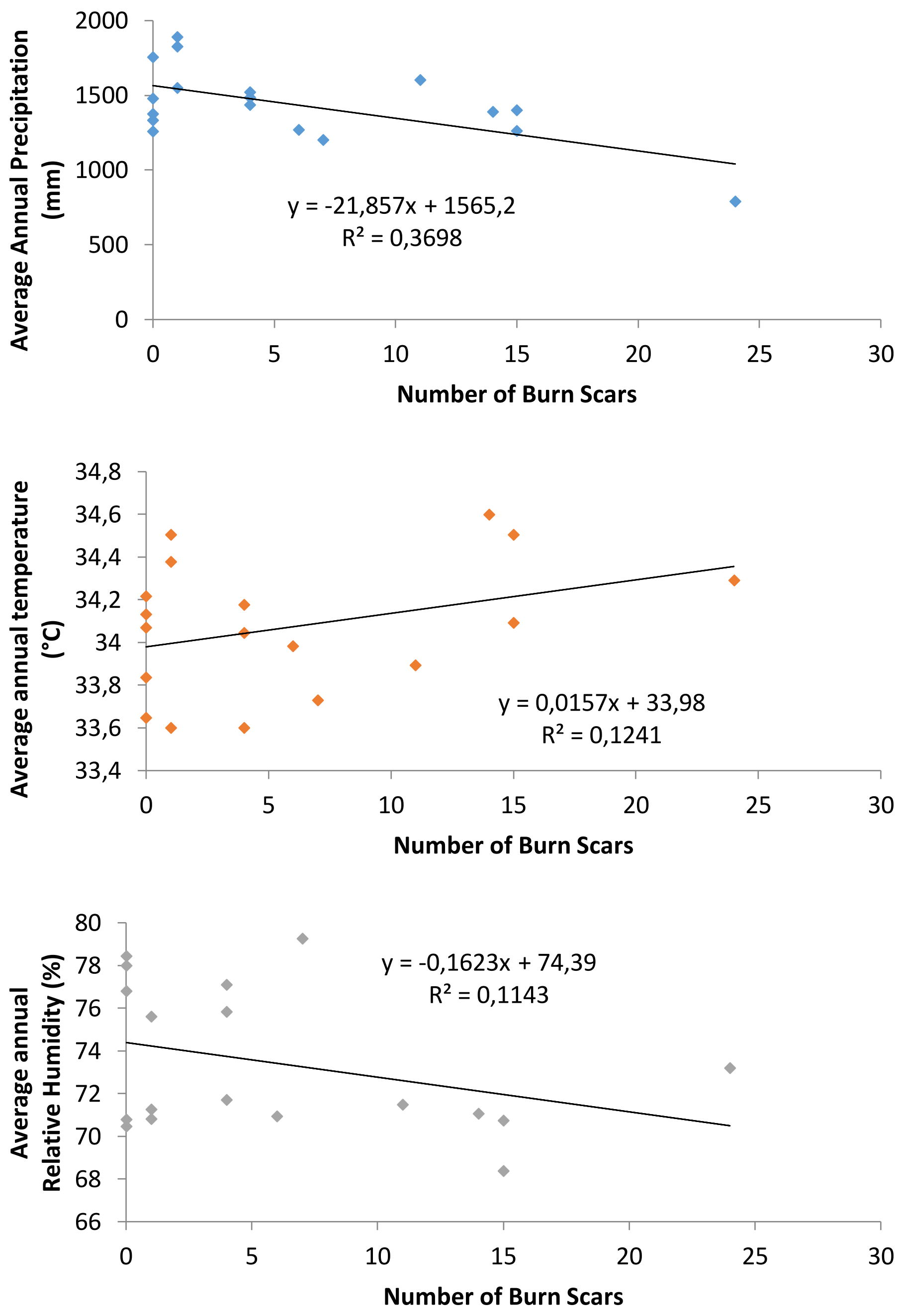

Figure 4. Dispersion graphs between the total number of scars mapped and the average annual precipitation, temperature and relative humidity.

Figura 4. Gráficos de dispersão entre o número total de cicatrizes mapeadas e a precipitação anual média, temperatura anual média e umidade relativa anual média.

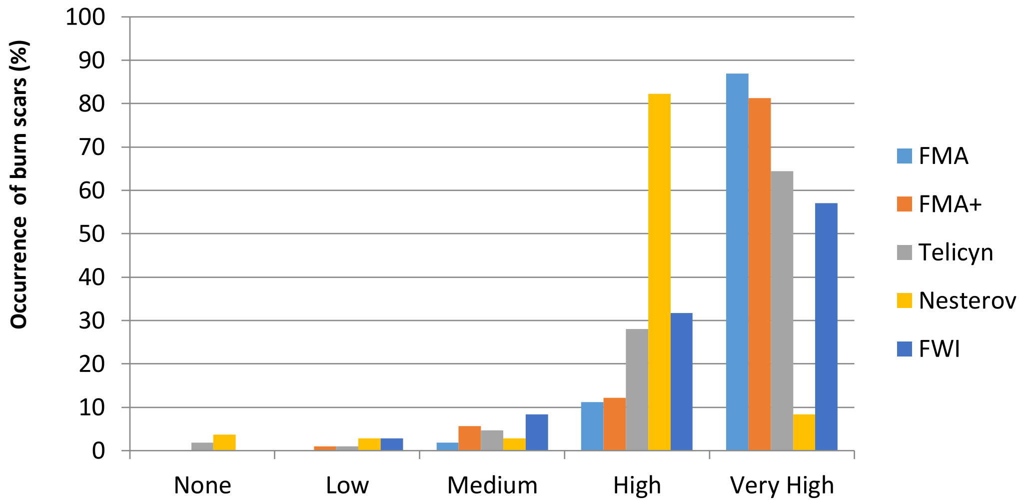

Figure 5. Degree of fire danger for each index mapped for percentage of burn scars at Governador TI.
Figura 5. Grau de perigo de incêndio para cada índice mapeados para a porcentagem de cicatrizes mapeadas na TI Governador.

Table 2. Classes of area and number of mapped large burn scars distributed in the months evaluated from 2001 to 2008 in Governador TI.
Tabela 2. Classes de área e número de cicatrizes mapeadas distribuídas nos meses avaliados no período de 2001 a 2008 na TI Governador.

Classes of Area (ha)	Jun	Jul	Aug	Total
50 - 100	16	20	17	53
100 - 150	5	7	5	17
150 - 200	3	7	8	18
200 - 250	2	2	-	4
250 - 300	-	-	1	1
300 - 350	-	1	-	1
350 - 500	1	7	2	10
> 500	-	3	-	3
Total	27	47	33	107

DISCUSSION

At Governador TI, 50% of the burn scars analyzed were larger than 100 ha and 3 scars were greater than 500 ha. In general, large fires are more favored by low precipitation, high temperatures and low relative humidity, all of which causing great risk of fire (Ferreira-Leite *et al*., 2017). Thus, the choice of appropriate fire danger indices for certain conditions is important for the management of these areas, in prescribed burning, public notifications and resource allocation (Torres *et al*., 2018). For the Governador TI region, the FMA obtained the best results, as well as observed in other Brazilian areas (Soriano *et al*., 2015).

In 2005 and 2010 the severe drought was related to an abnormal warming of the tropical North Atlantic Ocean surface (Marengo *et al*., 2011; Barbosa *et al*., 2019; Oliveira-Junior *et al*., 2020). Those years, together with 2015, stand out due to the occurrence of the ENSO phenomenon (El Niño-Southern Oscillation). These climatic events modify the behavior of the meteorological variables, highlighting the absence in rainfall, which have the highest impact in the presence of large burned scars.

The presence of roads inside the IT can favor access and facilitate illegal burning activities (Figure 1). Other anthropic factors, such as road distances and some current trends in decreasing agriculture and increasing idle areas, boost the likelihood of large fires (Moreira *et al*., 2010). Apart from that, shrub lands and pastures, low road density, and favorable climatic aspects, positively affect the occurrence of large fires (Ganteaume & Jappiot, 2013).

The negative correlation observed between the increase in rainfall and the decrease in large fire numbers, reveals a considerable increase in the risk of fires, since the scarcity of precipitation decreases the moisture content of the combustible material and increases leaf loss as a result of adaptation to water stress (Nepstad *et al*., 2004; Alencar *et al*., 2011). Fire danger indices are important tools to detect such risk and fire behavior conditions. Therefore, the more studies on the behavior of fire and its environmental relationships the better the predictions of dangerous situations and impacts of great magnitude (Linn *et al*., 2012). In general, the impacts of major fires in tropical regions may be even greater than the impacts on vegetations that are adapted to high-intensity fire regimes such as the forests of Australia, the coniferous forests of Yellowstone or the west coast of the USA (Adams, 2013). Therefore, new studies in different regions will provide important information that will mitigate the harmful effects of forest fires (Torres *et al*., 2017).

CONCLUSION

- The results achieved indicate that the Governador TI region is a critical area in terms of forest fires, with large impacted areas and climatic conditions with great fire danger. In addition, savanna formations, which predominate in the region, are highly prone to fires, as well as pastures in the surroundings.
- The Monte Alegre Formula index stands out with the best results, as well as the great correlation with climate and vegetation data, highlighting the period from June to August and savanna formations, as the most critical conditions.

ACKNOWLEDGMENT

We thank the ‘Conselho Nacional de Desenvolvimento Científico e Tecnológico’ (CNPq) for the financial support and scholarship of the first author and the support from the ‘Coordenação de Aperfeiçoamento de Pessoal de Nível Superior’ - Brazil (Capes) - Financing Code: 001.

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