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FIRES IN BRAZILIAN BIOMES

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Abstract

Increasingly, forest fires are occurring in large parts of the world due to warmer weather, more frequent and severe droughts and continuous changes in land use. In Brazil, the weakening of environmental public policies has further aggravated forest fires with widespread impacts throughout the country. This study aimed to evaluate the association between short-term variations in fire focis by precipitation, temperature in biomes in the state of Mato Grosso do Sul (MS) – Midwest Brazil. Generalized additive negative binomial regression models with distributed nonlinear lag terms were adjusted with daily counts of fire focis as results and total daily precipitation and other meteorological variables as predictors, adjusting for seasonality and trend. In general, higher precipitation was associated with fewer fire focis, with higher relative risks for the cerrado biome for the dry cutting and for higher temperatures the number of fire focis with higher relative risk for the pantanal biome. Stronger associations were observed in dry cutting (winter/spring). It was found that higher temperatures are associated with more fire focis. Fire focis are strongly associated with precipitation and temperature variation, but in opposite directions. Higher precipitation can become more clearly associated with fewer fire focis and higher temperature to more fire focis. If we maintain the burning culture to clear pastures and planting areas, the burnings will become increasingly uncontrollable.

Keywords: Hot Spots, Precipitation, Temperature, Weather, Risk Assessement, Regression Models, Fire Foci, Burned Area.

Resumo / Resumen

QUEIMADAS EM BIOMAS BRASILEIROS

Cada vez mais, incêndios florestais estão ocorrendo em grandes partes do mundo devido ao clima mais quente, secas mais frequentes e severas e mudanças contínuas no uso da terra. No Brasil, o enfraquecimento das políticas públicas ambientais tem agravado ainda mais os incêndios florestais com impactos generalizados em todo o país. Este estudo teve como objetivo avaliar a associação entre variações de curto prazo em focos de incêndio por precipitação, temperatura em biomas no estado de Mato Grosso do Sul (MS) – Centro-Oeste do Brasil. Modelos de regressão binomial negativo aditivo generalizado com termos de defasagem não lineares distribuídos foram ajustados com contagens diárias de focos de incêndio como resultados e precipitação diária total e outras variáveis meteorológicas como preditores, ajustando para sazonalidade e tendência. Em geral, maior precipitação foi associada a menos focos de fogo, com maiores riscos relativos para o bioma cerrado para o corte seco e para temperaturas mais altas o número de focos de fogo com maior risco relativo para o bioma Pantanal. Associações mais fortes foram observadas no corte seco (inverno/primavera). Verificou-se que temperaturas mais altas estão associadas a mais focos de incêndio. Os focos de incêndio estão fortemente associados à precipitação e variação de temperatura, mas em direções opostas. Precipitações mais altas podem se tornar mais claramente associadas a menos focos de incêndio e temperaturas mais altas a mais focos de incêndio. Se mantivermos a cultura das queimadas para limpar pastagens e áreas de plantio, as queimadas se tornarão cada vez mais incontroláveis.

Palavras-chave: Focos de Calor, Precipitação, Temperatura, Clima, Avaliação De Risco, Modelos De Regressão, Focos de Incêndio, Área Queimada.

INCENDIOS EN BIOMAS BRASILEÑOS

Cada vez más, los incendios forestales están causando estragos en gran parte del mundo debido al clima más cálido, las sequías más frecuentes y severas y los continuos cambios en el uso de la tierra. En Brasil, el debilitamiento de las políticas públicas ambientales ha agravado aún más los incendios forestales con impactos generalizados en todo el país. Este estudio tuvo como objetivo evaluar la asociación entre las variaciones a corto plazo en los brotes de incendios por precipitación, temperatura en biomas en el estado de Mato Grosso do Sul (MS) - Medio Oeste de Brasil. Se ajustaron modelos de regresión binomial aditivos negativos generalizados con términos de retardo no lineal distribuidos con recuentos diarios de brotes de incendios como resultados y precipitación diaria total y otras variables meteorológicas como predictores, ajustando por estacionalidad y tendencia. En general, mayor precipitación se asoció con menor número de focos de incendios, con mayor riesgo relativo para el bioma del cerrado por corte seco y para temperaturas más altas el número de focos de incendios con mayor riesgo relativo para el bioma Pantanal. Se observaron asociaciones más fuertes en el corte seco (invierno/primavera). Se encontró que las temperaturas más altas están asociadas con más incendios. Los incendios están fuertemente asociados con la precipitación y la variación de temperatura, pero en direcciones opuestas. Las precipitaciones más altas pueden asociarse más claramente con menos incendios y las temperaturas más altas con más incendios. Si mantenemos la cultura de la quema para limpiar los pastos y las áreas de siembra, las quemas se volverán cada vez más incontrolables.

Palabras-clave: Puntos Calientes, Precipitación, Temperatura, Clima, Evaluación de Riesgos, Modelos de Regresión, Focos de Incendio, Área Quemada.

INTRODUCTION

There are many factors that influence the occurrence of forest fires in terms of ignition and fire behavior, including climate, vegetation (or land cover), topography, human activity (Wu et al. 2014), and soil texture (Pradhan et al. 2007; Pourtaghi et al. 2016). Climate is certainly one of the main agents responsible for fire ignition, while average annual temperature and precipitation are commonly used as climatic variables for fire regimes, as they are the main parameters that control the moisture content of the fuel and the general characteristics of weather conditions (Xystrakis and Koutsias 2013; Wu et al. 2014). In fact, an important variation in air temperature can affect the severity and frequency of forest fires and, together with the modification of soil moisture induced by precipitation variation (Bui et al. 2017), can further alter the behavior of the fire. Climate projections for future scenarios have shown an increase in global temperature and a higher frequency of extreme climatic events (Oliveira-Júnior et al. 2021), e.g. storms, which could further aggravate the current Forest Fire Risk (FFR) – (Busico et al. 2019). In fact, for certain regions, extreme weather events have shown great impact on forest fire activity (Tian et al. 2013). The type of vegetation, as type of soil cover, has been shown especially relevant as an influence factor in fire ignition, along with the climatic variables (Saura-Mas et al. 2010; Carmo et al. 2011; Price and Bradstock 2014). The topography, in terms of elevation, slope and aspect, directly influences the composition of vegetation and the structure of the fuel and often determines where and why fires will occur and spread (Wu et al. 2014). Topography is an important factor influencing fire ignition and behavior. In fact, the slope is the primary factor for the progression of fire because it will define the speed of the fire. The fire will spread faster if the slope is sharper (Lentile et al. 2006). Thus, elevation is the main parameter that influences precipitation, temperature, humidity and evapotranspiration (Verde and Zêzere 2010). As for the aspect, it influences soil moisture and wind speed, which are strongly linked to the behavior of fire (Schmidt et al. 2008). In addition, human activities can directly affect fires in terms of ignition or suppression (Liu et al. 2012; Zumbrunnen et al. 2012), and may indirectly induce changes in the occurrence of fires, modifying the spatial pattern of vegetation (Wu et al. 2014). The latter is also correlated with the spatial distribution and density of fires (Sirca et al. 2017).

Brazil holds the highest frequency of fire in South America (SA) - (Li et al. 2020; Oliveira Júnior et al. 2021). Among the Brazilian biomes, the Cerrado is the only one whose ecosystems have evolved associated with fire, which plays an important role as an ecological process (Schmidt and Eloy 2020). However, large fires have historically devastated vast areas, not only in the Cerrado, but also in the Amazon (Schmidt and Eloy 2020) and in the Pantanal (Libonati et al. 2020). These three biomes recorded large fires during the dry seasons of 2019 and 2020, although for the Amazon, those dry seasons were not as exceptional as in the droughts of 2005, 2010, and 2015 (Libonati et al. 2020; Schmidt and Eloy 2020). In 2019, for the first time on record, the smoke from the forest fires in the Amazon reached São Paulo, the largest city in SA, more than 2.7 thousand kilometers to the southeast of the burned regions. And in 2020, one third of the Pantanal biome was burned (Libonati et al. 2020; Schmidt and Eloy 2020).

In this study, it aimed to explore the relationship between hot spots and climatological variables. It also examined whether the relationship between hot spots and climatological variables was non-linear.

METHODOLOGY

STUDY REGION

The study was carried out throughout the Brazilian territory, which has 8,516,000 km², analyzing the three Brazilian biomes: i) Cerrado, ii) Atlantic Forest and iii) Pantanal (IBGE 2004), which have their spatial distribution represented in Fig. 1, each with its scope out the territory, its specific physiognomies, and its own characteristics.

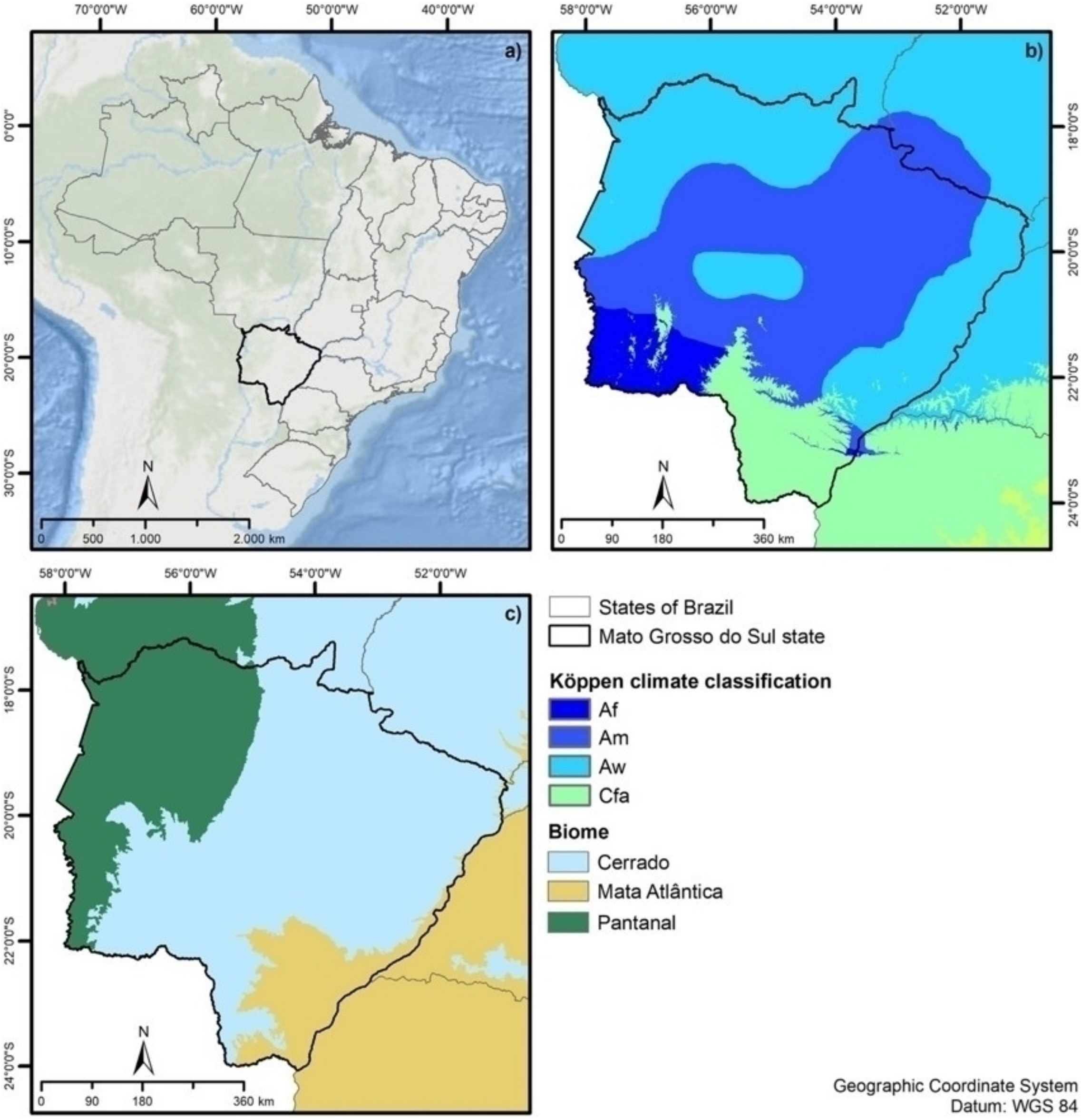

Figure 1 - Location of the state of Mato Grosso do Sul (Brazil) in South America (a), distribution of the climate Köppen types (Af, Am, Aw, and Cfa) (b) and biomes of Pantanal (wetland), Cerrado (savanna), and Atlantic Forest (c). Aw = tropical zone with winter; Am = tropical monsoon zone; Af = tropical zone without dry season; and Cfa = Humid subtropical zone with hot summer. Source: Abreu et al. (2022).

The Cerrado occupies an area of 2,036,448 Km2, about 22% of the national territory, being the second largest biome in SA (MMA 2022), being observed in the North, Northeast, Southeast and Midwest regions. It is formed by the physiognomies of: Campo Limpo, Campo Sujo, Campo Rupestre, Cerrado, Cerradão, Matas Secas, Ciliares and galeria, and Veredas (EMBRAPA 2018).

The Atlantic Forest is distributed along almost the entire Atlantic continental strip east of the country and originally occupied more than 1.3 million km² in 17 states of The Brazilian territory, but currently there are about 29% of its original coverage. It is composed of: Dense Ombrófila Forest; Mixed Anthropophilic Forest; Open Ombrófila Forest; Semidecidual Seasonal Forest; and Decidual Seasonal Forest, and associated ecosystems (mangroves, restinga vegetation, altitude fields, inland swamps and forest encraves of the Northeast) (MMA 2022a).

The Pantanal is considered one of the largest continuous wet expanses of the planet, despite being the smallest in Brazil, occupying 1.76% of the total area of the territory. This biome is directly influenced by three important Brazilian biomes: Amazon, Cerrado and Atlantic Forest, and because it is an alluvial plain is also influenced by rivers that drain the Upper Paraguay basin, and by the Chaco biome (denomination given to the Pantanal located in northern Paraguay and eastern Bolivia) (MMA 2018a).

Data collection

The meteorological variables analyzed were extracted from the geographic information system of the meteorological database of the National Institute of Meteorology (INMET) from 1999 to 2021.

Fire Focis

Data from the environmental variable number of foci were obtained from the Imaging Division (DGI) of the National Institute of Space Research (INPE), which collects and processes the reference satellite images of the National Oceanic Atmospheric Administration (NOAA-12) and the National Aeronautics and Space Administration - NASA AQUA, respectively using the Advanced Very High-Resolution Radiometer (AVHRR) and Moderate Resolution Spectroradiometer (MODIS) sensors.

Data Analysis

A quasi-Poisson regression model with a non-linear distributed delay model (DLNM) was used to examine the effects of hot spots on climatological variables. The quasi-Poisson function has the ability to capture over dispersion presented in the data (Souza et al. 2014).

The DLNM allows nonlinear exposure and delay functions to be modeled simultaneously in a very flexible way (Gasparrini and Armstrong 2010; Hardin and Hilbe 2011; Souza et al. 2014). To examine the non-linear relationship of hot spots and climate variables, a DLNM was used for hot spots with 5 natural cubic spline degrees of freedom and 4 natural cubic spline degrees of freedom was used for diary delays. We control temperature, precipitation using a DLNM with 5 natural cubic degrees of freedom for exposure (temperature and rainfall) and 4 natural cubic degrees of freedom spline. We control the day of the week using the category variable. We control for seasonality and long-term trend using the natural cubic spline with 7 degrees of freedom per year for time (Hardin and Hilbe 2011).

Results

There was a variation from 52,491 fire focis (maximum value) to 235 fire focis (minimum value) with average of 5,931, the average rainfall variation was 119 mm and the temperature of 31oC for the Cerrado biome during the study period (Table 1). There was a variation of 7,170 fire focis (maximum value) to 187 fire focis (minimum value) with an average of 1,490, the average rainfall variation was 122 mm and the temperature of 24oC for the Atlantic Forest biome during the study period (Table 1).

There was a variation from 8,106 fire focis (maximum value) to 2 fire focis (minimum value with an average of 568, the average rainfall variation was 96 mm and the temperature of 31ºC for the Pantanal biome during the study period (Table 1). Fig. 1 shows the time series of hot, rain, and average temperature outbreaks. The fire focis showed a seasonal trend, with higher concentration in winter and spring.

Among the Brazilian biomes, the Cerrado presented the highest number of fire focis throughout the historical series analyzed, with values higher than 20,000 fire focis for 2007, 2010, 2012, 2017, 2019, 2020 for the Atlantic Forest in the years 2005, 2007, 2011 fire focis were higher than 6,000, and for the Pantanal in the years 2005, 2007, 2020 were higher than 5,500 fire focis (Fig. 2). During this period, the other biomes also had a high record, with the highest annual number for the sequence of years analyzed.

Fig 2. Time series of precipitation (mm), average temperature (°C) and fires in biomes during 2005-2020.

There is an annual oscillation in all biomes, with years with additions and others with decreases throughout the time series analyzed, the highest peaks as can be observed were in 2010 for the Cerrado, 2011 for the Atlantic Forest and 2020 for the Pantanal. The descriptive analysis of the data can be observed in Table 1, in which the minimum (Min), maximum (Max), mean and standard deviation (SD), variance, asymmetry and curtosis are presented for the number of fire foci used in statistical modeling. In view of this table, it is verified that all biomes present positive asymmetry.

	Cerrado	Pantanal	Atlantic Forest
	RR-CI	RR-CI	RR-CI
lag 0	1.0035; (0.9758 - 1.0321)	1.0153; (0.9850 - 1.0466)	0.9775; (0.9465 - 1.0095)
lag 1	1.0128; (0.9989 - 1.0270)	1.0191; (1.0039 - 1.0345)	0.9921; (0.9764 - 1.0080)
lag 2	1.0119; (1.0046 - 1.0336)	1.0211; (1.0056 - 1.0369)	1.0031; (0.9868 - 1.0196)
lag 3	**1.0209; (1.0056 - 1.0365)**	**1.0209; (1.0043 - 1.0376)**	**1.0115; (0.9970 - 1.0263)**
lag 4	1.0196; (1.0068 - 1.0325)	1.0189; (1.0051 - 1.0328)	1.0092; (0.9918 -1.0269)
lag 5	1.0160; (1.0021 - 1.0302)	1.0157; (1.0006 - 1.0310)	1.0113; (0.9954 - 1.0274)
lag 6	1.0114; (0.9883 - 1.0352)	1.0120; (0.9870 - 1.0376)	1.0097; (0.9832 - 1.0369)

Table 1 - Descriptive analysis of the number of outbreaks of fires for the three biomes of Brazil, from January 1999 to December 2021.

Biomes	Variables	All years	Dry seasons	Rain seasons
		RR-CI	RR-CI	RR-CI
Cerrado	Rainfall	0.9891(0.9396-1.0385)	**1.0014(0.9513-1.0515)**	0.9908(0.9413-1.0404)
	Temperature	1.1736(1.1148-1.2322)	**1.5968(1.5170-1.6766)**	1.2068(1.1465-1.2672)
Atlantic Forest	Rainfall	0.9945(0.9448-1.0443)	**1.0012(0.9511-1.0513)**	0.9942(0.9445-1.0439)
	Temperature	1.0323(0.9807-1.0839)	**1.1782(1.1193-1.1782)**	1.1354(1.0786-1.1922)
Pantanal	Rainfall	0.9839(0.9347-1.0331)	**0.9933(0.9437-1.0430)**	0.9798(0. 9308-1.0288)
	Temperature	1.0492(1.2887-1.4796)	**1.6177(1.5368-1.6986)**	1.4391(1.3671-1.1510)

Table 2 - Estimated relative risks (RR) corresponding to biomes for all years and by dry and rainy season at the 75th percentile compared to the 25th percentile.

Table 2 shows the relative risks of hospitalizations in the 75% percentile of Fire Focis compared to the 25% percentile over the days of delay. The results show that the effects of Fire Focis were delayed by two days and lasted four days.

	Variable	Mean	StDev	Variance	Median	Skewness	Kurtosis
Cerrado	Fire focis	6141	9040	8E+07	2345	2,81	9,6
	Rainc	119,54	78,48	6158,9	117,68	0,42	-0,47
	Tc	31,308	3,36	11,289	31,704	-0,14	-0,42
Atlantic Forest	FCma	1491	1560	2E+06	728	1,74	2,48
	Rainma	122,09	72,1	5198,4	123,85	0,52	0,22
	Tma	29,493	3,908	15,273	30,576	-0,4	-0,69
Pantanal	Fcp	568,1	1071,9	1E+06	186	4,07	20,4
	Rainp	96,06	69,09	4773,1	89,38	0,64	-0,22
	Tp	31,136	3,225	10,401	31,069	0,08	-0,66

Table 3 - Relative Risk (RR) of Hotspots at the 75th percentile of climate variables compared to the 25th percentile across days in the three biomes in Mato Grosso do Sul, Brazil during 1999-2021.

The three-dimensional graphs show the entire surface between temperature and rainfall and fires on all days of delay (Figure 1). The estimated effects of temperature and rainfall were non-linear for all fires, with greater relative risks at high temperatures and low precipitation. For example, extreme temperature (30°C) was positively associated with fires. Neither heat effects (i.e., significant increases in hot spots associated with warm temperatures) nor rainfall effects (i.e., significant increases in hot spots associated with temperatures and small amounts of rainfall) were apparent after an interval of 20 days, with relative risks close to 1 across the range of temperatures and low rainfall for the Cerrado, Atlantic Forest and Pantanal biomes.

Figure 1 Relative risks of fires by temperature (°C) and precipitation (mm), using a natural cubic spline–natural cubic spline DLNM with natural cubic spline of 5 degrees of freedom for temperature and precipitation and 4 degrees of freedom for lags for the Cerrado, Atlantic Forest and Pantanal biomes.

To conclude this section, we ask whether the notions presented in the texts examined (social movements, urban social movements; popular movements; mass movements; demanding movements; protest movements; urban struggles; social activisms; social conflicts and urban revolution; and "occupations") produced in different contexts, different temporalities and different disciplines, were dealing with the same issues. Another challenge, and even more important, is to bring this discussion to other temporal contexts in Historical Geography.

DISCUSSION

The aim of this study was to examine the effects of climatic variables on fire focis in three biomes of Mato Grosso do Sul - Midwest, Brazil during 1999-2021. We found that the relationship between fire focis and climatic variables were not linear. The magnitude of the association of fire focis and climatic variables was similar to studies conducted by Abreu et al. (2022), which investigated the frequency of fires and performed a trend analysis for monthly, seasonal and annual fires in three different biomes: Cerrado, Pantanal and Atlantic Forest. Using burned area and integrated models at different scales (interannual, intraseasonal and monthly) using probability density functions (PDFs). The best fit was found for the distribution of Generalized Extreme Values (GEV) in all three biomes of the various PDFs tested. It found most of the fire in the Pantanal (wetlands), followed by the Cerrado (Brazilian Savannah) and Atlantic Forest (Semidecidual Forest). The findings indicated that trends in land use and land cover have changed over the years. There was a strong correlation between fire and agricultural areas, with growing trends pointing to the conversion of land to agricultural areas in all biomes. The high probability of fire indicates that the expansion of agricultural areas through the conversion of natural biomes impacts several natural ecosystems, transforming land use and land cover (LULC) – (Fortin and DeBlois 2007; Oliveira-Júnior et al. 2020). This land conversion is promoting more fires every year.

The climatic variable lag effect is also considered a critical factor in fire focis estimates. This study applied the DLNM to calculate the nonlinear association and cumulative risks in days of delay for fire focis. The results allow greater flexibility when presenting a nonlinear curve of exposure-response to fire focis.

The largest burned areas occur in the dry season, especially in the middle of this season. This relationship occurs because the prevailing climatic conditions in ecosystems or arid moments are generally more favorable to the spread of fire, although they have less combustible material, while the reverse is limited by humidity conditions.

Thus, another factor to be considered in the study of fire pattern is the characteristic of different plant typologies, since the pattern of distribution of its burning is associated with the combustible material as its load and structure, being the vegetation more susceptible to fire. In addition, one should consider the influence of anthropic activities in these events, because even the fire caused by the climatic condition can be intensified by land use, since the anthropic action is caused by the use of fire in the burning of forests or management of agricultural crops pastures. In addition to the relationship between the type and vegetation conditions in the dispersion of the fire, other characteristics can also influence this process, such as: topography, event history and the climate itself need to be taken into account to define effective management strategies, especially in Conservational Units.

Therefore, it is necessary to apply a clear National Policy for fire fighting management and conservation strategies, such as: inclusion of fire in the management plans of protected areas, training for the planning and application of fire in vegetation, government promotion for research and experimentation in fires, and even with the dissemination of the benefits of fire for environmental conservation Cerrado (Durigan and Ratter 2016).

The meteorological variables that most favor the occurrence of foci according to the analysis of change for application of the methods are temperature, which affected the state of vegetation raising the internal temperature of plant tissues, dissecting it and awaiting emission and flammability.

Precipitation is the predictive factor that most contributes to the burning process. Being a component inversely proportional to the number of foci, it is directly related to low rainfall, becoming a decisive factor for the occurrence of forest fires, as it affects the vegetation in terms of humidity and oxygen availability in the plant, favoring the conditions that stimulate the combustion process.

In general, the highest foci values correspond to the lowest precipitation values (relative humidity), evidencing the inversion between these two variables, as can be observed for the months of August/September/October. The low precipitation values (relative humidity) directly influence the vegetation, making it drier, which facilitates the increase of combustible material and consequently susceptibility to the combustion process. The peaks of outbreaks occurred in August and September in the dry season.

The maximum average temperature was 39°C and it can be observed that for the highest temperatures the number of foci is higher, such as August and September. The temperature is significant with the number of foci but must be associated with the low relative humidity factor so that it is significant within the models, because if the temperature is high and the relative humidity is also high, there may be a decrease in the number of fire focis.

Alves et al. (2021) investigated the relationship of meteorological variables, wind speed, temperature, air humidity and others observed with fire focis in the Caatinga biome area, based on the historical series of fire focis 2002-2018, collected from the INPE database. It also analyzed the monthly and seasonal characteristics of hot spots in the Caatinga biome for the composition of El Niño, La Niña and neutral years in the Tropical Pacific and with types of southern Sea Surface Temperature gradients (SSTs) in the Tropical Atlantic. Using a quantitative methodology, a monthly fire risk index (FRI) was calculated. Through data analysis and realization through the proposed methodology and enabling the achievement of the results, a profile of the characteristics of the fire focis recorded in the Caatinga biome in monthly and seasonal periods (seasons) and its interannual variability (2002-2018) was identified. It should be noted that the results did not imply the insignificance of wind speed or air temperature on the surface over hot spots. The results also inferred, due to the importance of the influence of meteorological elements on the humidity of the combustible material. According to Nunes et al. (2015), the moisture of the combustible material expresses the percentage of water it contains, in relation to its dry weight, also stated that atmospheric humidity is a decisive element in forest fires, having a direct effect on the flammability of forest fuels. The dry period (July to December) showed the highest number of fires and fire focis in the Caatinga biome. Weather conditions and fires maintain a close relationship, from the probability of fires occurring due to atmospheric conditions in a given period, to the maintenance and spread of fire (Torres et al. 2010).

Viganó et al. (2018) evaluated the occurrences of fires in the Pantanal South-Mato-Grossense, associated with meteorological variables and performed a predictive modeling based on multivariate data analysis techniques, observed that temperature, relative humidity and solar radiation, are closely related to the occurrence of fire focis and the resulting correlations were satisfactory for the application of the forecast modeling.

This study investigated the associations between fire focis and precipitation, temperature in the biomes of the state of Mato Grosso does Sul (Pantanal, Atlantic Forest and Cerrado). Generally, higher precipitation was associated with fewer fire focis, more fire focis by high temperatures. When the analysis was stratified by season, there was a higher risk of fire focis with residual rain than without rain in winter, but not in summer. Above rainfall, the negative association was considerably stronger during the winter, with a relatively lower risk of rain than a summer risk. In addition, the association of extreme precipitation with fire focis in winter persisted for longer than the duration of the analysis throughout the year or in the summer. For fire focis, the exposure-response association was stronger in the summer than in the winter. However, the response-lag association was not significantly influenced by seasonal modification. Temperatures above 20°C were associated with less fire focis.

The findings of the present study strengthened the existing evidence stout evaluating the comprehensive exposure-lag-response association between fire focis, the group most susceptible to fire focis in the dry cutting. In addition, a higher volume of rain could increase the humidity of the environment, which could probably interrupt the increase in fire focis, since a higher HR and' less favorable for an increase in fire focis.

Although fire focis was more common in winter/spring, when precipitation was lower (beginning of the dry season), we still found that higher precipitation was associated with less HR after seasonality and the long-term trend was accounted for, both in annual and seasonal analyses. This suggests that the strong seasonality of fire focis may mask the real effect of climatic variations.

As a result of higher temperatures and reduced rainfall, a greater water deficit would be expected, particularly in the central and eastern parts of the biomes during spring and summer. The largest anomalies projected for the dry season months (June to August) are due to relatively low precipitation rates during those months. However, the dispersion between the results of the model projections is considerably greater both in the period of low rainfall and in the rainy season. In addition, more extreme floods and droughts are expected (Marengo et al. 2021).

There are fewer forest fires in dense vegetation cover. The vegetation cover affects the fire affecting the temperature of the fine fuel on the underlying surface. In areas with high vegetation cover, the surface temperature is low, which makes it difficult to evaporate soil moisture, leading to a high moisture content of the fuel, which is not easy to burn (Gabban et al. 2008). Even if the vegetation cover is dense and accompanied by more human settlements, a low level of fire density is likely to occur (Lampin-Maillet et al. 2010).

Meteorological factors have a significant impact on forest fires and their spatial heterogeneity is quite explicit. There are more fires in areas with lower rainfall, high temperatures and relative humidity. Our results shows that temperature has a significant positive impact on the occurrence of fires, which is also supported by others (Liu et al. 2012; Hu and Zhou, 2014). The temperature changes will bring about changes in fuel humidity, which will have an impact on forest fires. However, the positive relationship between relative humidity and the probability of fires may sound opposite to people's expectations. One explanation is that relative humidity has no direct impact on the occurrence of fires, but affects forest fires by affecting the growth of forest vegetation. Higher RH is beneficial for the growth of soil cover, which further increases the fuel load. The amount of surface fuel load aggravates the occurrence of forest fires if exposed to high temperature and low rainfall situations, resulting in a positive relationship between forest fires and relative humidity (Guo et al. 2016).

To model a count response variable, people usually start with a Poisson regression, which, however, is criticized for its restrictive assumption of average equality and variance and the underestimation of standard errors of poisson regression model coefficients due to excessive dispersion. A better alternative to correct this superdispersion problem is to use negative Binomial regression, because the negative Binomial distribution automatically creates a scatter parameter in its distribution function so that the estimation of both model coefficients and its standard errors are corrected for overdispersion in the data (McCulloch and Searle 2001; Myers et al. 2002). In this study, the observed mean of forest fire counts and variance can be observed in (Table 1), revealing the problem of overdispersion in the data.

High evaporation can contribute to an increase in the number of fire danger days (Zhu et al. 2007). However, the relationship between evaporation and fire occurrence is negative. This can be explained because evaporation depends on a complex form with three main factors of temperature, humidity and wind; the influence of any of which can be compensated by a pronounced change in one or both of the other two (Munns 1921). In a warmer climate, the general occurrence of fires is likely to be higher as a result of the increase in temperature (Lv and Yang 2011).

Although the Poisson model is the simplest counting data model, it is highly restrictive because the variance of the result is assumed to be equal to its expectation count datasets always display overscattering. The NB distribution offers a scatter parameter that explains well the overdispersion of positive count data (MacNeil et al. 2009).

It should also be noted that the prediction of the occurrence of forest fires is a complex issue in relation to climate, tree species, geographical conditions and human activities. Non-meteorological factors can also play a considerable role in the occurrence of fires. For example, the spread of fire can be influenced by topography, forest vegetation (fuel distribution) and ignition rates by humans (Pyne et al. 1966; Conederaa and Tinner, 2000). Among non-climatic factors, human activities in particular increase the likelihood of fires occurring. These include human demographic patterns and activities, especially land use and fire management (Chuvieco et al. 2008; Zumbrunnen et al. 2008). Humans can also indirectly promote or contain fires, for example, by modifying landscape patterns, forest composition, or fuel quantities. Substantial changes in the frequency of fires have also been associated with changes in human population densities (Keeley and Fotheringham 2001; Wallenius et al. 2004; Oliveira-Júnior et al. 2020). We believe that if non-climatic factors had been included in the analysis, the study would be improved and produce more accurate predictions.

CONCLUSION

Biomes face different types of disasters. Among them, fires are the most recurrent, which causes severe loss of biodiversity. Descriptive statistics show that occurrences of fire disasters vary with the month. It is moderated during January to July and November and December and high in August to October.

Our study provided more evidence on the association of rainfall, temperature and fire focis in a subtropical environment. In MS, periods of heavy precipitation are followed by low fire focis numbers. It was found that higher temperatures are associated with higher fire focis. With the need for effective environmental surveillance and a corresponding early warning system, better public awareness and government preparedness are ensured to facilitate the prevention of fires.

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