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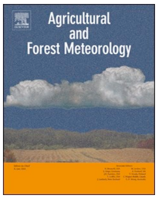

Fire foci related to rainfall and biomes of the state of Mato Grosso do Sul, Brazil

José Francisco de Oliveira-Júnior[a], Paulo Eduardo Teodoro[b], Carlos Antonio da Silva Junior[c], Fabio Henrique Rojo Baio[b], Ricardo Gava[b], Guilherme Fernando Capristo-Silva[d,*], Givanildo de Gois[e], Washington Luiz Félix Correia Filho[a], Mendelson Lima[f], Dimas de Barros Santiago[g], Welington Kiffer Freitas[e], Paulo José dos Santos[a], Micejane da Silva Costa[a]

[a] *Universidade Federal de Alagoas, Instituto de Ciências Atmosféricas, Maceió, Alagoas, Brasil*
[b] *Universidade Federal de Mato Grosso do Sul, Chapadão do Sul, Mato Grosso do Sul, Brasil*
[c] *Universidade do Estado do Mato Grosso, Departamento de Geografia, Sinop, Mato Grosso, Brasil*
[d] *Universidade Federal de Mato Grosso, Programa de Pós-Graduação em Agronomia, Sinop, Mato Grosso, Brasil*
[e] *Universidade Federal Fluminense, Programa de Pós-Graduação em Tecnologia Ambiental, Volta Redonda, Rio de Janeiro, Brasil*
[f] *Universidade do Estado do Mato Grosso, Alta Floresta, Mato Grosso, Brasil*
[g] *Universidade Federal de Campina Grande, Campina Grande, Paraíba, Brasil*

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ABSTRACT

The state of Mato Grosso do Sul (SMS), located in the Midwest of Brazil, is devoid of climatological studies, mainly on the characterization of rainfall regime and producers' meteorological systems and rain inhibitors. This state has different soil and climatic characteristics distributed among three biomes: Cerrado, Mata Atlântica, and Pantanal. This study aimed to investigate the temporal variability of fire foci in different SMS biomes. Data regarding fire foci and rainfall were obtained on an annual scale, collected from 15 municipalities (nine in Cerrado, four in Mata Atlântica, and two in Pantanal). Boxplot and distribution graphs were constructed for fire foci data and rainfall data associated with the biomes in each year. Subsequently, we applied the Mann–Kendall test to verify if there is a significant trend to the rainfall and fire foci data of the biomes. Pantanal revealed the higher occurrence of fire foci in relation to Cerrado and Mata Atlântica. The highest records of fire foci in Pantanal are caused by the longer drought period and anthropogenic activities (based on extensive agriculture). There is a tendency for positive growth in the occurrence of fire foci in the Pantanal, Cerrado and Mata Atlântica. Therefore, it is necessary to establish public policies to mitigate the occurrence of hot flashes in the SMS biomes, especially in the Pantanal.

1. Introduction

The state of Mato Grosso do Sul (SMS), Brazil, covers an area of about 350,000 km^2; however, only 4% is exploited in agriculture. Soybean, maize, cotton, sugar cane, and upland rice are the main crops of this region. Livestock is also an important activity, favored by the extensive flat areas of fields and the construction of a hydroelectric and thermoelectric plant—which contributes to the environmental degradation of the region (Teodoro et al., 2015; Silva Junior et al., 2015; CONAB, 2018). This state has different soil and climatic characteristics distributed among three biomes: Cerrado, Mata Atlântica, and Pantanal. Such phytophysiognomies are prone to fires, which may occur accidentally or be caused by improper management practices (Soriano et al., 2015; Soares-Filho et al., 2016).

In the last 20 years, the number of fire foci has increased significantly in Brazil due to agropastoral activities, arson, and uncontrolled burning (Caúla et al., 2015). Brazil, along with Russia, Canada, Angola, and the Democratic Republic of Congo are the leading countries facing the highest risk of forest fires in the world (Meng et al., 2015; Úbeda and Sarricolea, 2016). Forest fires and burnings are significant sources of several greenhouse gases (GHG), such as CO$_2$ (carbon dioxide), CH$_4$ (methane), and N$_2$O (nitrogen dioxide)

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* Corresponding author at: Programa de Pós-Graduação em Agronomia, Campus de Sinop, Universidade Federal de Mato Grosso (UFMT), Sinop, Mato Grosso, Brazil.

E-mail address: guilhermecapristo51@gmail.com (G.F. Capristo-Silva).

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(Artaxo et al., 2005), besides increasing pollution and worsening air quality via CO_2, NO_2, NMHC (non-methane hydrocarbons), and particulate matter - (PM, 2.5 and 10 µm) - (Freitas et al., 2005; Liu et al., 2014; Weise and Wright, 2014; Zeri et al., 2016).

The interest in burning and forest and urban fire events has increased due to their environmental consequences to urban areas, and mainly protected areas (Legal Reserves, Permanent Preservation Areas and Conservation Unit) (Bontempo et al., 2011; Zeri et al., 2011, 2016; Clemente et al., 2017). These events transport the combustion product via smoke, affecting the air quality and public health (Armenteras-Pascuala et al., 2011; Silva de Souza et al., 2012; Reisen et al., 2015). Thus, the Instituto Nacional de Pesquisas Espaciais (INPE) created an operating Database and Burnings (DBBurnings) system to detect fire foci and burnings via orbital sensors aboard the several environmental satellites, aiming to monitor the fire foci at real time (Caúla et al., 2015, 2016).

Knowing the spatial and temporal distribution of fire foci is essential for the SMS due to the direct impact on agricultural and urban planning, local businesses, industry, tourism, civil defense, and the establishment of public policies on conservations for the SMS biomes. According to Caúla et al. (2015), SMS is the 12th state with the highest density of fire foci per unit area and the tenth in total fire foci in Brazil. The hypothesis of this study refers to the fact that the fire foci in the SMS may be associated with the different biomes and the rainfall spatial-temporal variability in the state. This fact is shown by Teodoro et al. (2015), who demonstrated that rainfall varies throughout the biomes Cerrado, Mata Atlântica, and Pantanal. Therefore, this study aimed to investigate the temporal variability of fire foci in different SMS biomes.

2. Material and methods

2.1. Characterization and location of the study area

The state of Mato Grosso do Sul (SMS) is located in the Midwest of Brazil. The SMS presents an area of 357,145.32 km^2, with 78 municipalities. The edaphoclimatic characteristics of the state are diverse and distributed among the three biomes: Cerrado, Mata Atlântica, and Pantanal. Altitudes range from 24 to 1000 m in the center of the South American continent (Fig. 1).

Cerrado is the second largest biome in South America (SA). This biome covers 22% of the Brazilian territory and about 65% of the SMS (Sartori and Pott, 2018). This biome holds the source of the three most significant watersheds in South America (Amazon/Tocantins, San Francisco, and Prata), which determines its high aquifer potential and great biodiversity (Arruda et al., 2018). Due to its latitudinal positioning, the region is characterized by the transition between the low-latitude, warm climates, and the medium-latitude, temperate mesothermal climates (Mesquita et al., 2013). Pantanal covers 25% of the SMS, characterized by long-term floods (due to poorly permeable soil) that annually occur in the plain and cause changes to the environment, wildlife, and daily life of locals (Resende, 2000). The climate at Pantanal is classified as Aw, with total rainfall ranging from 1000 to 2000 mm/year and two well-defined seasons, dry (May–September) and wet (October–April). The latter accounts for over 80% of the total annual rainfall (Resende, 2000; Mesquita et al., 2013; Dubreuil et al., 2018). Mata Atlântica is an environmental complex that encompasses mountain ranges, valleys, and plateaus, with one of the most abundant and most varied rainforests in SA. However, Mata Atlântica is currently recognized as the most threatened Brazilian biome (Clemente et al., 2017).

2.2. Historical series of annual fire foci, rainfall and ENSO events

Annual fire foci data and rainfall data were collected between 2000 and 2015 in 15 municipalities in the SMS, located in the three biomes (Table 1). These municipalities were chosen due to the availability of rainfall and fire foci data for the analyzed period. Fire foci data were obtained from the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC-INPE, 2018) via Database and Burnings (DBBurnings, called BDQueimadas) – (http://www.inpe.br/queimadas/bdqueimadas/). The CPTEC's environmental satellite observation network is currently composed of 31 satellites (Polar Orbit and Geostationary) and travels through the country in the morning, afternoon, evening, and night. Fire foci assessments in the SMS biomes were based on all data from environmental satellites. Rainfall data were collected from 15 stations (sites) of Mato Grosso do Sul (MS), from Agência Nacional de águas (ANA) database (http://www.snirh.gov.br/hidroweb/publico/medicoes_historicas_abas.jsf) - (ANA, Agência Nacional de Águas (2014) Hidroweb. http://hidroweb.ana.gov.br/. Access in January 2014) and National Institute of Meteorology (INMET (Instituto Nacional de Meteorologia) (2014) Dados Meteorológicos. http://www.inmet.gov.br/. Access in 13 January 2018).

Data were processed by removing the outliers, which are observations that sharply deviate from the others in the sample in which they occur, causing inconsistencies. About 10% historical series showed failures (outliers), which are filled by the climatological normal of each of the 11 micro-regions of the state (THOM, E.C. Cooling degrees - days air conditioning, heating, and ventilating. Transactions of the ASAE, v.55, n.7, p.65-72, 1958).

Information on the occurrence of ENSO was obtained from the National Oceanic and Atmospheric Administration/Climate Prediction Center - NOAA/CPC (NOAA-CPC, 2017). Table 1 shows El Niño, La Niña and Neutral years from 2001 to 2013, classified as warm (red) and cold (blue), based on a range ± 5 °C of the sea surface temperature (SST) (NOAA/CPC - National Oceanic and Atmospheric Administration/Climate Prediction Center. Available in: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. Access in 17 July 2017).

2.3. Statistical analysis

Boxplot and distribution graphs were constructed for fire foci data and rainfall data associated with the biomes in each year. Afterward, canonical variables analysis was carried out to establish the interrelationship between the variables evaluated (fire foci and rainfall) and the municipalities (Downing et al., 2017). This technique is similar to the principal component analysis (PCA), but it considers the residual dispersion among the variables—variation over the years, in the case of this study.

Subsequently, we applied the Mann–Kendall test (MK) (Mann 1945; Kendall 1975) to verify if there is a significant trend to the rainfall and fire foci data of the biomes. This procedure considers the stability hypothesis of the occurrence of successive and independent values with the probability distribution remaining the same. The rainfall and fire foci data of the homogenous groups identified were subject to the Pettitt (1979) nonparametric test, which enables identifying the year of occurrence of abrupt change in a time-series.

Finally, Pearson's correlations (r) between fire foci and rainfall data over the years were estimated. The correlation network was used to graphically express the functional relationship between the estimates of the correlation coefficients. In the correlation network, the proximity between the nodes (traces) is proportional to the absolute value of the correlation between these nodes. Edge thickness was controlled by using a cut-off value of 0.70, which means that only $|r_{ij}| \geq 0.70$ have their edges highlighted. Finally, positive correlations were highlighted in green, and negative correlations were highlighted in red.

All the analyses were performed in the R software (version 3.4.3) (R Development Core Team, 2018), using the packages ggplot2 (Wickham and Chang, 2008), candisc (Friendly et al., 2017), ape (Paradis and Schliep, 2018), and qgraph (Epskamp et al., 2012).

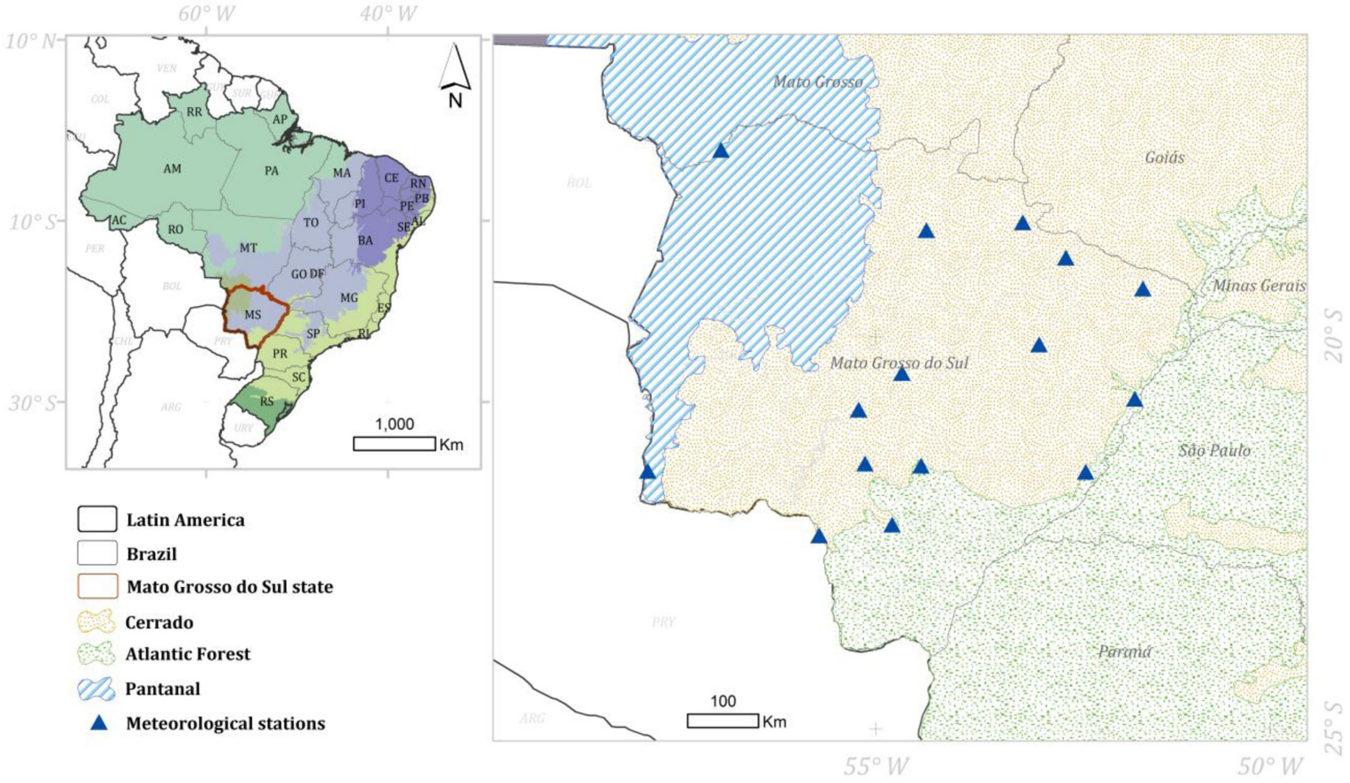


Fig. 1. Location of the state of Mato Grosso do Sul in South America, with its respective biomes (Pantanal, Cerrado, and Mata Atlântica) and hypsometry (m).

Table 1
Altitude (m), latitude, longitude (°) and biomes of where meteorological stations are located in 15 municipalities in the state of Mato Grosso do Sul, Brazil.

Sites	Altitude (m)	Latitude (S, °)	Longitude (W, °)	Biomes
Amambai	395	−20.933	−55.217	Mata Atlântica
Dourados	293	−22.398	−54.792	Mata Atlântica
Rio Brilhante	287	−21.647	−54.425	Mata Atlântica
Três Lagoas	313	−20.795	−51.713	Mata Atlântica
Água Clara	376	−20.102	−52.926	Cerrado
Bataguassu	293	−21.726	−52.334	Cerrado
Campo Grande	559	−20.467	−54.667	Cerrado
Chapadão do Sul	840	−18.998	−52.588	Cerrado
Costa Rica	635	−18.547	−53.135	Cerrado
Coxim	250	−18.649	−54.357	Cerrado
Maracaju	356	−21.619	−55.137	Cerrado
Paranaíba	458	−19.391	−51.609	Cerrado
Ponta Porã	650	−22.533	−55.717	Cerrado
Corumbá	101	−17.623	−56.965	Pantanal
Porto Murtinho	83	−21.714	−57.892	Pantanal

2.4. Burning mapping using MCD64 MODIS products

The product of the Burning Area data obtained with Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) product, combined (MCD64A1 Version 6) was applied to quantify fire foci in the years when the Pettitt test identified changes in the time-series of the clusters. This product has a 500-meter monthly grid scale containing burned area information per pixel. The burned area mapping employs surface reflectance images from the MODIS (Giglio et al., 2015). The burn-sensitive vegetation index is calculated from MODIS time-series, using shortwave infrared channels, and then dynamic thresholds are applied to guide the statistical characterization of changes related to burning and non-burning. Finally, spatial and temporal active fire information is used to create regional functions of probability density to classify each pixel as burned or unburned (Zhou et al., 2019).

MCD64's burned area mapping employs MODIS images and 1-km fire active MODIS observations. The hybrid algorithm applies dynamic thresholds to composite images generated from a burn-sensitive index derived from shortwave MODIS infrared channels 5 and 7, and a measure of temporal texture (Eq. (1)).

$$\frac{\rho 5 - \rho 7}{\rho 5 + \rho 7}$$

where: ρ5 and ρ7 are atmospherically corrected surface reflectance in band 5 and band 7, respectively.

The mapping was used to identify the recording date of the satellite's passage to the nearest record for individual grid cells. The date was then encoded in a single layer of output data for Julian day, where the burning (interval 1–366), in which 0 was assigned to "no burn" pixels and additional special values were assigned to missing data and water grid cells. The evolution of orbital sensors that detect fire foci allows identifying variability in the SMS biomes, especially regarding the switch from Advanced Very High Resolution Radiometer (AVHRR) to the Moderate Resolution Imaging Spectroradiometer (MODIS) - (Antunes, 2000; Caúla et al., 2015), which changes the reference satellites over the time-series (NOAA-12, from 2005 to 2007, and T-AQUA, from 2008 to 2015).

3. Results

3.1. Distribution of fire foci in the Cerrado, Pantanal, and Mata Atlântica biomes

Throughout the study, 280,326 fire foci were recorded in the SMS biomes by the environmental satellites. Pantanal accounted for 240,381 fire foci (85.75%), followed by Cerrado, with 28,752 fire foci (10.26%), and Mata Atlântica, with 11,193 fire foci (3.99%). Regardless of the

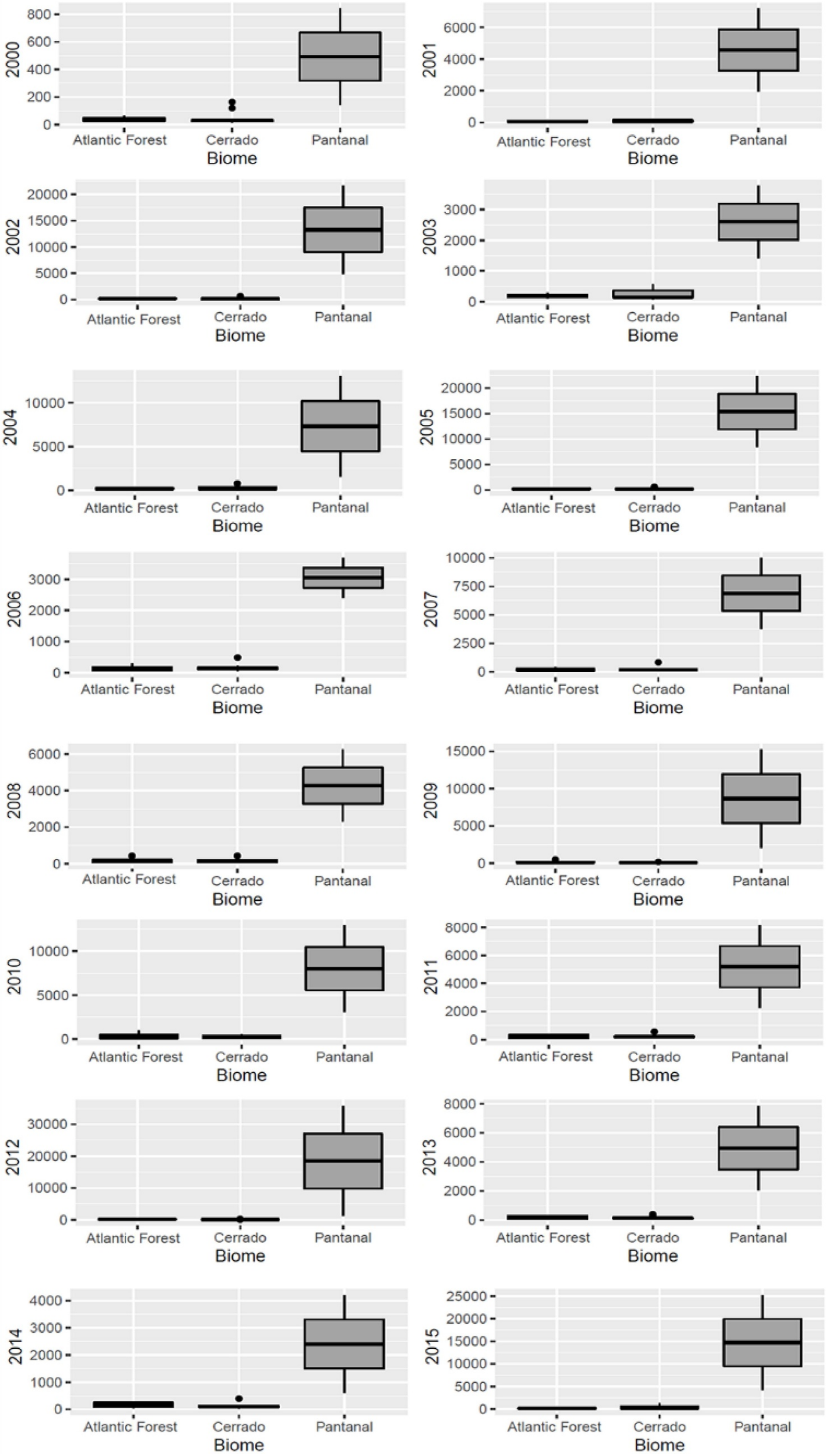


Fig. 2. Boxplot of the annual fire foci of Cerrado, Pantanal, and Mata Atlântica, located in SMS, between 2000 and 2015.

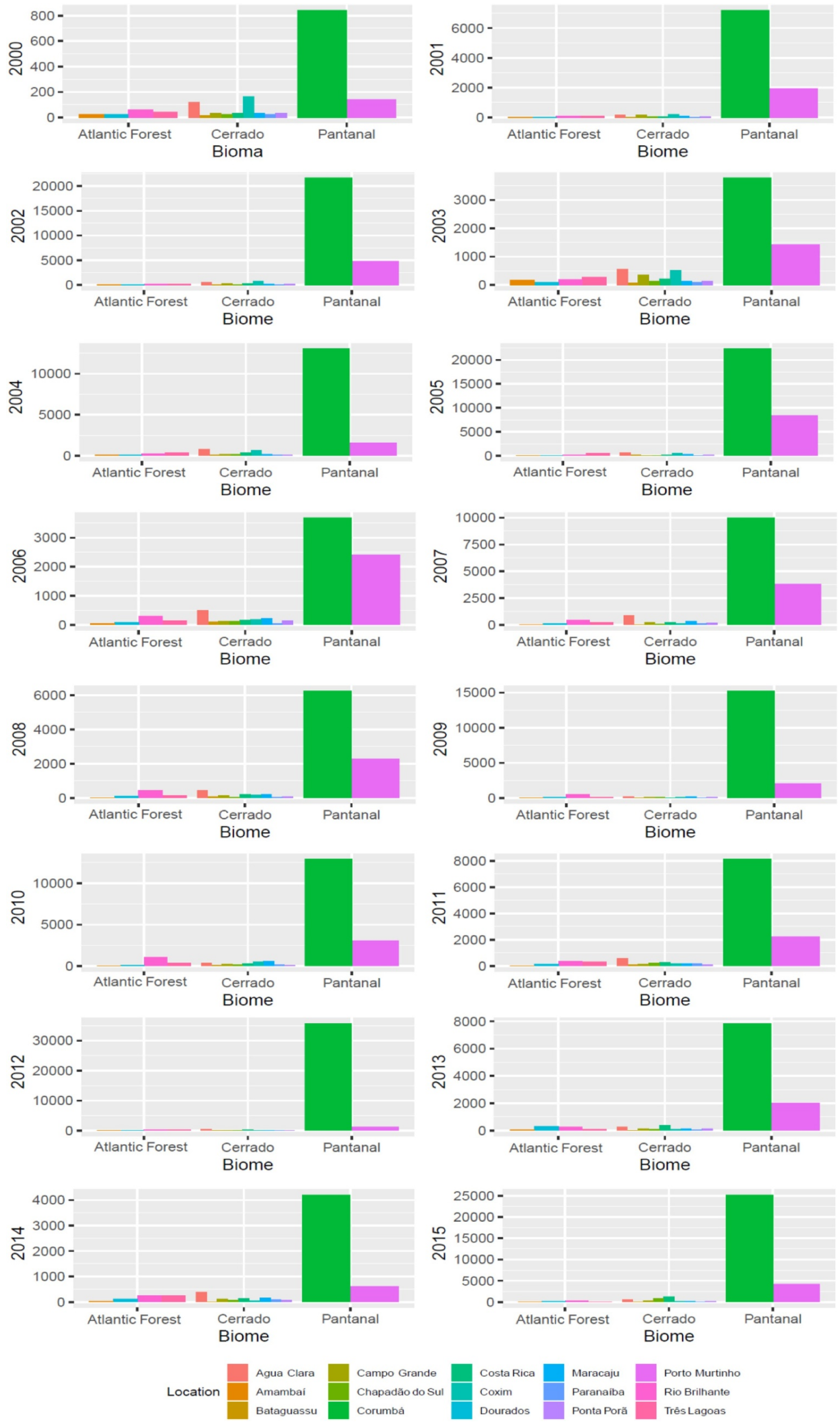


Fig. 3. Annual fire foci distribution in municipalities in the SMS in function of Cerrado, Pantanal, and Mata Atlântica, between 2000 and 2015.

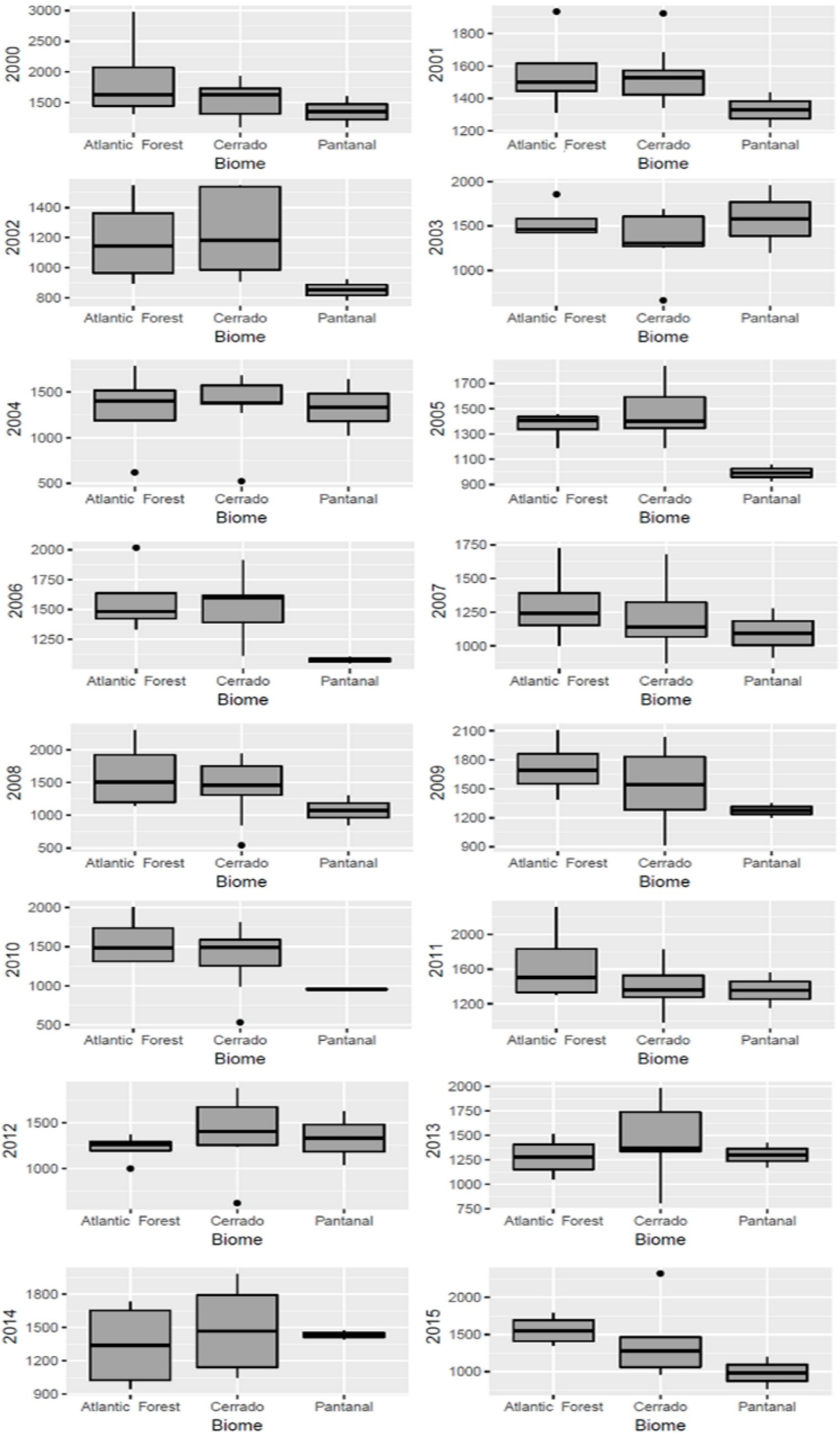


Fig. 4. Boxplot of the annual rainfall (mm) in Cerrado, Pantanal, and Mata Atlântica, between 2000 and 2015.

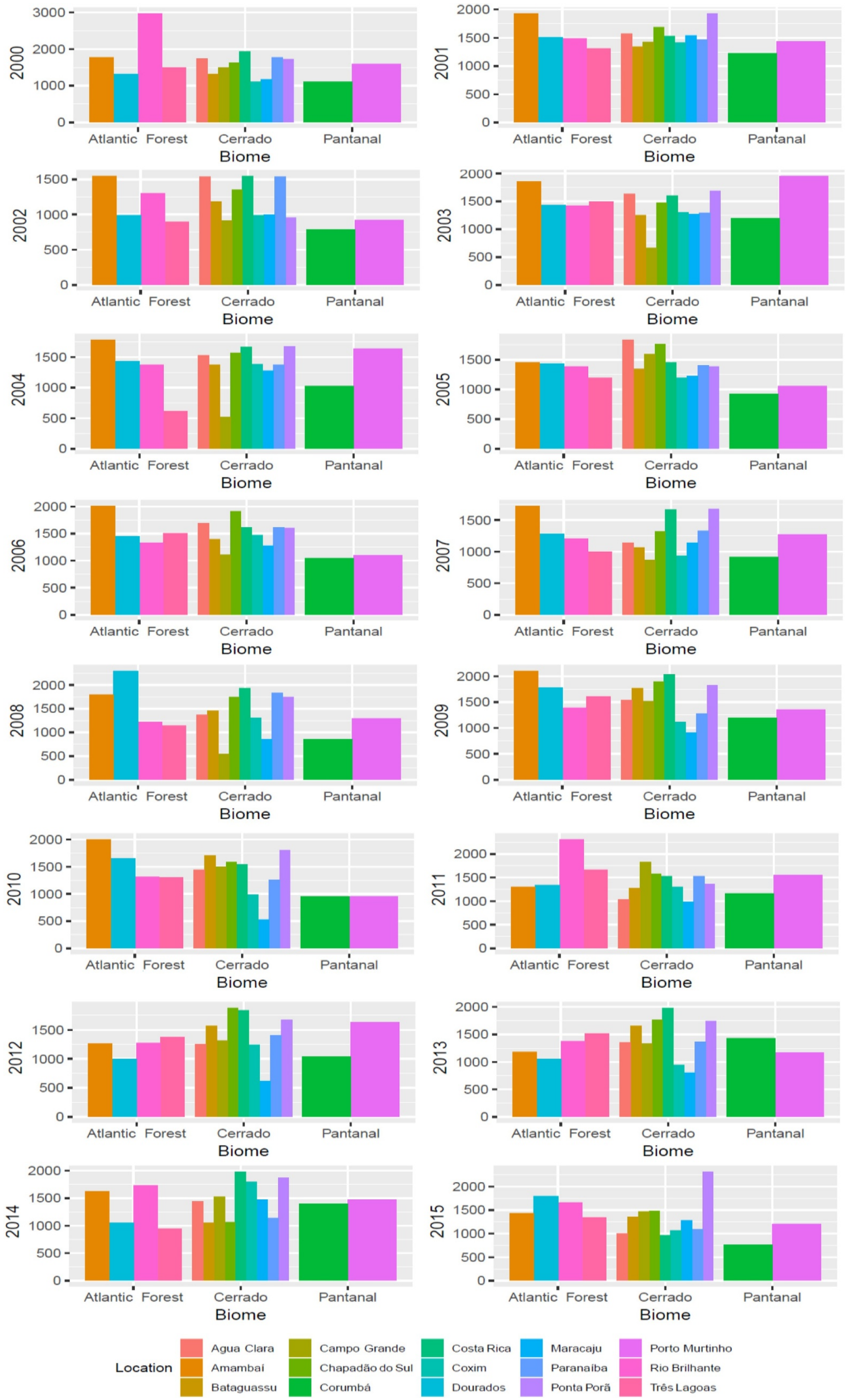


Fig. 5. Annual rainfall distribution (mm) in municipalities in the SMS in function of Cerrado, Pantanal, and Mata Atlântica, between 2000 and 2015.

year, Pantanal had the highest record of fire foci (Fig. 2). Outliers in the time-series were exclusive to Cerrado, except for the biannual cycle (2008/2009) of Mata Atlântica.

Pantanal showed the highest mean of fire foci over the years (7512 ± 5576 fire foci), followed by Cerrado (200 ± 140 fire foci) and Mata Atlântica (175 ± 115 fire foci). Fig. 3 shows the distribution of fire foci by the municipality, over the years, associated with the different SMS biomes. The municipalities Corumbá (12,386 ± 9534 fire foci) and Porto Murtinho (2638 ± 1979 fire foci) stand out with the highest occurrences of fire foci in all years. 2000 was the only exception—the municipality of Coxim had the second highest number of fire foci, higher than that of Porto Murtinho, in 20 records.

In Cerrado, the municipalities Água Clara (462 ± 214), Coxim (282 ± 220), and Costa Rica (281 ± 291) showed the highest occurrence of fire foci (Fig. 3). In Mata Atlântica, the municipality of Rio Brilhante stood out for showing 321 fire foci over the years and a standard deviation of 232 foci. The means of the other municipalities analyzed in these biomes were lower than 200 fire foci over the years.

3.2. Rainfall distribution in Cerrado, Pantanal, and Mata Atlântica biomes

The exploratory analysis of rainfall data in the different biomes over the 16 years is shown in Fig. 4. Significant temporal variability is verified over the years, where Cerrado and Mata Atlântica changed in relation to the highest annual means. However, Cerrado had higher mean rainfall in most years of the time-series (2000, 2001, 2002, 2005, 2006, 2010, 2012, 2013, and 2014). Conversely, Pantanal had higher rainfall only in 2003. In the remainder years, Mata Atlântica had the highest mean annual rainfall. These values were higher in relation to those of Pantanal (1207 ± 240 mm). The outliers were observed again, mainly in Cerrado. Mata Atlântica showed outliers in 2001, 2003, 2004, 2006, and 2012.

Fig. 5 shows the rainfall distribution in the municipalities located in the different SMS biomes over the years. In the Cerrado biome, the municipalities of Chapadão do Sul, Costa Rica, and Ponta Porã recorded the highest mean annual cumulative rainfall, over 1600 mm (with a standard deviation between 230 and 290 mm). In addition, Água Clara and Paranaíba had a mean annual rainfall higher than the overall mean of the entire biome (1444 mm and 1417 mm, respectively). In Mata Atlântica, the municipalities of Amambaí and Rio Brilhante had a mean annual rainfall of 1675 mm and 1547 mm, respectively, which are higher than the overall mean of the entire biome. In Pantanal, the municipality of Porto Murtinho had the highest mean annual rainfall (1352 ± 283 mm).

3.3. Relationship between fire foci and rainfall in Cerrado, Pantanal, and Mata Atlântica biomes

The Mann-Kendall and Pettitt tests were applied to each biome to verify the trend of the data series (Table 3). Mann-Kendall test did not detect a significant trend for rainfall data over the years for all biomes. Conversely, for the fire foci data, a significant increasing trend was observed for all biomes. The Pettitt's test identified 2005, 2007, and 2004 as changing points for biomes Pantanal, Cerrado and Mata Atlântica, respectively.

Thus, monitored burning densities were quantified for 2004, 2005, 2007, and 2015 (the latter was used to demonstrate a more current situation), using the MODIS sensor (MCD64) product (Fig. 6). The orbital sensor allied to the index distinguished the burning areas in every year.

For 2004 (Fig. 7A), 6229 burning polygons were identified, totaling 10,113 km^2, with 2384, 640, and 7089 km^2 found in Cerrado, Mata Atlântica, and Pantanal, respectively. In 2005 (Fig. 7B), burnings recorded in Cerrado (6862 Km^2), Mata Atlântica (625 km^2), and Pantanal (16,049 km^2) were similar, totaling 8559 polygons identified (Figure XB). 2007 revealed 7929 polygons, which included 8318 km^2 of burning in Cerrado, 1212 km^2 in Mata Atlântica, and 10,413 km^2 in Pantanal (Fig. 7C). 2015 revealed fewer polygons (5023); however, the total area was similar to that of the previous years (2626, 566, and 4490 km^2 for Cerrado, Mata Atlântica and Pantanal, respectively) (Fig. 8D). Although the similarity in the number of burning polygons between Cerrado and Pantanal, the burning area of the latter is much larger in relation to the biome's size. In 2015, Pantanal registered 489 fewer polygons than Cerrado; however, its burning area was larger (1864 Km^2).

The analysis of canonical variables (Fig. 8) allowed relating the municipalities located in the different SMS biomes with the fire foci and rainfall on an annual scale. Corumbá and Porto Murtinho are located near the fire foci vector. Costa Rica, Ponta Porã, Amambaí, Chapadão do Sul, Rio Brilhante, and Água Clara were located near the annual rainfall vector. The other municipalities were far from the vector of all the variables evaluated.

The correlation network analysis (Fig. 9) showed a high relationship between the occurrence of fire foci obtained from the environmental satellites over the years. Overall, the correlation between fire foci and annual rainfall is negative. The positive and high magnitude correlation was also observed between the biennia 2003/2004, 2007/2008, 2009/2010, and 2012/2013.

4. Discussion

The annual orbital monitoring of fire foci in the SMS biomes showed the highest records for Pantanal (Fig. 2). Since 2000, Embrapa Pantanal has been monitoring the meteorological variables and fire occurrences in Pantanal (Soriano et al., 2008). This biome is characterized by its low-altitude plains that flood during the rainy season (Resende, 2000). However, severe drought occurs between April and August, contributing to the increase in the number of fire foci events in the study period. This spatial-temporal variability increases the fire foci records in the study period (Mesquita et al., 2013; Viganó et al., 2018).

In the Pantanal biome, anthropogenic fire has been an efficient and inexpensive tool (Silio-Calzada et al., 2017; Schulz et al., 2019) to remove native vegetation prior to pasture or cultivation, stimulating the growth of native grasses or the establishment of new pastures (Evans et al., 2014; Bergier et al., 2019; Schulz et al., 2019). Beef cattle breeding has been the main economic activity in Pantanal for over two centuries (Soriano et al., 2015). The increase in fire foci records in Pantanal is strongly associated with economic activity, mainly from extensive agriculture, based on natural pastures that are burnt in order to enable the regrowth of the grass– intended to cattle feeding–when the rain comes. Some studies have mentioned that most of the burnings and fires occur for anthropogenic causes (Trejo, 2008; Santos and Nogueira, 2015; White e White, 2016; Clemente et al., 2017).

Burning and fire processes can cause other damages to the various components of the biome, such as: (I) loss of native plant species; (II) destruction exposure and weakening of the soil organic layer; changes in the soil physical properties (porosity and water penetrability); landslides and erosion; (III) animals' death, nest destruction, and habitat modification (animals migrate for food and shelter); (IV) destruction of houses, buildings, vehicles, machinery, and various equipment; (V) respiratory problems caused to population due to air pollution; road accidents caused by smoke; and death of those involved in the firefighting (Freitas et al., 2005; Pereira et al., 2012; Soares et al., 2009; Silva, 2014; Nunes et al., 2015).

Cerrado had low annual variability. However, the study period evidences the decrease in fire foci between 2008 and 2009, followed by the period between 2011 and 2014. When fire foci result from fire or burning, depending on the intensity and duration of the fire, they affect the biodiversity's and ecosystem's sustainability (Úbeda and Sarricolea, 2016; Soares-Filho et al., 2016). Fire is considered one of the determining factors of Cerrado's vegetation. Usually, natural fires in this biome are caused by lightning and occur in the rainy season,

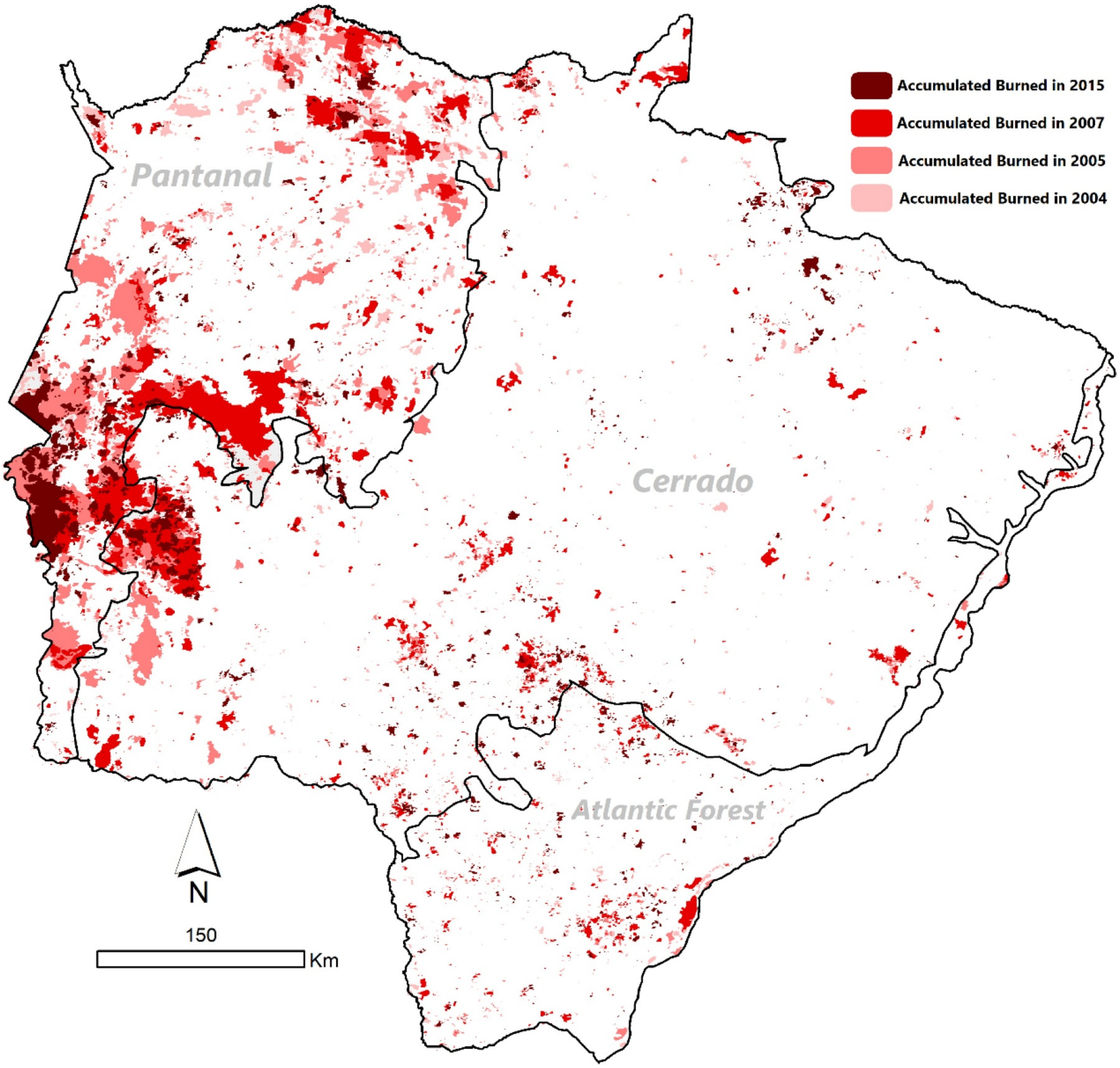


Fig. 6. Monitoring of burned areas by the MODIS sensor (MCD64) in function of Cerrado, Pantanal, and Mata Atlântica accumulated for 2004, 2005, 2007, and 2015.

causing low-intensity fire, which can exert positive feedback, favoring the growth of grass species in detriment of the tree species (Hoffmann et al., 2012). However, when resulting from anthropogenic activities, the fires are more intense and last longer, mainly in the dry season, resulting in changes in the floristic composition and community structure of the tree-shrub vegetation of Cerrado (Gomes et al., 2018).

According to Bustamante et al. (2012), about 36.8% of Brazil's pastures are contained in the Cerrado (546,250.9 km^2), while in the Pantanal this value is 1.1% (16,517.8 km^2). The extensive use of anthropic fire in these biomes and its threat to the remaining native vegetation is evident at the spatial pattern level. However, these practices result in large emissions of carbon and other gasses, contributing to increased greenhouse gas emissions and global warming (Pivello, 2011). The Cerrado represents approximately 50% (1.69 Mt CO_2eq) of total CO_2 emissions for pasture management in Brazil, while in the Pantanal this figure is 5% (0.06 Mt CO_2eq) (Bustamante et al., 2012).

In Mata Atlântica, fire foci presented similar magnitude to the Cerrado. In this biome, the fire has also been modifying the structure, composition, and regeneration of plant communities, compromising the maintenance of these ecosystems (Aximoff and Rodrigues, 2011). The effects of fires or burning have caused the advance of the Cerrado biome towards Pantanal biome, that is, they have favored the occurrence of Cerrado species, which are adapted to burnings (Pott and Pott, 2004). Thus, assessing the dynamics of fires and burnings in biomes is essential, especially in the SMS. The increase in fire foci may also be associated with the expansion of sugarcane crops in the state (Britts et al., 2016). This increase reached 65.7% only between 2010 and 2016. Sugarcane crops are burned at the pre-harvest stage to reduce the amount of straw, facilitating the operation, and increasing the manual cutting yield and mechanical loading. Including in mechanical harvesting, burning has some benefits for prostrate crops, even today, with the excessive use of machines.

Environmental satellites have increased significantly since the 2010s (Caúla et al., 2016; CPTEC, 2018; Viganó et al., 2018). In the time-series, all the biomes showed a decrease in the accumulated years of fire foci, mainly in 2004, 2007, and 2010. Phytogeographically, Pantanal is influenced by four other biomes: Cerrado (over 70%); Amazon Forest (approximately 20%); Chaco (approximately 8–9%), and Southern Forests (around 1%) (Rodrigues et al., 2002) and a large amount of territorial area (Mesquita et al., 2013; Viganó et al., 2018). This fact explains why Pantanal has twice as many fire foci than Cerrado and ten times as many as Mata Atlântica.

Viganó et al. (2018) evaluated the fire foci mean per month, from 2005 to 2015, in the municipality of Corumbá. The authors identified a significant increase from July, with higher values in August and

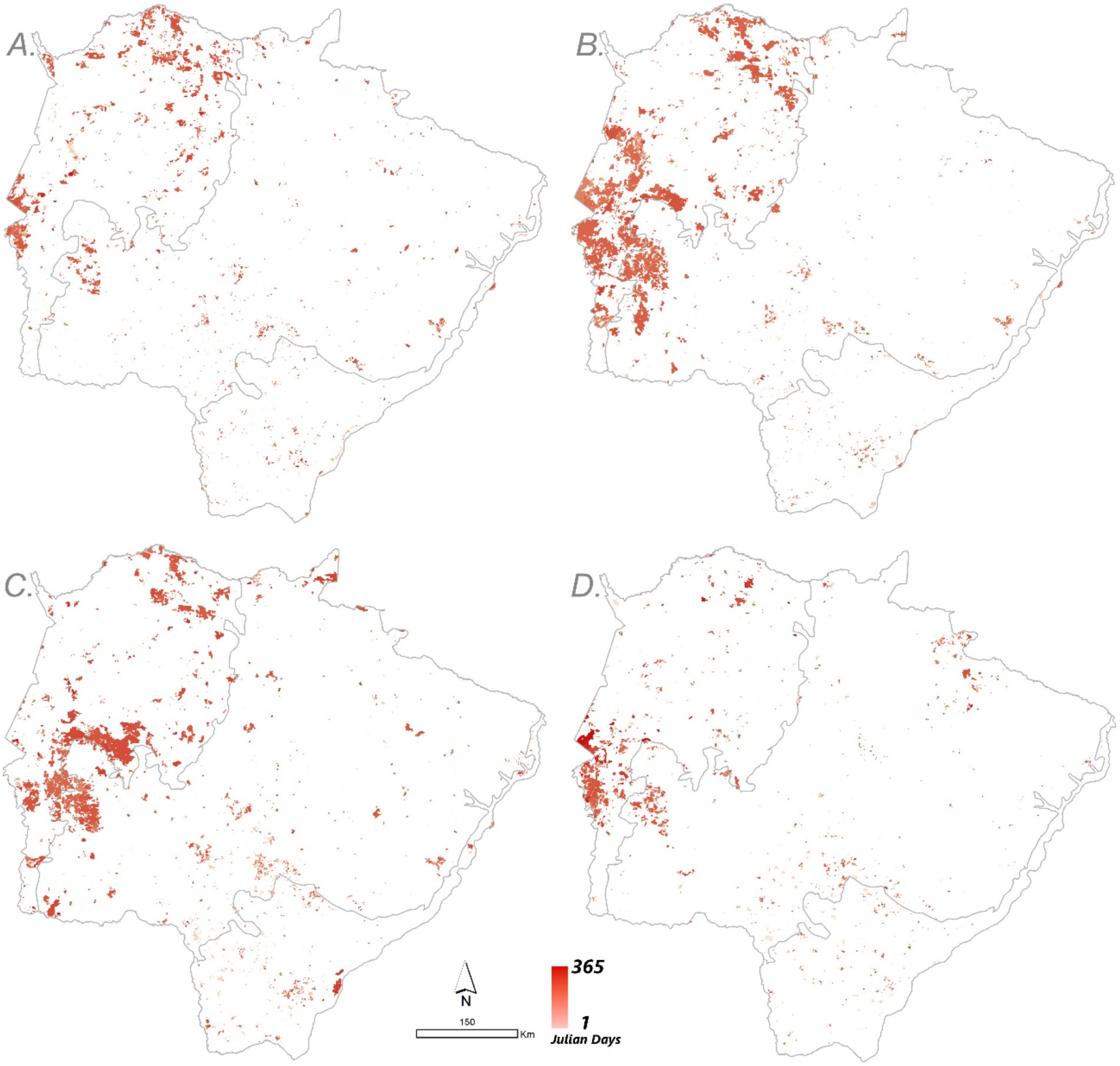


Fig. 7. Burned areas detected via MCD64 (MODIS) for 2004 (A), 2005 (B), 2007 (C), and 2015 (D), in function of the Julian day of each year.

September, respectively. Standard deviations and coefficients of variation (CV,%) showed high values, which indicated high heterogeneity of the time-series. In the monthly scale, the first semester had few fire foci, while the dry season had a considerable increase, similar to that observed for G_1. In addition, the municipalities allocated in G_1 stand out for having large farms intended for livestock and are among the main SMS for this purpose. By 2015, Corumbá, in the Pantanal biome, was ranked as the second municipality by number of cattle, with 1.82 million cattle or 0.8% of the bovine population in Brazil (IBGE, 2017).

The Pettitt's test applied to each biome identified changes in the time-series of fire foci in 2004, 2005 and 2007. These years, together with 2015, stand out due to the occurrence of the ENSO phenomenon (El Niño-Southern Oscillation) can be seen in Table 2: 2002 (Neutral/El Niño), 2004, 2005 (both Neutral/El Niño), 2007 (Neutral/La Niña), 2010 (El Niño/La Niña), and 2015 (El Niño). In Pantanal, 2002, 2005, 2012 (La Niña / Neutro) and 2015 (El Niño) had means higher than the annual mean (19,954 ± 16,037.4 fire foci). Finally, in Mata Atlântica, the years above the annual mean (2292 ± 1697.11 fire foci) were 2010, 2011 (La Niña), and 2012. The years previously mentioned were under the influence of the mode of climate variability El Niño-Southern Oscillation (ENSO) (Grimm and Tedeschi, 2009; Kayano et al., 2016; Lyra et al., 2017) and their respective stages and duration events, according to the Oceanic Niño Index (ONI) criteria for the 3.4 Niño region (NOAA/CPC, 2018). In some cases, in the same year, fire foci increase was recorded in more than one of the biomes. Therefore, the climatic component influences the dynamics of fire foci, mainly regarding the interannual variability of rainfall and other meteorological variables (air temperature and humidity, wind, among others). This subject has been addressed in studies in other Brazilian states (Kitzberger et al., 2001; Jolly et al. 2015; Clemente et al., 2017). ENSO has a noticeable influence on the climate of the Midwest of Brazil and, consequently, on the dynamics of the meteorological systems that act on the region (Lyra et al., 2014; Teodoro et al., 2015; Silva Júnior et al., 2015).

The local study carried out by Soriano et al. (2015) used a 10-year time-series (1999–2008) of daily rainfall data - P (mm); air temperature - T (°C), relative air humidity - RH (%), and wind speed - VV (m s^{-1}) in Nhecolândia, SMS Pantanal. Their results indicated that VV ($r = 0.79$) and RH ($r = -0.69$) are the variables that best correlate with the number of fire foci. Regression based on exponential model revealed that the independent variables VV and RH had better fit than T and PP. Conversely, the present study showed a high correlation between the occurrence of fire foci in several SMS municipalities in all biomes. In

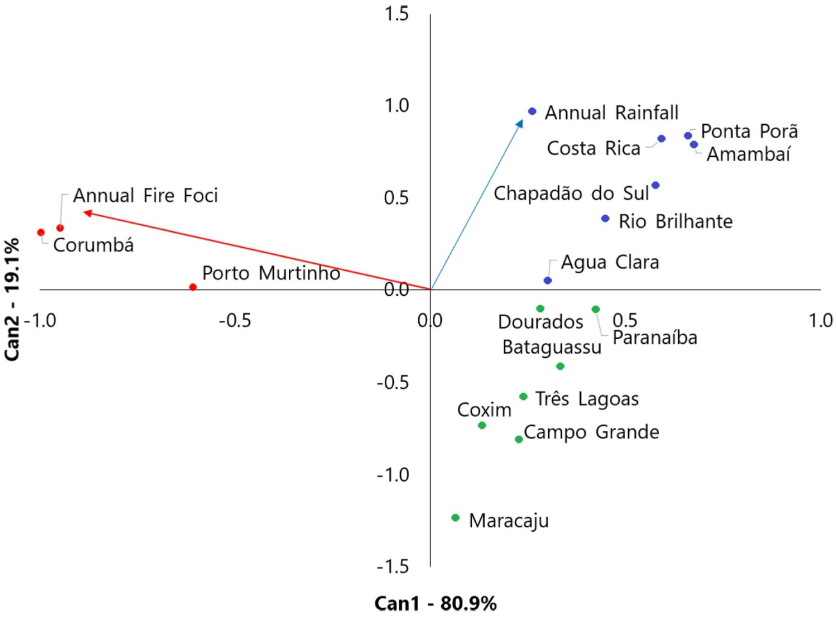


Fig. 8. Canonical variables analysis between fire foci and rainfall (mm) of 15 SMS municipalities evaluated over 16 years.

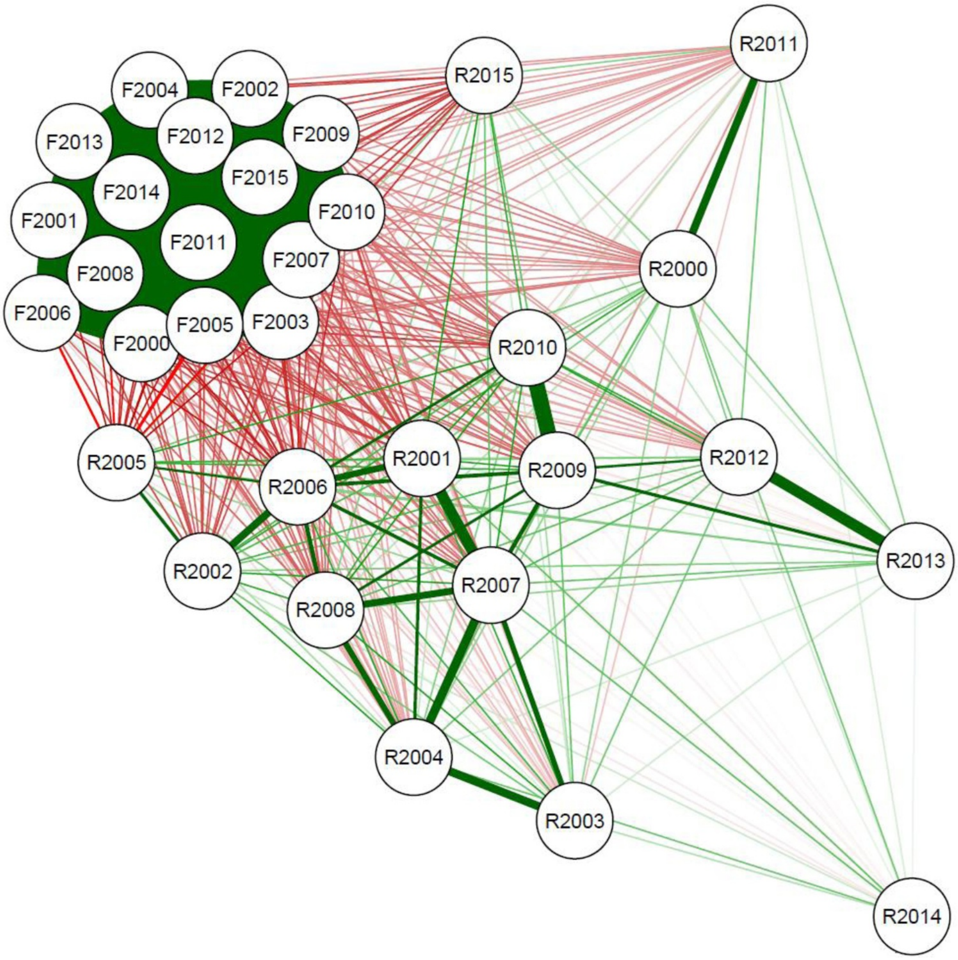
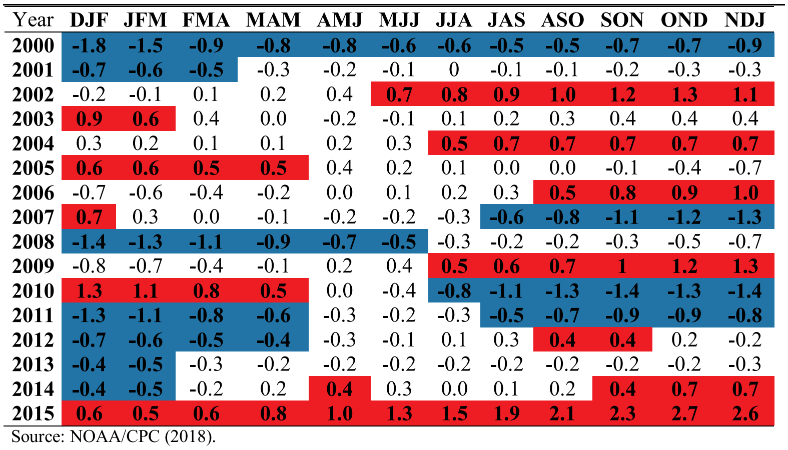


Fig. 9. Pearson's correlation network (r) between fire foci and rainfall (mm) from 15 SMS municipalities evaluated over 16 years. The letter F indicates fire foci, while the letter R indicates the rainfall in the respective year.

Table 2
Years and trimester of El Niño (values in red box), La Niña (values in blue box) and Neutral occurrence (values in white box).
Source: NOAA/CPC (2018).



Year	**DJF**	**JFM**	**FMA**	**MAM**	**AMJ**	**MJJ**	**JJA**	**JAS**	**ASO**	**SON**	**OND**	**NDJ**
2000	**-1.8**	**-1.5**	**-0.9**	**-0.8**	**-0.8**	**-0.6**	**-0.6**	**-0.5**	**-0.5**	**-0.7**	**-0.7**	**-0.9**
2001	**-0.7**	**-0.6**	**-0.5**	-0.3	-0.2	-0.1	0	-0.1	-0.1	-0.2	-0.3	-0.3
2002	-0.2	-0.1	0.1	0.2	0.4	**0.7**	**0.8**	**0.9**	**1.0**	**1.2**	**1.3**	**1.1**
2003	**0.9**	**0.6**	0.4	0.0	-0.2	-0.1	0.1	0.2	0.3	0.4	0.4	0.4
2004	0.3	0.2	0.1	0.1	0.2	0.3	**0.5**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
2005	**0.6**	**0.6**	**0.5**	**0.5**	0.4	0.2	0.1	0.0	0.0	-0.1	-0.4	-0.7
2006	-0.7	-0.6	-0.4	-0.2	0.0	0.1	0.2	0.3	**0.5**	**0.8**	**0.9**	**1.0**
2007	**0.7**	0.3	0.0	-0.1	-0.2	-0.2	-0.3	**-0.6**	**-0.8**	**-1.1**	**-1.2**	**-1.3**
2008	**-1.4**	**-1.3**	**-1.1**	**-0.9**	**-0.7**	**-0.5**	-0.3	-0.2	-0.2	-0.3	-0.5	-0.7
2009	-0.8	-0.7	-0.4	-0.1	0.2	0.4	**0.5**	**0.6**	**0.7**	**1**	**1.2**	**1.3**
2010	**1.3**	**1.1**	**0.8**	**0.5**	0.0	-0.4	**-0.8**	**-1.1**	**-1.3**	**-1.4**	**-1.3**	**-1.4**
2011	**-1.3**	**-1.1**	**-0.8**	**-0.6**	-0.3	-0.2	-0.3	**-0.5**	**-0.7**	**-0.9**	**-0.9**	**-0.8**
2012	**-0.7**	**-0.6**	**-0.5**	**-0.4**	-0.3	-0.1	0.1	0.3	**0.4**	**0.4**	0.2	-0.2
2013	**-0.4**	**-0.5**	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3
2014	**-0.4**	**-0.5**	-0.2	0.2	**0.4**	0.3	0.0	0.1	0.2	**0.4**	**0.7**	**0.7**
2015	**0.6**	**0.5**	**0.6**	**0.8**	**1.0**	**1.3**	**1.5**	**1.9**	**2.1**	**2.3**	**2.7**	**2.6**

Source: NOAA/CPC (2018).

Table 3
Trend of reported by the Mann-Kendall's and Pettitt's tests applied to the rainfall and fire foci data in biomes Pantanal, Cerrado and Mata Atlântica.

Biomes	Man-Kendall's test		Pettitt's test	
	Z-score	*p*-value	Year	*p*-value
	Rainfall			
Pantanal	0.21	0.80	2004	0.12
Cerrado	0.34	0.71	2005	0.31
Mata Atlântica	0.22	0.65	2007	0.40
Biomes	Fire foci			
Pantanal	4.55	0.01	2005	0.01
Cerrado	3.09	0.02	2007	0.01
Mata Atlântica	2.95	0.03	2004	0.01

general, the correlation between fire foci and annual rainfall was negative and followed a biennial cycle.

Viganó et al. (2018) used the Multiple Linear Regression (MLR) and Autoregressive Integrated Moving Average (ARIMA) models. The analysis techniques MLR and ARIMA were used; MRL explained 41% of the variance in the number of foci, proving to be an inefficient prediction technique. ARIMA explained 66.5% and hence is the most suitable prediction model. The meteorological factors solar radiation, relative humidity of the air, and temperature established an important relation among each other.

5. Conclusions

Pantanal revealed the higher occurrence of fire foci in relation to Cerrado and Mata Atlântica. The highest records of fire foci in Pantanal are caused by the longer drought period and anthropogenic activities (based on extensive agriculture).

There is a tendency for positive growth in the occurrence of fire foci in the Pantanal, Cerrado and Mata Atlântica. Therefore, it is necessary to establish public policies to mitigate the occurrence of hot flashes in the SMS biomes, especially in the Pantanal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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