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Artigos

Causes and period of occurrence of forest fires in Brazilian federal protected areas from 2006 to 2012

Causas e período de ocorrência de incêndios florestais em unidades de conservação federais brasileiras de 2006 a 2012

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ABSTRACT

Forest fires, regardless of their causes, represent one of the greatest threats to biodiversity in Brazilian protected areas. Collecting data on the causes, periods, and sites with the highest occurrence of fires allows for the adoption of more effective prevention strategies. The aim of this study was to characterize forest fires in Brazilian federal protected areas from 2006 to 2012, thus contributing to improving the knowledge of the dynamics of fires in these areas. Data were obtained from Fire Occurrence Records (ROIs, in Portuguese) available in the National Fire Information System (SISFOGO, in Portuguese) database. The total number of records found was 2,259, of which 88.2% had reported causes. Among the records with a reported cause, 42.2% correspond to unknown causes, 26.7% to debris burning, and 18.5% to arson events, which shows that the majority of fires with a known cause are the result of accidental or intentional human action. Forest fires were more frequent from July to October, with a mean of 50.6 occurrences per year, influenced by the annual precipitation distribution. Minas Gerais, Rio de Janeiro and Ceará were the states with the highest number of records, with 19.8%, 15.5%, and 12.0%, respectively. Forest fires reported without any cause information or reported as unknown cause indicate, respectively, a poor use of the tool (ROI) or an unsatisfactory expertise in identifying the cause of the fire, resulting in an obstacle for planning actions to prevent and fight forest fires in protected areas.

Keywords: Fire behavior; Fire management; Fire occurrence record; Fire prevention

RESUMO

Os incêndios florestais, independentemente de suas causas, representam uma das maiores ameaças à biodiversidade nas unidades de conservação brasileiras. A coleta de dados sobre as causas, períodos e locais com maior ocorrência de incêndios possibilita a adoção de estratégias de prevenção mais eficazes. O objetivo deste estudo foi caracterizar os incêndios florestais nas unidades de conservação federais brasileiras de 2006 a 2012, contribuindo assim para aprimorar o conhecimento da dinâmica dos incêndios nessas áreas. Os dados foram obtidos a partir dos Registros de Ocorrência de Incêndio (ROIs) disponíveis no banco de dados do Sistema Nacional de Informações sobre Fogo (SISFOGO). O número total de registros encontrados foi de 2.259, dos quais 88,2% indicavam a causa do incêndio. Entre os registros com a causa indicada, 42,2% corresponderam à categoria "causa desconhecida", 26,7% à queima para limpeza e 18,5% à incendiários, o que evidencia que a maioria dos incêndios com causa conhecida decorre da ação humana acidental ou intencional. Os incêndios florestais foram mais frequentes de julho a outubro, com uma média de 50,6 ocorrências por ano, influenciados pela distribuição anual da precipitação. Minas Gerais, Rio de Janeiro e Ceará foram os estados com maior número de registros, com 19,8%, 15,5% e 12,0%, respectivamente. Os incêndios florestais registrados sem informação de causa ou registrados como "causa desconhecida" revelam, respectivamente, mau uso da ferramenta (ROI) ou conhecimento insatisfatório na identificação da causa do incêndio, resultando em um obstáculo para o planejamento de ações de prevenção e combate a incêndios em unidades de conservação.

Palavras-chave: Comportamento do fogo; Manejo do fogo; Registro de ocorrência de incêndio; Prevenção de incêndio

1 INTRODUCTION

Fire is one of the most important agents of disturbance in ecosystems, being widely used by humans to manage the land (PIVELLO, 2011). Fire is called forest fire when it escapes human control and reaches vegetation (AXIMOFF; RODRIGUES, 2011). This subject is widely studied in several countries (ZHANG; LIM; SHARPLES, 2016), as it causes economic, social, and environmental impacts, such as the destruction of forests and other natural environments (CAMARGO; BARRIO; CAMARGO; MENDONÇA; RIBEIRO; RODRIGUES; VIEIRA, 2018). Forest fires are increasing around the world, fragmenting and degrading the landscape and causing an imbalance between fire occurrences and ecosystem recovery (ADÁMEK; BOBEK; HADINCOVÁ; WILD; KOPECKÝ, 2015).

In recent decades, climate change has promoted a favorable season for forest fires around the world. Fires are highly influenced by climatic factors, which may have induced the recent global spread of forest fires. If this trend continues, the advancement of forest fires will increase even further (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015). In addition, forest fire itself can favor climate change, as it is a major source of greenhouse gases, especially CO_2 (SETIANI; DEVIANTO; RAMDANI, 2021).

Over the past three decades, global average temperatures have increased by ≈ 0.2°C per decade (HANSEN; RUEDY; SATO; LO, 2010), which favors the spread of fires. Forest fires require a combination of oxygen, combustible material and an ignition source to occur (PÉREZ-SÁNCHEZ; JIMENO-SÁEZ; SENENT-APARICIO; DÍAZ-PALMERO; CABEZAS-CEREZO, 2019). Ignition is influenced by temperature, relative humidity, precipitation and wind speed. Such climatic factors also affect the rate of fire spread and thus the intensity of forest fires, which is increased on hot, dry days (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015).

In Brazil, forest fires are a constant threat to protected areas (PAs) (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). These PAs are intended to maintain biodiversity (MARCUZZO; ARAÚJO; GASPARIN, 2015) and the occurrence of fires reduces its forest cover. Harboring rare, endemic, and endangered species, many Brazilian PAs are located in fire-sensitive biomes or in small and isolated areas in an anthropic matrix (such as crops and built-up areas). Such settings are detrimental to the conservation of the areas, which is already compromised by forest fires (BONTEMPO; LIMA; RIBEIRO; DOULA; SILVA; JACOVINE, 2011).

The landscape matrix where Brazilian PAs are located is often composed of different types of land use, which vary with the economic activity of the region and immediate surroundings (IBAMA, 2007). The process of land occupation and conversion of natural vegetation into crops, where fire is used as a management technique, exposes PAs to forest fires (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR,

2016). In this scenario, the profile of forest fires reflects the type of activity carried out by rural landowners in the surrounding areas, making it possible to correlate the fire causes with the activities observed (IBAMA, 2007). The main causes of forest fires in PAs are anthropogenic, mainly due to arson events and out-of-control debris burning (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). Natural caused forest fires in Brazil are triggered exclusively by lightning (PIVELLO, 2011).

In Brazil, the 1,004 existing federal PAs cover 1,717,976 km², distributed across all biomes (MMA, 2019). The analysis of the spatial distribution of fires makes it possible to determine the areas of greatest incidence and, thus, to establish specific prevention and combat strategies for each region or biome. Fire seasons must be known in order to structure effective prevention and combat programs, keeping them active exclusively in the most critical months as to ensure their economic viability and, at the same time, to avoid large-scale fires (IRLAND, 2013).

Fire behavior varies according to the region, thus requiring knowledge about local characteristics for the adoption of effective measures (PEZZATTI; ZUMBRUNNEN; BÜRGI; AMBROSETTI; CONEDERA, 2013). The most frequent causes must be known in order to take preventive action against forest fires in PAs (TORRES; RIBEIRO; MARTINS; LIMA, 2010) and awareness of the period of occurrence is crucial for the prevention techniques to be applied at the appropriate time. This study aimed to assess the causes of forest fires in Brazilian federal PAs from 2006 to 2012, developing a diagnosis that will assist public managers and stakeholders in their decision-making related to forest fires.

2 MATERIAL AND METHODS

The data consists of Fire Occurrence Records (ROIs, in Portuguese) of federal PAs and were obtained from the National Fire Information System (SISFOGO, in Portuguese), managed by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, in Portuguese) through the National Center for the Prevention of Forest Fires (PREVFOGO, in Portuguese).

ROIs provide a variety of information, such as causative agents and likely cause of the fire, with 33 and 26 different options, respectively, for each. These fire causes were categorized as proposed by the Food and Agriculture of Organization (FAO) (SANTOS; SOARES; BATISTA, 2006). FAO does not provide a category titled "unknown cause" as they consider it can cause inaccurate reporting (SOARES, 1988). However, this category was included in this study due to the large number of records. Thus, the causes were grouped into seven categories, namely: I) unknown; II) miscellaneous; III) campfire and related; IV) arson fire; V) forest exploitation; VI) debris burning; and VII) lightning. The FAO category titled "miscellaneous" includes hunting, high voltage cable, wind-borne spark, fireworks, balloon drop, reignition, and others.

The period assessed span from 2006 to 2012 due to data availability in SISFOGO. Statistical analysis was performed using R software, applying Generalized Linear Modeling (GLM) under Poisson error distribution corrected for overdispersion. Model simplification was performed by contrast analysis, grouping treatment levels up to a change in deviation of $P<0.05$, determining the effects of categorical explanatory variables (months, Brazilian states, and causes of fires) in the continuous response variable (number of fire occurrences).

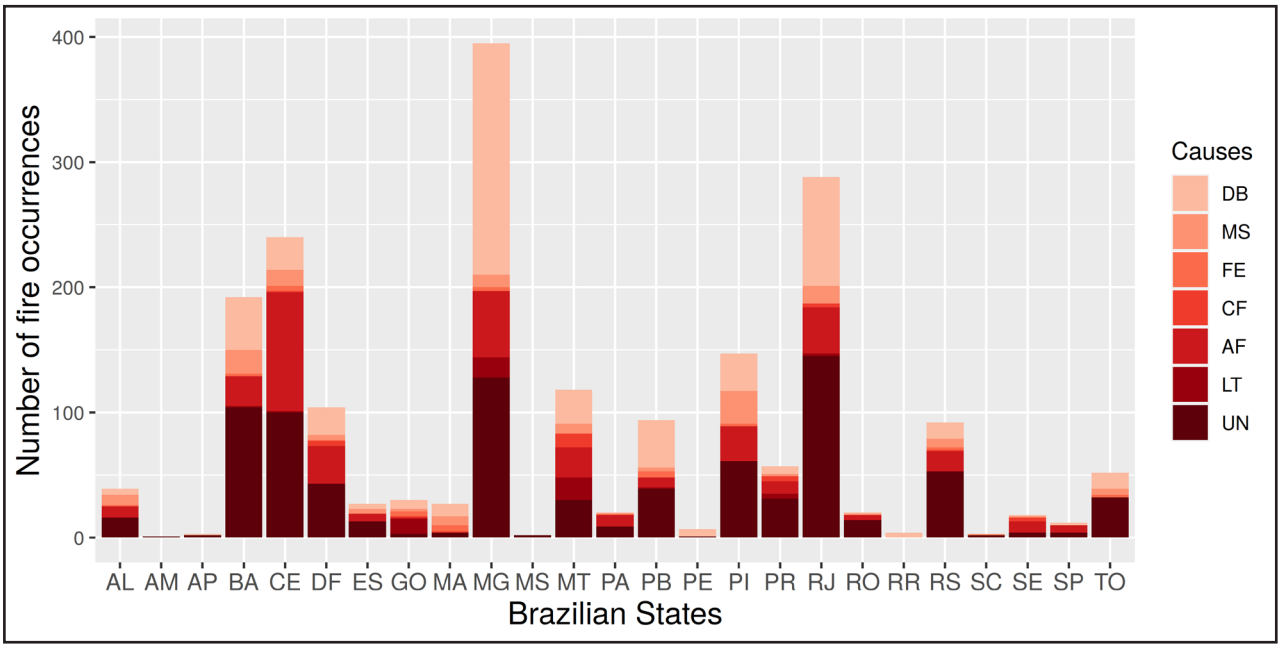
3 RESULTS

The number of occurrences recorded from 2006 to 2012 was 2,259, of which 88.2% had a reported cause for the fire. The remaining occurrences (11.8%) did not have their causes reported, indicating an unsatisfactory fire origin investigation. The variables "year" and "cause" were both statically significant ($p<0.001$). Fires with unknown causes were the most frequent, with a mean of 120.14 per year, and statistically different from the other cause categories ($p>0.05$). The fires caused by arson and by debris burning had the same number of records, with a mean of 64.29 per year. The categories "campfire and related", "forest exploitation", "lightning", and "miscellaneous" were statistically equal ($p>0.05$) and had a mean of 9.47 per year. The

categories “smokers” and “railroads” are provided by FAO, however, no records for either were observed in this study.

Among the 27 Brazilian states, including Distrito Federal, only Acre and Rio Grande do Norte had no fire occurrences recorded from 2006 to 2012. The state with the highest number of occurrences was Minas Gerais (with a mean of 56.42 per year), which also stood out for being the only in which debris burning was the main cause of fires, surpassing fires of unknown causes (Figure 1). Besides Minas Gerais, the states with the highest number of fires were Ceará and Rio de Janeiro ($p>0.05$), with a mean of 37.71 per year, followed by Mato Grosso, Piauí, and Bahia ($p>0.05$), with a mean of 21.76 per year, and Alagoas, Tocantins, Paraná, Rio Grande do Sul, Paraíba, and Distrito Federal ($p>0.05$), with a mean of 10.42 per year. The other states had a mean of 1.91 per year.

Figure 1 – Number of fire occurrences by state and cause in Brazilian federal protected areas from 2006 to 2012. Legend: debris burning (DB), miscellaneous (ML), forest exploitation (FE), campsite or related (CS), arson fire (AF), lightning (LT), unknown (UN)



Source: Authors (2023)

Combined, eight federal PAs concentrated 395 occurrences, of which 26% occurred in the Sempre-Vivas National Park, 18% in the Serra do Cipó National Park, and 15% in the Serra da Canastra National Park.

The states with the highest number of federal PAs are Bahia (137), Minas Gerais (107), Rio de Janeiro (83), and São Paulo (63) (MMA, 2019). An empirical index obtained by dividing the number of occurrences by the number of federal PAs was calculated for a comparison between states, with results of 1.40; 3.69; 3.47; and 0.19, respectively, for the aforementioned states. The state with the highest index was Piauí (10.50), which has 14 federal PAs and 147 fire records, standing out for having 40% of all fire occurrences in the country caused by hunting (23 of 57 records).

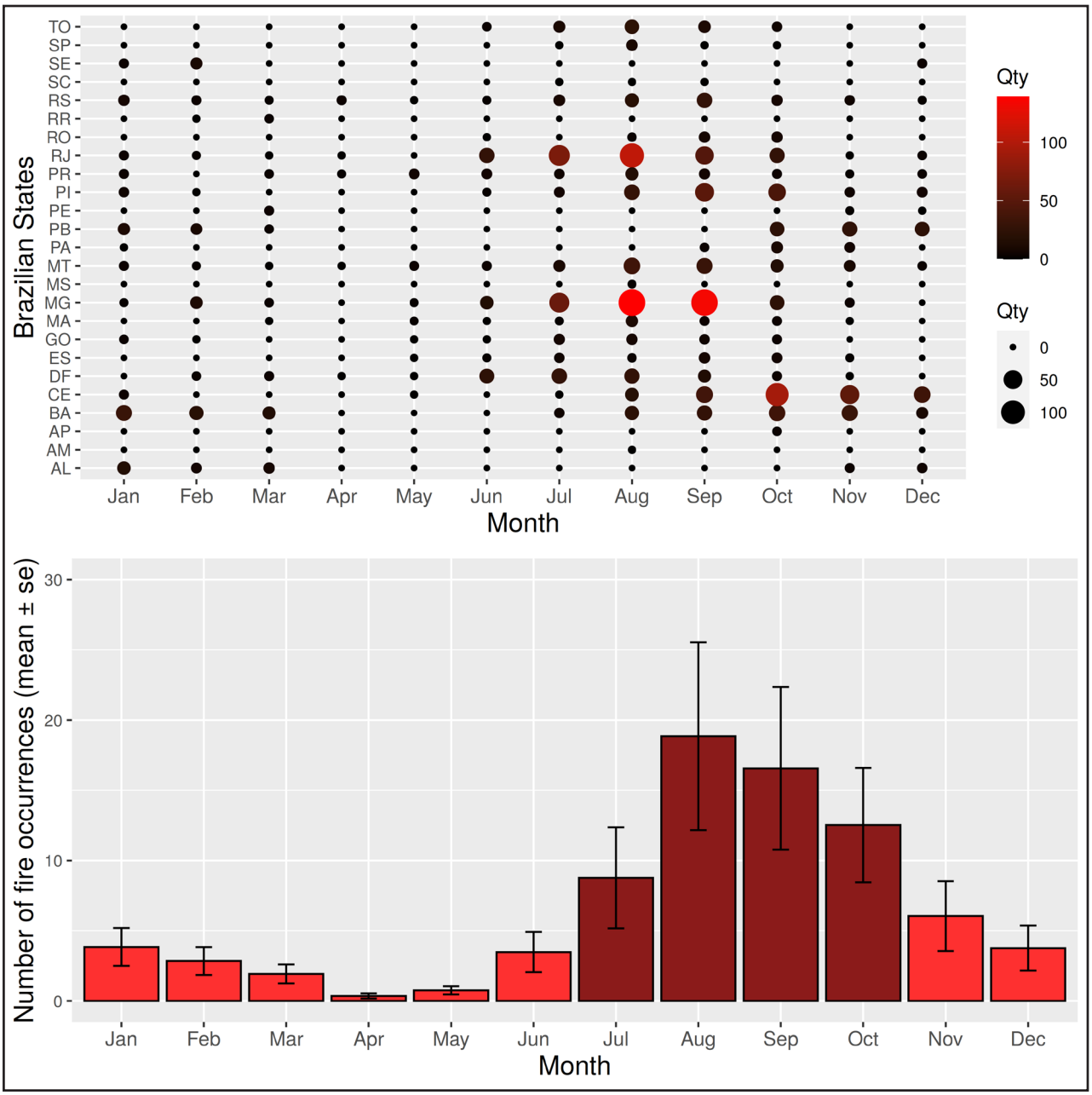
The number of fires was higher from July to October ($p>0.05$), corresponding to the critical period for fires in Brazilian federal PAs, with a mean of 50.61 events per year (Figure 2).

4 DISCUSSION

The records without a specified fire cause, as well as those recorded as “unknown cause”, reveal a failure in the fire investigation or in the preparation of the ROIs, which need to be carefully filled out in order to issue a reliable report (IBAMA, 2007). The lack of regularity in the recording of forms and the incomplete data sent to PREVFOGO by several PAs may occur due to inadequate structure and insufficient personnel or the absence of basic information, such as the size of the burned area, geographical coordinates, cause of the fire and type of vegetation affected (IBAMA, 2007). This indicates the need for investment in training, equipment, and tools to obtain reliable data on the occurrence and prevention of fires in PAs (BONTEMPO; LIMA; RIBEIRO; DOULA; SILVA; JACOVINE, 2011).

The amount of fires caused by debris burning, arson, and “unknown cause” was similar to that found by Torres, Lima, Costa, Félix and Silva Júnior (2016), who evaluated federal PAs between 2008 and 2012. The fire causes mentioned above are the most common in the majority of regions, propitiated by human activities around PAs (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016).

Figure 2 – Number of fire occurrences by month and state in Brazilian federal protected areas from 2006 to 2012 (top graph). Mean and standard error (se) per month for fire occurrences in Brazilian federal protected areas from 2006 to 2012 (bottom graph)



Source: Authors (2023)

The socioeconomic activities developed by people trigger forest fires (TORRES; LIMA; COSTA; FÉLIX; SILVA JÚNIOR, 2016). Agricultural fires reach the surrounding vegetation, becoming the main cause of fires in tropical forests (BARLOW; PARRY;

GARDNER; FERREIRA; ARAGÃO; CARMENTA; BERENGUER; VIEIRA; SOUZA; COCHRANE, 2012). Fires caused by debris burning occur due to inadequate burning techniques for land preparation and pasture renewal, carried out between winter and early spring, when the vegetation is dry and there are favorable meteorological conditions for fire spread (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013).

Environmental awareness actions focused on the rational use of fire are important for landowners neighboring PAs to learn and properly apply burning techniques, in accordance with environmental legislation. The diagnosis of burning techniques used around PAs is essential for their managers to design and implement a participatory environmental education program (MAGALHÃES; LIMA; RIBEIRO, 2012).

Criminal fires have diverse and complex motivations and, therefore, it is crucial to know the period of occurrence of these fires to intensify surveillance in PAs (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013), aiming to prevent the crime and penalize those involved.

Fires with unknown or criminal causes also occur recurrently in countries with environmental characteristics different from Brazil. In Bohemia Switzerland National Park (BSNP), located in the Czech Republic, 83% of fires are of unknown cause (ADÁMEK; BOBEK; HADINCOVÁ; WILD; KOPECKÝ, 2015). In southern France, fires caused by arsonists account for 42% in areas larger than 100 hectares (including pyromaniacs, hunters, and fishermen), followed by unknown cause (30%) and negligence (20%) (GANTEAUME; JAPPIOT, 2013).

The results of this study corroborate with the low occurrence of fires caused by smokers or railroads reported in other studies. In the period between 1998 and 2002, the category “smoker” corresponded to 1.65% of the occurrences in protected areas, while the category “railroads” corresponded to 0.11% (SANTOS; SOARES; BATISTA, 2006). Whereas between 1994 and 1997, the category “smokers” corresponded to 6.1% and the category “railroads” corresponded to 1.6%, also being among the categories with the lowest occurrence (SOARES; SANTOS, 2002).

Lightning is the only cause of natural fires in Brazil, however, this type of fire is not frequent, corresponding to less than 1.5% of reported cases in PAs (SANTOS; SOARES; BATISTA, 2006), as they occur predominantly in the rainy season (SILVA JUNIOR; TEODORO; DELGADO; TEODORO; LIMA; PANTALEÃO; BAIO; AZEVEDO; AZEVEDO; CAPRISTO-SILVA; ARVOR; FACCO, 2020), when combustible material has a higher humidity. The "miscellaneous" category has low occurrence and includes causes that do not fit into the other categories (SOARES, 1988).

The PAs in Acre and Rio Grande do Norte are located exclusively within the geographic boundaries of these states, i.e., they do not share their territories with neighboring states. Both states are among those with the lowest number of PAs nationwide, with 12 and 11, respectively (MMA, 2019). On the other hand, the state of Minas Gerais encompasses 107 federal PAs (MMA, 2019). However, most of the PAs (60%) in Minas Gerais exhibit unsatisfactory management effectiveness and 87% do not have a management plan, leading to noncompliance with the main objectives for which these PAs were created (LIMA; RIBEIRO; GONÇALVES, 2005).

The higher occurrence of forest fires in the state of Minas Gerais may be related to the extended dry season throughout most of the territory (SOARES; SANTOS, 2002). Minas Gerais also stood out regarding the number of forest fire occurrences between 1994 and 1997, with 62.7% of the reported cases, followed by São Paulo with 14.2% and Paraná with 9.6% (SOARES; SANTOS, 2002), which corroborates the results of the present study. In addition, from 1998 to 2002, Minas Gerais accounted for 50.3% of the reported cases, followed by Espírito Santo and Bahia, with 24.8% and 10.1%, respectively (SANTOS; SOARES; BATISTA, 2006).

Forest fires caused by debris burning have a greater chance of getting out of control when they occur during the dry period that predominates in Minas Gerais. During this critical period, farmers usually use fire to renew pastureland or for debris burning (PIVELLO, 2011). A large part of the population has no equipment to carry out prescribed burning. Moreover, there is a lack of knowledge about firefighting

techniques and the most favorable hours and period of the year for conducting prescribed burning (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013). Thus, it is essential that environmental agencies provide information on the rational use of fire, in order to minimize its negative effects, as well as raise awareness among the population about the most appropriate periods for burning, and the availability of alternative management techniques (RODRÍGUEZ; SOARES; BATISTA; TETTO; BECERRA, 2013).

In Minas Gerais, among fires of anthropic cause, those caused by arsonists occur in large proportion. These criminal events are difficult to prevent, since their motivations are diverse and complex. In this sense, it is essential to combine preventive and inhibitory actions, such as environmental education and surveillance (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013).

Ceará encompasses 46 federal PAs, of which three also cover neighboring states (MMA, 2019). The climate is hot and dry, with high average temperatures (23 to 27ºC) and negative annual water balance (BARRETO; SANTOS; CRUZ, 2012). These characteristics favor the ignition and spread of fire (SOARES; SANTOS, 2002).

In Rio de Janeiro, a maximum fire alert was declared in October 2007 by the State Secretary of the Environment (SEA, in Portuguese) and the State Forestry Institute (IEF, in Portuguese), due to the extended dry season that favored the increasing number of fire occurrences in the state (IEF/RJ, 2007). It is worth noting that there are many municipalities in Rio de Janeiro, especially the state capital, with sugarcane crops, where management is based on debris burning (FERNANDES; COURA; SOUSA; AVELAR, 2011).

The higher occurrence of fires between July and October is due to the dry season experienced by most of the Brazilian territory and corresponds to the period between winter and spring. During this period, farmers commonly use fire to manage their agricultural areas, despite the low humidity of the combustible material on the ground and the favorable meteorological conditions for fire propagation (SOARES; SANTOS, 2002). Furthermore, it is worth mentioning that frosts, which are common in the southern region of the country, create favorable conditions for fires to occur (SEGER;

BATISTA; TETTO; SOARES; BIONDI, 2018). The fires in PAs reported between 1994 and 1997 by Soares and Santos (2002) were concentrated in a similar period, with 82.4% of the occurrences from June to October. The same pattern was observed by Santos, Soares and Batista (2006) between 1998 and 2002, in which 68.9% of the fires occurred in the same months. Arson can occur throughout the year, under the most varied meteorological conditions, and tend to affect larger areas when they occur in the dry season (SOARES; SANTOS, 2002). In order to reduce such occurrences, environmental education and surveillance actions are essential, especially during the critical fire period (TEBALDI; FIEDLER; JUVANHOL; DIAS, 2013). Knowledge about the months with the highest occurrence of fires is of utmost importance, since it allows planning more effective preventive actions (SOARES; SANTOS, 2002). Fire prevention is more feasible, operationally and economically, than firefighting (SOARES; SANTOS, 2002). Combat actions include high costs related to setting up the operation and suppressing the fire itself. There are also economic losses due to the destruction of forest resources (JOLLY; COCHRANE; FREEBORN; HOLDEN; BROWN; WILLIAMSON; BOWMAN, 2015).

5 CONCLUSIONS

The main causes of forest fires in federal PAs from 2006 to 2012 were “unknown”, “debris burning”, and “arson”. The high number of fires recorded with an unknown cause reveals a need for improving the investigation of fire causes. The fires caused by debris burning, in turn, point to a need for environmental education actions within the communities surrounding the PAs, as well as technical guidance on the rational use of fire. The recurrence of fires caused by arsonists indicates that surveillance also needs to be improved.

The period with the highest fire occurrence was from July to October, when PAs managers should be ready to execute firefighting actions that were planned during the period of lowest occurrence (November to June).

The Brazilian state with the highest occurrence of fires in federal PAs during the evaluated period was Minas Gerais, and debris burning was the main cause recorded. The state of Piauí also stood out, since there was a significant number of fire occurrences recorded even though there is a small number of federal PAs in its territory.

The diagnosis of fires in Brazilian federal PAs regarding their causes and period of greatest occurrence enables the development of prevention and firefighting strategies suited to each situation. Failures in filling out the ROIs could be minimized through training of PA personnel, especially fire brigades, thus providing information for improving environmental education and surveillance programs.

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