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Biology-Ecology

Long-term detection of active fires in a Neotropical National Forest: implications for management

Detecção a longo prazo de incêndios ativos em uma Floresta Neotropical Nacional: implicações para o manejo

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ABSTRACT

Fire, depending on its intensity, frequency, and duration, can have undesired and pernicious effects in natural protected areas (NPAs). However, little is known about fire dynamics in NPAs located in developing countries. In this paper, we address the following question: How often, on an annual basis, can a natural protected area near a densely populated urban center experience wildfire? To answer this, we mapped and classified active fires in the Brasília National Forest (Federal District, Brazil) over a twenty-year period (2001–2020). A total of 1,339 active fires were detected during this period, with occurrences recorded every year. Most active fire hotspots were concentrated in areas dominated by forest plantations, grasslands, savannas, and natural forests. A significant increase in fire detections was observed after 2009. The fact that fires occurred annually highlights the need for (i) a greater number of firefighters and (ii) enhanced environmental education campaigns about fire in the areas surrounding the NPA.

Keywords: Wildfire; Prescribed Fire; Wilderness management

RESUMO

Fogo, dependendo de sua intensidade, frequência e duração, pode ter efeitos indesejados e nocivos em áreas naturais protegidas (ANPs). No entanto, pouco se sabe sobre a dinâmica do fogo em ANPs localizadas em países em desenvolvimento. Neste artigo, abordamos a seguinte questão: com que frequência, em termos anuais, uma área natural protegida próxima a um centro urbano densamente povoado pode sofrer queimadas? Para responder a essa pergunta, mapeamos e classificamos focos ativos de incêndio na Floresta Nacional de Brasília (Distrito Federal, Brasil) ao longo de um período de vinte anos (2001–2020). Um total de 1.339 focos ativos foi detectado durante esse período, com ocorrências registradas todos os anos. A maioria dos focos ativos de incêndio se concentrou em áreas dominadas por plantações florestais, pastagens, savanas e florestas naturais. Um aumento significativo nas detecções de fogo foi observado após 2009. O fato de que os incêndios ocorreram anualmente destaca a necessidade de (i) um maior número de brigadistas e (ii) campanhas de educação ambiental mais intensas sobre o uso do fogo nas áreas do entorno da ANP.

Palavras-chave: Incêndios florestais; Fogo prescrito; Manejo de áreas naturais

1 INTRODUCTION

Fire plays a fundamental role in shaping the structure and function of fire-prone ecosystems (Gil-Romera et al., 2014; Tucker & Kashian, 2018). Key ecological processes such as flowering (Fidelis & Zirondi, 2021), resprouting (Day, 2021), animal migration (Holdo et al., 2007), evapotranspiration (Poulos et al., 2021), and exotic species invasion (Fisher et al., 2009) are, to some extent, regulated by fire. Nonetheless, fire can also have catastrophic effects when it occurs with both high intensity and long duration (Gliessman, 2014). In such cases, it may lead to severe impacts on biological diversity (Foulkes et al., 2021; Tomas et al., 2021) and air quality (Reddington et al., 2015).

In many natural protected areas (NPAs) around the world, including those in Brazil, fire is often perceived as a threat to biodiversity (Durigan & Ratter, 2016; Barradas et al., 2020), as wildfires can have disastrous effects (Tomas et al., 2021) that, in the interest of conserving ecosystems and the services they provide, must be avoided at all costs. Nevertheless, despite the ecological importance of fire, few studies have quantified its frequency and magnitude within NPAs in savanna-dominated biomes (see Morelli et al., 2009; Vallejo, 2016), or mapped wildfire risk in these areas (Santos et al., 2018).

Understanding fire dynamics is essential information to be incorporated into management plans aimed at protecting biodiversity and other natural resources (e.g., forest stands, water) within NPAs. In this regard, special attention must be given to NPAs located near densely populated urban areas, such as those in the Brazilian neotropical savanna (regionally known as the Cerrado). These NPAs exist in a particularly delicate context due to three main factors: (i) they are situated in regions with a long (six-month) and well-defined dry season (see Brito et al., 2022); (ii) they are surrounded by urban centers; and (iii) they are subject to human activity from populations with diverse income levels and limited awareness of the social and ecological consequences of human-caused wildfires. This combination of factors significantly contributes to the occurrence of anthropogenic wildfires.

Understanding fire dynamics in this context can offer valuable insights for fire management strategies in other parts of the world that share similar environmental and social conditions.

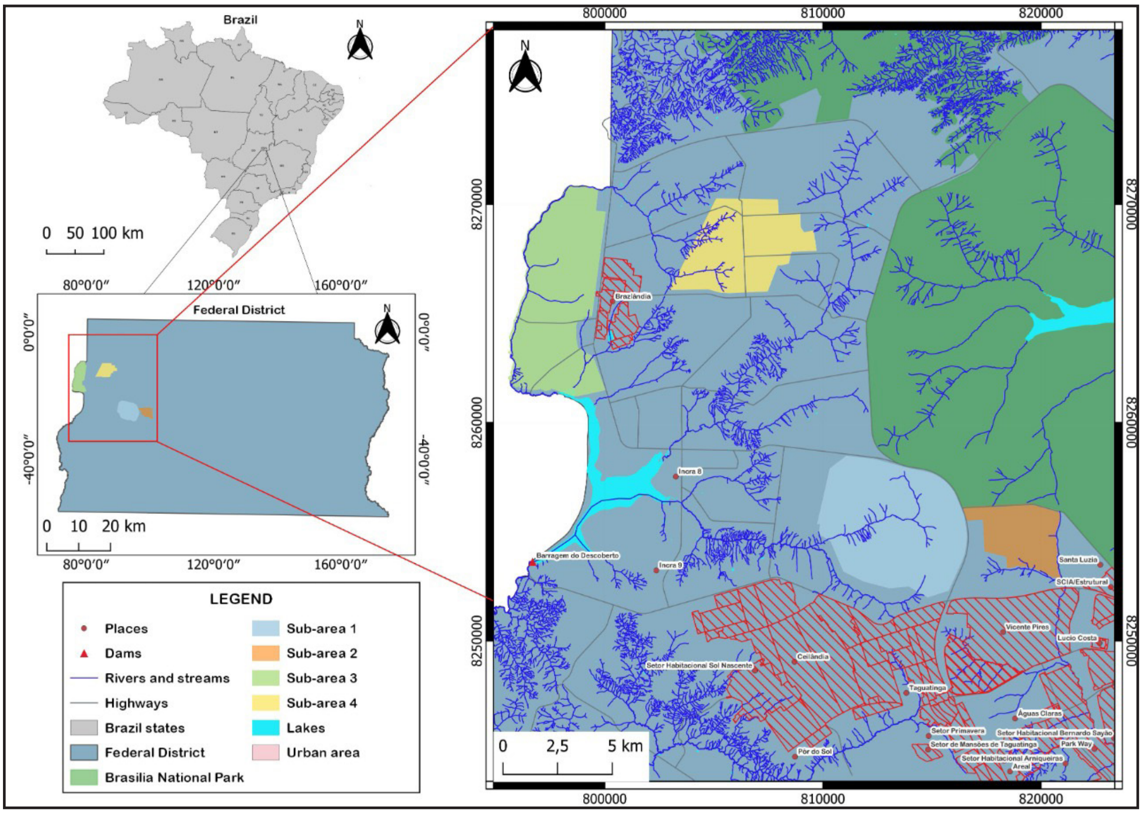
The objective of this study was to answer the following question: How often, on an annual basis, can natural protected areas located near densely populated urban centers experience wildfires? To address this, we mapped and classified active fires in the Brasília National Forest (BNF) over a twenty-year period (2001–2020). The BNF is a natural protected area within the Brazilian Neotropical Savanna and, unlike many others, it is a disjunct NPA composed of four separate sub-areas. Because the BNF is adjacent to urban centers in a developing country, its sub-areas are exposed to a wide range of anthropogenic influences that may trigger fires, thereby increasing the complexity of fire prevention and control efforts.

2 METHODS

The Brasília National Forest (BNF) is located within Brasília, Federal District, Brazil, and was established in 1999. According to the Köppen-Geiger classification, the climate is tropical savanna (Aw), with two distinct seasons: a cool, dry winter (April to September) and a hot, wet summer (October to March) (Alvares et al., 2013). The mean annual precipitation and temperature are 1,501 mm and 22 °C, respectively. June is the coldest and driest month, with only 7 mm of rainfall and a mean temperature of 18.5 °C. January is the wettest month, with an average rainfall of 263 mm. September is the hottest month, with a mean temperature of 21.9 °C. Relative humidity frequently drops below 20% during the driest months. The elevation of the area is approximately 1,000 m a.s.l. (ICMBIO, 2020).

The BNF is a disjunct natural protected area (NPA) composed of four sub-areas: 1, 2, 3, and 4. Sub-areas 1 (3,353 ha) and 2 (996 ha) are located within the municipalities of Taguatinga and Vicente Pires, respectively, while sub-areas 3 (3,071 ha) and 4 (1,925 ha) are situated in the municipality of Brazlândia. Illegal settlements have been reported in sub-areas 2 and 3. Among the 31 administrative regions that make up the Federal District, Taguatinga, Vicente Pires, and Brazlândia rank as the 4th, 14th, and 17th most populous, with populations of approximately 208,000; 73,000; and 64,000 inhabitants, respectively (Vasconcelos et al., 2019).

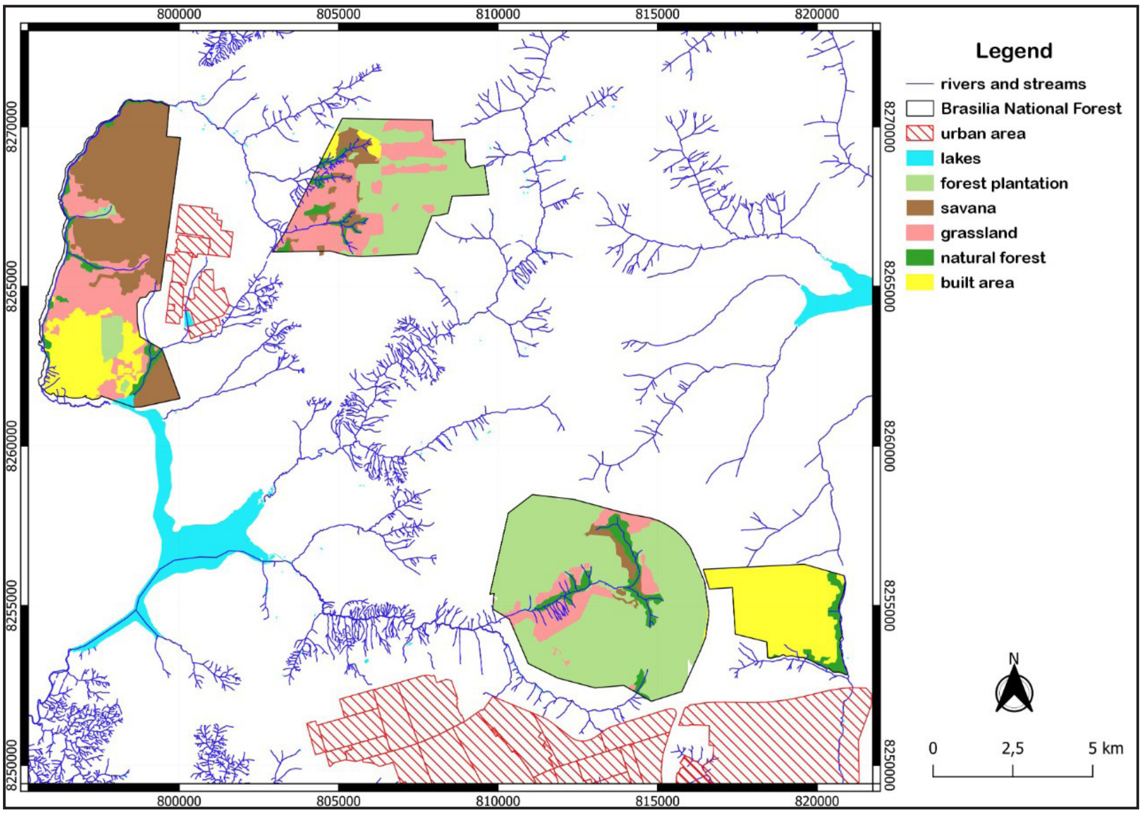
Figure 1 – Location of the four sub-areas of the Brasilia National Forest in Brasília, Federal District, Brazil



Source: Authors (2025)

Regarding land cover, the BNF contains a wide variety of ecosystems, including gallery forests, wetlands, grasslands, savannas, and forest plantations (*Pinus* spp. and *Eucalyptus* spp.) (ICMBIO, 2020). The ecological diversity within the NPA is under constant threat due to the unregulated expansion of settlements around the BNF, which compromises its environmental quality. Sub-areas 1 and 4 best represent the savanna-dominated biome regionally known as the Cerrado (Figure 2). Natural forest (6%), grasslands (27%), and savannas (19%) together account for 52% of the BNF's total area. However, forest plantations also occupy a significant portion, covering 32% of the land. These plantations include springs and important recharge zones for streams such as Das Pedras and Currais (both in sub-area 1), and Bucanhão and Capão da Onça (in sub-area 4). Roads within and surrounding the BNF are a source of concern for NPA managers, as their margins are often used for the illegal disposal of garbage, debris, and stolen goods.

Figure 2 – Land-cover within the four sub-areas of the Brasília National Forest



Source: Authors (2025)

2.1 Database

The cartographic database used in this study was obtained from official Brazilian government sources, including the Geoportal, the Brazilian Institute of Geography and Statistics (IBGE), and the National Institute for Space Research (INPE). The Geoportal provides information related to the Spatial Data Infrastructure of the Federal District, while IBGE supplied the national state grid. Data on fire frequency and magnitude were obtained from INPE (Table 1).

Table 1 – Geospatial data used in the present study

Cartographic products	Year	Source
BNF boundaries	2020	Geoportal
Highways	2020	Geoportal
Dam	2020	Geoportal
State boundaries	2020	IBGE
Satellite Imagery	2020	Sentinel 2
Active fires	2001 to 2020	INPE

The monitoring of wildfires and forest fires in Brazil is carried out by the Burning and Forest Fire Monitoring Program of the National Institute for Space Research (INPE). Since June 1998, the program has used thermal infrared radiation to detect and map fire events, focusing on the most suitable spectral intervals for fire detection, specifically 3.5–4.2 μm and 4.4–5.0 μm. This monitoring relies on data from various polar-orbiting and geostationary satellites, including those from the NOAA, GOES, MSG-3, AQUA, TERRA, MODIS, VIIRS, and METOP-B/C series, which observe the Earth's surface daily or multiple times per day.

2.2 Mapping active fires

The data were tabulated in shapefile format and subsequently imported into the open-source software QGIS 3.10. During data processing, point vector files were generated in shapefile format, initially using the WGS 84 geographic coordinate reference system and later reprojected to SIRGAS 2000, UTM Zone 22S.

During the analysis, an accumulation of points was generated, providing information on fires occurring each year within the boundaries of the Brasília National Forest. These data served as the basis for creating density maps. The Kernel density estimator, integrated within the QGIS Heat Map tool, was employed for map generation. Using the Heat Map function, a matrix file was produced by summing the stack of *n* circular rasters with radius *h* for each point in the input dataset (Oliveira & Oliveira, 2017), as described by the following function:

$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \quad (1)$$

Where:
K = Kernel function;
h = search radius;
x = position of the center of each cell in the output raster;
Xi = position of point i coming from the centroid of each polygon;
n= total number of active fires.

The Kernel density estimator defines a circular area around each sample point corresponding to its radius of influence. It then applies a mathematical function that assigns a value of 1 at the point's location, decreasing to 0 at the boundary of the neighborhood. The value of each cell is determined by summing the overlapping Kernel values and dividing by the area of the search radius (Silverman, 1986; Souza et al., 2013; Oliveira & Oliveira, 2017; MPAP, 2020).

In mapping regions with higher concentrations of active fires, the following classification was applied: very low (blue), low (green), medium (yellow), high (orange), and very high (red). This color scale aids in analysis, as warmer colors (e.g., red) indicate a high concentration of hotspots, while cooler colors (e.g., blue) signify a low density of hotspots (Souza et al., 2013; Oliveira & Oliveira, 2017; MPAP, 2020).

After mapping active fires, the raster data were reclassified, rendering the image using the false-color single-band option with five categories, following the method outlined by Walraven and Lucassen (1992). For each active fire, a polygon algorithm with a 500 m radius and 20 m pixel resolution was applied to enhance the visualization of fire spot concentrations.

To map areas within the BNF with higher fire frequencies, the vector layers representing hotspots for each year were merged using the “Merge Vector Layers” tool to create a cumulative layer spanning 2001 to 2020. Subsequently, the same procedure was applied to visualize the intensity of fire hotspots by rendering the image in a single-band false-color mode with five categories: very low frequency (blue), low frequency (green), medium frequency (yellow), high frequency (orange), and very high frequency (red).

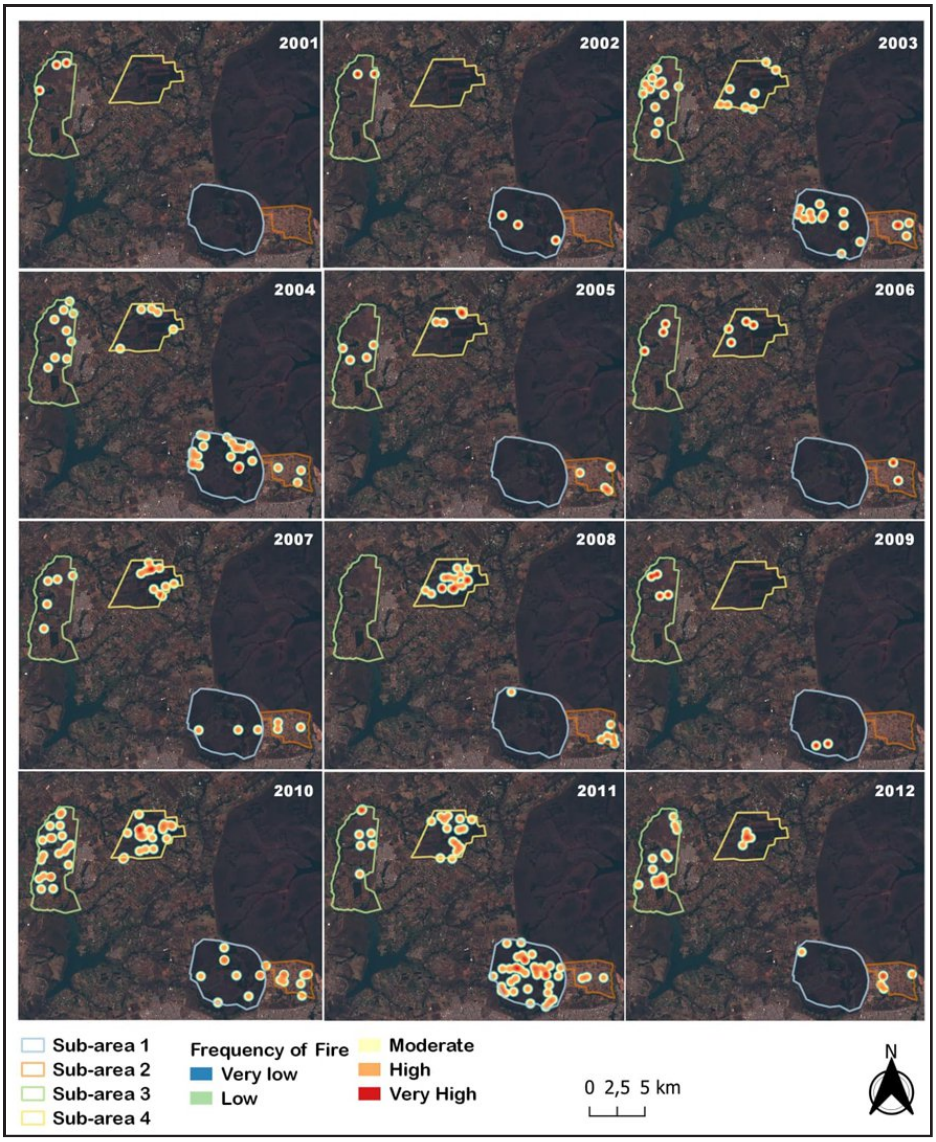
2.3 Statistical analysis

The residuals of the annual number of active fires in the sub-areas were assessed for normality using the Shapiro-Wilk test, and homoscedasticity was checked using Levene’s test. The data exhibited violations of both normality and homoscedasticity assumptions. Consequently, Welch’s ANOVA (unequal variance) was employed to examine differences over time. All statistical analyses were performed using PAST software, with the significance level set at $\alpha < 0.05$.

3 RESULTS

Active fires frequently occurred in all four sub-areas of the BNF (Figures 3 and 4). A total of 1,339 active fires were detected throughout the 20-year period. Sub-area 1 accounted for 424 (31.6%) of the active fires, while sub-areas 2, 3, and 4 experienced 89 (6.6%), 294 (22.9%), and 532 (39.7%), respectively (Figure 5). Virtually all parts of each sub-area experienced fire (Figure 6). The mean annual number of active fires was 67. Most fire hotspots were concentrated in areas dominated by forest plantations, grasslands, savannas, and natural forests.

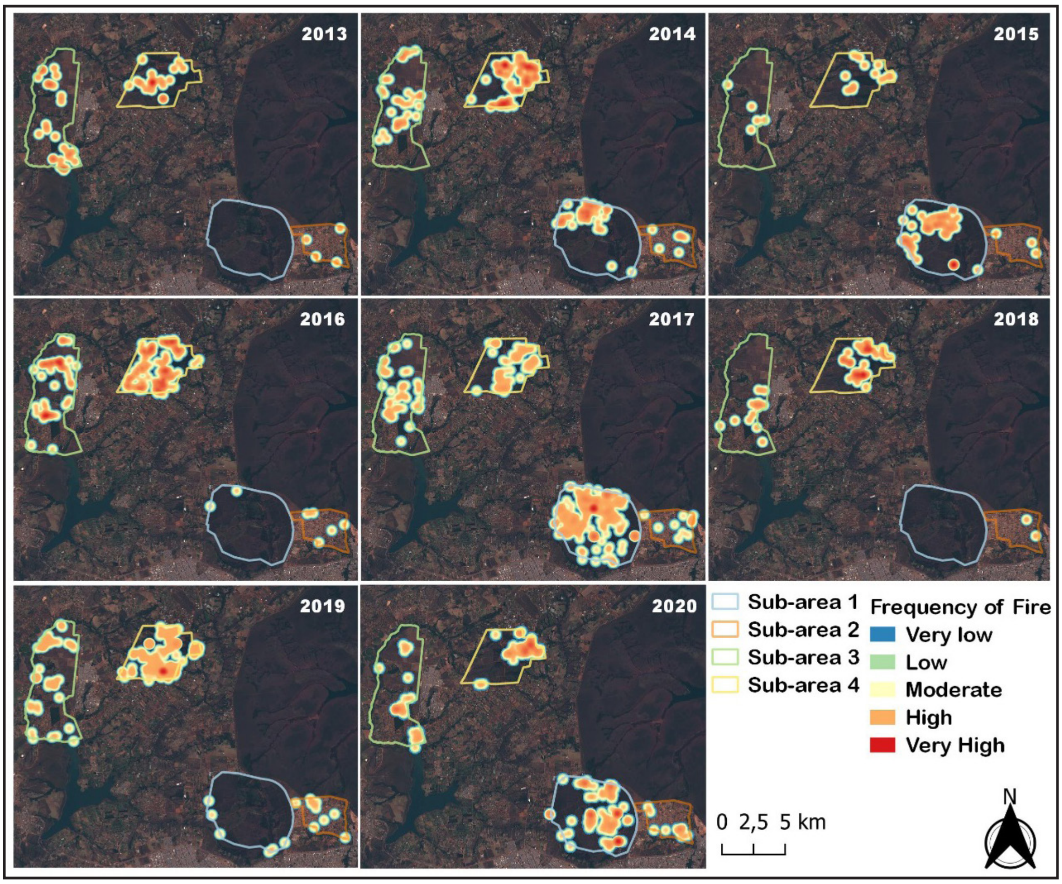
Figure 3 – Maps of annual cumulative active fire from 2001 to 2012 in the Brasilia National Forest



Source: Authors (2025)

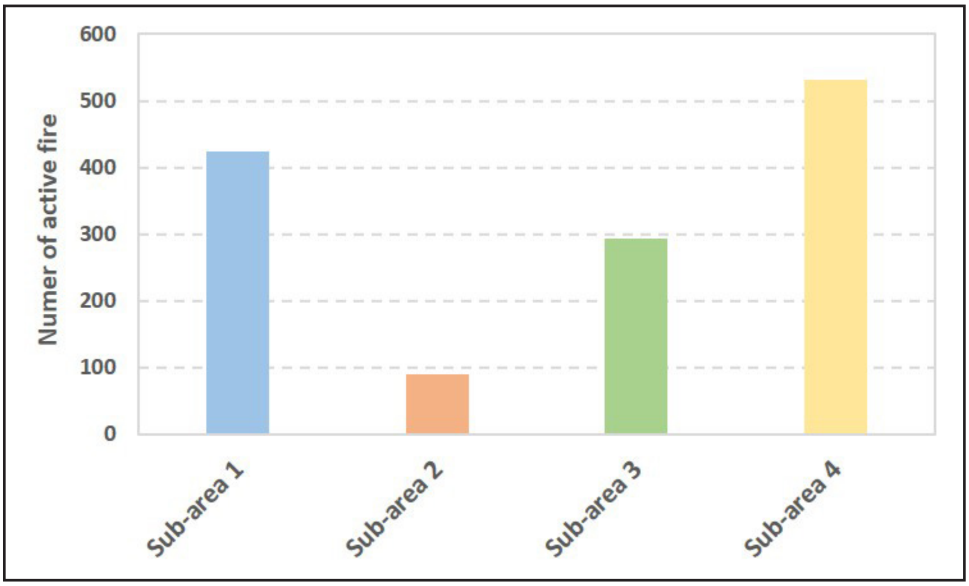
The years 2017 and 2019 recorded the highest number of active fires, while 2001 and 2002 had the lowest. An increasing trend in the number of active fires has been observed since 2009 (Figure 7a, b). Most fire hotspots were concentrated in areas dominated by forest plantations and grasslands. The occurrence of active fires was lower during the 2001–2009 period (17 ± 13 fire spots per year; mean ± standard deviation) compared to the 2010–2020 period (107 ± 79 fire spots per year), and this increase was statistically significant ($p = 0.003$). The highest number of active fires recorded in a single year was 275, occurring in 2017.

Figure 4 – Maps of annual cumulative active fire from 2013 to 2020 in the Brasilia National Forest



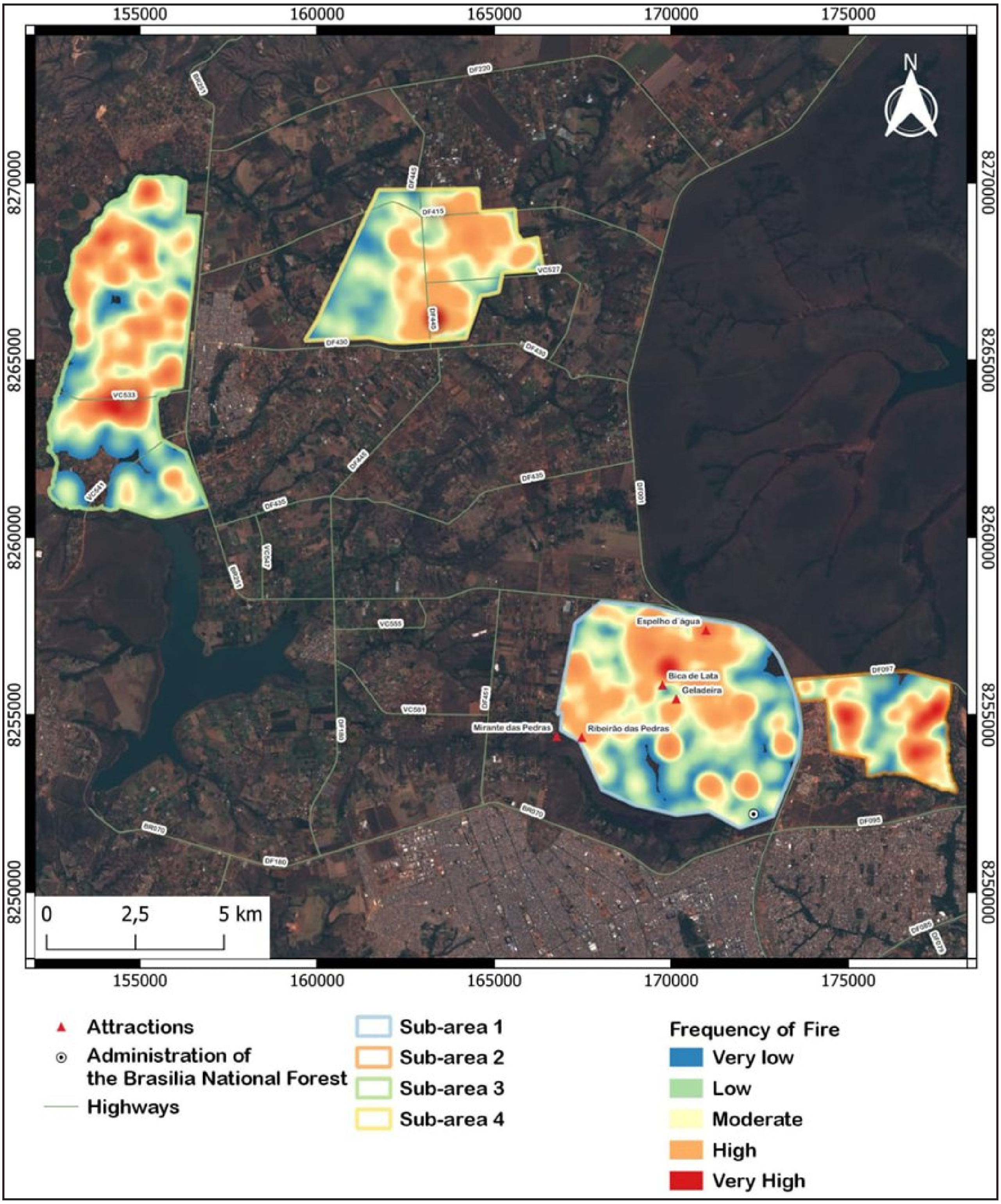
Source: Authors (2025)

Figure 5 – Total number of active fires in each sub-area during 2001 to 2020



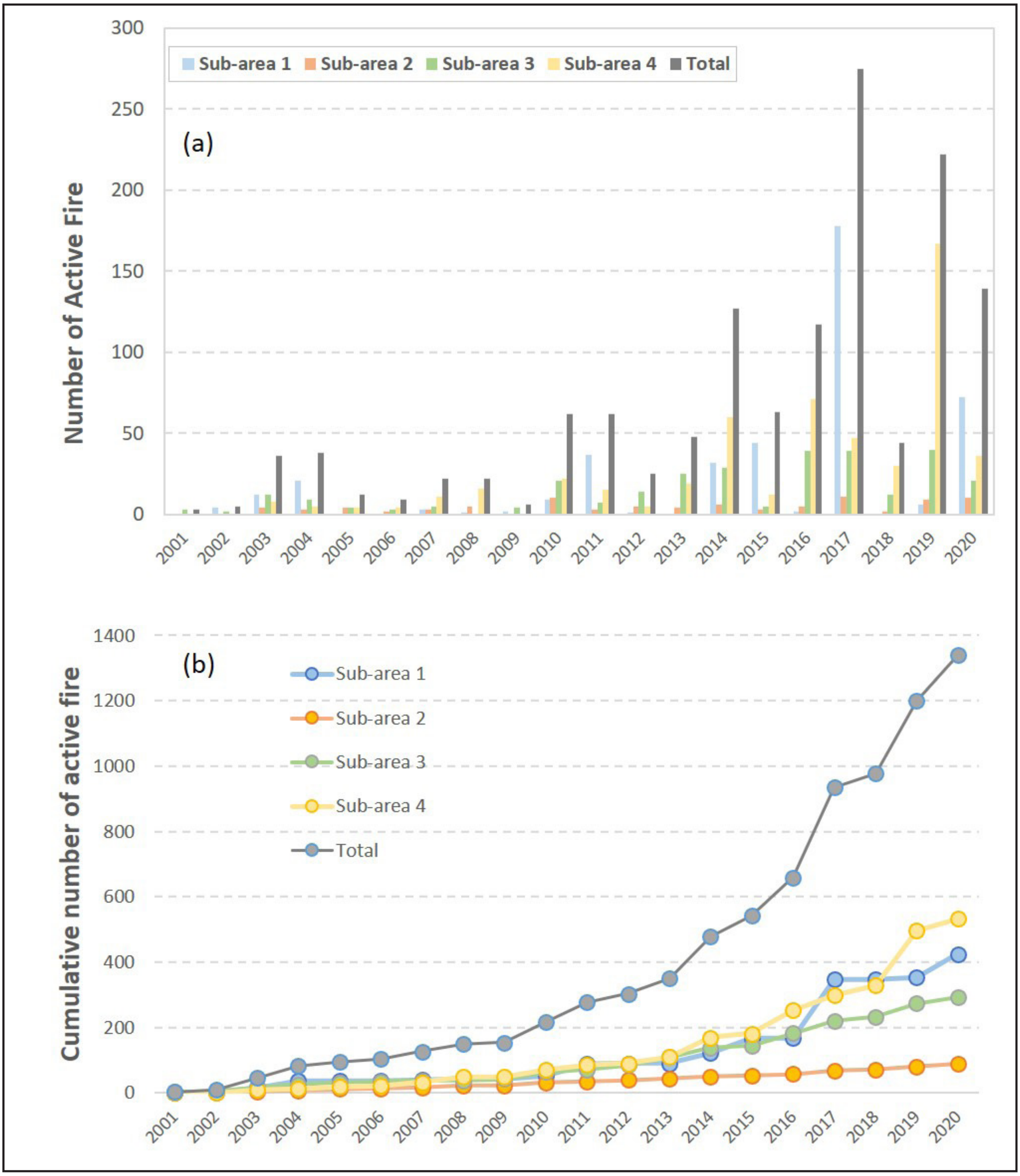
Source: Authors (2025)

Figure 6 – Frequency of active fire in the Brasília National Forest (2001 to 2020)



Source: Authors (2025)

Figure 7 – (a) Number of active fires over 2001-2020 in the BNF; (b) Cumulative number of active fire within each sub-area and total



Source: Authors (2025)

4 DISCUSSION

Active fires occurred in all years analyzed. Sub-areas 1 and 4, which are less populated compared to sub-areas 2 and 3, exhibited the highest frequency of active fires. These two sub-areas are predominantly covered by natural vegetation and forest plantations. Two main factors may explain the higher fire frequency in sub-areas 1 and 4: (i) natural vegetation and forest plantations accumulate more biomass (both above and below ground) and soil organic matter, increasing the available fuel during the dry season; and (ii) the very low population density in sub-areas 1 and 4 may reduce the number of residents actively managing and stewarding the land. When people reside in an area, they often develop a sense of ownership and responsibility, which encourages better care and management (Ostrom, 1990).

There was a significant increase in the number of fires after 2009. Possible reasons for this rise include: (i) a reduction in the number of firefighters available in the NPA; (ii) more favorable climatic conditions, such as drought, leading to an increase in fire occurrences; and (iii) an influx of visitors. These factors may act independently or synergistically, complicating the management of the NPA. Regarding climatic conditions, this factor could be particularly crucial given the anticipated increase in the frequency of climate extremes (van der Wiel & Bintanja, 2021) and the high costs associated with firefighting efforts (Hope et al., 2016).

Regarding the number of employees involved in firefighting, in 2005 the BNF had 48 hired firefighters who worked fixed and mobile surveillance shifts across 24 posts, operating 24 hours a day in the four BNF sub-areas (IBAMA, 2007). However, by 2011, this number had decreased to 44 employees (ICMBIO, 2021). This reduction can be attributed to financial difficulties faced by the environmental agency, the Chico Mendes Institute for Biodiversity Conservation (ICMBIO), in recent years. Consequently, the number of permanent employees declined and was gradually replaced by temporary workers hired as forest firefighters (ICMBIO, 2020). Currently, the BNF has only two security cabins operating 24 hours, both located at the administrative office within sub-area 1. These cabins are staffed by a total of four employees (two forest brigades and two security guards) hired through an outsourced company. At the time of this study, there was a total of nine employees, seven of whom were firefighters working 12-hour shifts. Their responsibilities include surveillance, firefighting, and fire prevention within the NPA. Given that the BNF is a large and disjunct NPA, this number of employees is insufficient for effective management. The highest number of fires (275) was recorded in 2017. Given that there was a major water shortage in the Federal District (see Lima et al., 2018), one could argue that this climatic condition would have favored fire occurrence. From 2015 to 2018, there was a reduction of annual rainfall around 20 to 30% (Lima et al., 2018) coinciding with an increase in the number of fires. Therefore, climatic conditions may contribute to explaining the increase in fires from 2015 to 2017.

4.1 Implications for the management of the natural protected area

Effective wildfire management requires a multifaceted approach that goes beyond the exclusive policy of fire suppression (North et al., 2015). In this context, measures aimed at enhancing environmental awareness about the ecological and social impacts of fire should be central, as human activities can significantly alter fire regimes (Taylor et al., 2016). The BNF received 70,623 visitors in 2019 (Breves et al., 2020), including hikers, cyclists, joggers, researchers, students, and other recreational users. The diversity and large number of visitors raise management concerns due to common incidents of fires caused by vandalism (Félix et al., 2021). For instance, in 2020, a three-day fire started by three minors resulted in the burning of approximately 160 hectares before being fully extinguished (Félix et al., 2021). Therefore, low-cost tools such as environmental education campaigns and educational booklets (printed and/or digital) addressing the problems caused by forest fires could be implemented to raise awareness among visitors and residents in the surrounding areas of the NPA.

Finally, improvements in NPA management require hiring a larger workforce, as well as acquiring additional vehicles and equipment to maximize the efficiency of firefighters across the four sub-areas. Implementing these measures will enhance inspection, prevention, and firefighting efforts. Moreover, due to the well-demarcated climate of the region (see Brito et al., 2022), most fires in the BNF occur during the dry season (Morelli et al., 2009; ICMBIO 2016). We suggest increasing the number of firefighters and strengthening environmental education initiatives to address the effects of fire both before and throughout the entire dry season.

5 CONCLUSIONS

Active fires occurred in the NPA every year analyzed. These fires were more frequent in sub-areas 1 and 4. The annual occurrence of fires highlights the need for (i) an increased number of firefighters and (ii) enhanced awareness campaigns about fire prevention in the surrounding areas of each BNF sub-area.

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