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Spatialization of fire occurrences in Brazil within the context of the fire events detected by the Fire Panel

Espacialização de ocorrências de fogo no Brasil dentro do contexto dos eventos detectados pelo Painel do Fogo

Jack Endrick Pastrana Mojica[*], Henrique Bernini[**], Daniela Ramos Guimarães de Faria[***], Eduardo Hauck Antunes[****], Leonardo Siqueira[****], Camila Souza Silva[******], Sarah Correia Fontoura[*******], Fernando Rodovalho[********]

[*]Centro Gestor e Operacional do Sistema de Proteção da Amazônia -CENSIPAM, jack.mojica@sipam.gov.br
[**]Centro Gestor e Operacional do Sistema de Proteção da Amazônia -CENSIPAM, henrique.bernini@sipam.gov.br
[***]Centro Gestor e Operacional do Sistema de Proteção da Amazônia -CENSIPAM, eduardo.antunes@sipam.gov.br
[****]Ministério da Fazenda, danielargf@gmail.com
[*****]Corpo de Bombeiros Militar –CBM RS, bombeiro.siqueira@gmail.com
[******]Instituto Chico Mendes de Conservação da Biodiversidade-ICMBIO, camila.s-silva.@icmbio.gov.br
[*******]Instituto Chico Mendes de Conservação da Biodiversidade-ICMBIO, sara.fountoura@icmbio.gov.br
[********]Instituto de Pesquisas Ecológicas –IPÊ, fvrodovalho@gmail.com

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Abstract

The reliability of fire information in Brazil is essential for the most efficient deployment of firefighting teams. In Brazil, information from remote sensing has been fundamental in guiding the management and monitoring of fire in rural areas. During a firefighting operation and the observation of a fire or burning, the collection of data in the field becomes essential to complement the information the observation data on the ground. This research analyzed the relationship between the data collected by the institutions involved in fire control and monitoring, and the fire events provided by CENSIPAM, with the objective of carrying out a first methodological approximation of these two forms of fire data collection. The second step was to analyze the characteristics of the occurrences that were cross-referenced using the properties of the remote sensing data. To do this, it was necessary to build a model for cross-referencing data in Posts and extract data from the fire reports provided by ICMBio, PREVFOGO and the Military Fire Brigades (CBM). A low level of spatial correspondence was obtained between the occurrences collected in the field and the fire events. As a consequence,has been taken advantage of the analysis possibilities offered by remote sensing data, such as spatial parameters that reveal different occurrence patterns due to the type of fire.

Keywords:
Wildland fire, Fire occurrences, Firefighting brigades, Federal Conservation Units, Indigenous Lands.

Resumo

A fidedignidade das informações do fogo no Brasil, é fundamental para o acionamento mais eficiente das equipes de combate à incêndios. No Brasil, informações a partir de sensoriamento remoto têm sido fundamentais para orientar as ocorrências de fogo em áreas rurais. Durante um acionamento de

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combate e observação de um incêndio ou queimada, a coleta de dados em campo se torna então basilar para complementar as informações de observação da terra. Esta pesquisa analisou a relação entre os dados coletados pelas instituições envolvidas no combate ao fogo, e os eventos de fogo fornecidos pela plataforma Painel do Fogo com o objetivo de realizar uma primeira aproximação metodológica destas duas formas de coleta de dados. Em um segundo momento se analisou as características das ocorrências que foram cruzadas usando as propriedades dos dados de sensoriamento remoto. Para isso foi necessário construir um modelo para o cruzamento de dados em PostGis e extrair dados dos relatórios de queimas fornecidos pelo ICMBio, PREVFOGO e os Corpos de Bombeiros Militares (CBM). O resultado evidenciou uma baixa correspondência espacial entre os dados de campo e os eventos de fogo. Como consequência, pouco têm se aproveitado das possibilidades de analises ofertado pelos dados de sensoriamento remoto, a exemplo de parâmetros espaciais que revelam diferentes padrões de ocorrência em virtude do tipo de fogo.
Palavras-chave:
Incêndios florestais, Ocorrências de fogo, Brigadas de combate, Unidades de Conservação Federais, Terras Indígenas.

I. INTRODUCTION

The lack of standardization of the data provided by the stakeholders involved in fire control in Brazil represents a challenge in understanding the current reality of the fire data paradigm in Brazil, which is essential for using quantitative data in decision-making (MORELLO et al., 2020). This apparent standardization, as addressed in this research, refers to the absence of a systematic national understanding of the definition of the dataset to be collected during occurrences, leaving it up to the stakeholders to define how and which data will be collected, based on the conditions of their biomes, their operational capacities, their legal attributions, among other factors.

Given that this problem encompasses multidisciplinary factors, this research aims to understand how these different dataset sources are collected and how they can correlate with fire occurrence data from remote sensing. It is believed that the integration of these types of databases contributes at different moments of Integrated Fire Management – IFM (i.e MIF in portuguese). This is because the intersection one database allows learning from past dataset, which in turn generates spatiotemporal patterns. With these patterns, it is possible to assess prevention, mitigation, preparation, response, and recovery techniques (Law No. 12,608/2012).

Using a modeling method to track wildland fires, the Management and Operational Center of the Amazon Protection System – Censipam, operationalized a system based on earth observation satellites for dispatching firefighting resources based on selected fire perimeter by Brazilian firefighting teams. The tracking, based on the fire events product, is updated in Near Real Time – NRT resolution (BERNINI et al., 2023) and covers

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the entire brazilian territory as well as the entire Amazon biome, including the countries that are part of the Amazon Cooperation Treaty Organization (ACTO).

When operationalized, this system revealed that fire diversity generates different behaviors that allows differentiation and prioritization of fire combat in rural areas. Driven by field dataset, it would be possible to confirm that the dispatching firefighting indicators are effective in guiding decision-making. Therefore, it becomes fundamental to the sample universe of field-collected dataset, as in Brazil there is no standardization in data collect (DE FARIA et al., 2022).

Currently, the main federal entities (IBAMA and ICMBio) dealing with fire use in Brazil, have actions centered on protected areas, with occasional dispatching in level 2 or 3 of an Incident Command System - ICS through the National Multi-Agency Integrated Coordination Center - CIMAN. These are usually observed by the requester of activation, which is generally centralized in the Military Fire Departments – CBM.

Additionally, with the IFM culture, Brazil has adopted practices such as prescribed burning for controlling natural landscapes that have been dealing with fire occurrences for thousands of years. Although such practices have mitigated fire occurrence in susceptible protected areas (DE ANDRADE et al., 2021), it is still necessary to improve the integration between remote sensing data with an integrated risk management system based on field data so that all entities involved in combat are monitoring not only fire occurrence, but also holistically observing the stakeholders of these entities to avoid duplicity of efforts (ANDERSON et al., 2019).

These actions involve limited and specific monitoring, which does not reflect the major fire occurrences in public areas without land use designation that are targets of deforestation, as explained above (MORELLI et al., 2019). Authors such as Dutra et al. (2022) and Barlow et al. (2023) consider that, to understand fire occurrence patterns, it is necessary to use remote sensing data to better represent the current reality in firefighting in Brazil regarding mining and gold mining activities in the region (HOFMANN et al., 2021; ANDERSON et al., 2023).

Thus, great part of the developed technological resources must be explored to complement the firefight reality, which also allows a database synergy to assess if the fire events that is being detected by the Fire Panel largely correspond to fire occurrences recorded by the stakeholders involved in fire occurrences, enabling the identification of land degradation patterns and the spatial relationship between the datasets.

In this context, there is an assumption that because the lack of normative instructions standardizing the actions of entities involved in fire combat and the gap in the integration of these databases, there is no consolidated basis in Brazil that allows a holistic view of fire occurrences. Therefore, studies like this have the

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potential to broaden knowledge between the relationship of wildland fire with society and nature, especially at this delicate moment of this relationship, which involves direct contact with this phenomenon.

II. MATERIALS AND METHODS

The method employed to achieve the objectives of this study consists of: 1 - establishing the field sample universe of fire occurrence reports provided by the stakeholders; 2 - spatializing and create match ups with the fire event data available on the fire panel platform, and; 3 - after the match up, conducting an analysis of the attributes contained in the fire event for fire occurrences filtered in the previous steps. It is important to emphasize that, to reach this level of inter-institutional synergy, Censipam periodically conducts seminars on the use of the data provided, creating an environment where information exchange allows understanding the real necessity to advance in the topic addressed by this study. In addition to the seminar, Censipam maintains an open data policy so that the entire user community can work with this data according to their own needs.

STUDY AREA

As shown in Figure 1, this study covers the entire Brazilian territory, since the reports of fire occurrences provided by different institutions involve Federal Units of the country from all regions. According to MapBiomas (2022), in the last decades (1985 and 2022), the national fire panorama mainly affected native vegetation in the national territory. Regarding seasonality, in the Amazon biome, the fire cycle begins during its austral winter in the southern hemisphere, mainly between August and November. In the Cerrado biome, the relationship between landscape and wildland fire stands out, where vegetation has adapted to natural fire occurrences, and for this reason, it has been widely managed in terms of prescribed burning.

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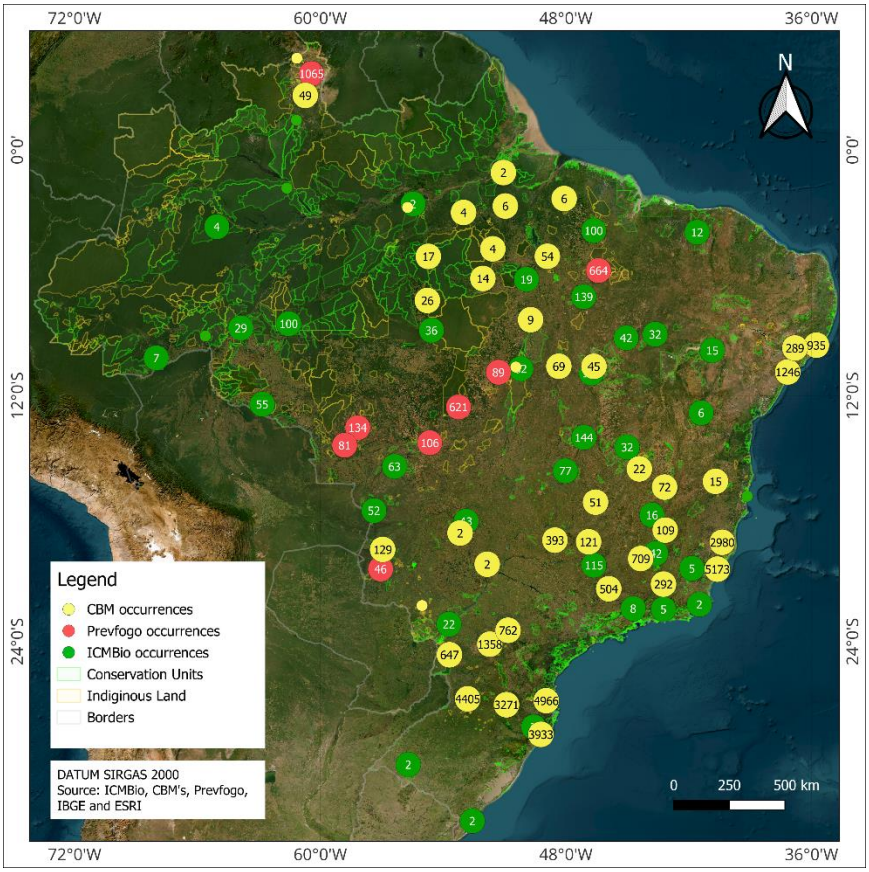

Figure 1 - Map of the spatial distribution of fire occurrences in the brazilian territory. (Source: the authors,2024).

Further, the relationship of the landscape with wildland fire, savannas, and grassland areas have been affected by 89.5% due to the increase and intensity of fire occurrences. Just like in the Cerrado, the vegetation cover of savannas in the Caatinga Biome has been the most affected by fire occurrences, with almost 76% of the biome burned, between the months of September, October, and December 2022. This dynamic corroborates with the increase in loss of native vegetation (SOUZA et al., 2020), mainly in areas with higher vegetation density.

In this context, pasture vegetation cover has been most affected in the Mata Atlântica biome (Santos Clemente et al., 2017), and works like Souza et al. (2020) mentioned that between 1985 and 2017, agriculture replaced large pasture fields. Therefore, fire practices are associated with the loss of vegetation in these areas. According to MapBiomas (2022), in the Pantanal, fire occurrences mainly happen in native vegetation, registering losses of almost 93.5%, while in the Pampa, the lowest vegetation losses are recorded, with grassland formations having the highest loss (89%), which so far, have been the least recurring compared to other biomes.

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FIRE COMBAT REPORTS COLLECTION

Fire occurrence reports from 2020 to 2022 were verified, necessitating a visual validation of the records to review the basic parameters for their spatialization. The analyzed database in this study includes reports from the Military Fire Departments (CBM) of Brazil, the Coordination of Integrated Fire Management at the Chico Mendes Institute for Biodiversity Conservation (CMIF/ICMBIO), and the National Center for the Prevention and Combat of Forest Fires at the Brazilian Institute of Environment (PREVFOGO/IBAMA).

The data workflow started with the verification of each of the reports, as well as the key attributes for the spatialization of occurrences. The following attributes were considered as a key: "date", "coordinates", "UF Code", "TI Name", "UCs Name". It is worth noting that in this work, data from CBM, PREVFOGO, and ICMBio reports that did not have coordinates were excluded from the information mapping process.

ICMBio monitors daily the active fires captured within and around Federal Conservation Units (UCs). From this service, CMIF contacts UC management to obtain detailed information on wildland fire type (whether it is firebreaks, prescribed burns, controlled burns, burns by isolated indigenous peoples, or whether it is a natural or anthropic fire). The number of people and aircraft involved, and a brief description of the prevention or firefighting activity being carried out are collected also. Some activities using fire are not detected by satellites, and managers send the information even without prior contact from the coordination, also sending the coordinate of the location, since it is not available on the platforms used in the monitoring phase (FIRMS/NASA, BDQueimadas/INPE, Alarmes/LASA, Fire Panel/ Censipam).

To exemplify the data format available among the studied institutions, Table 1 shows the tabulation of data provided by ICMBio. It can be seen that the attributes "date" and "UCs Name", "observations" and "coordinates" were filled in, facilitating the process of spatializing fire occurrences. Regarding the temporal scale, it is emphasized again that there is a record from 2020 to 2022. This temporal range was selected because the Fire Panel started the service in April 2020, allowing comparison of the reference and forecast dates of the reports with the information recorded on the Panel from that year.

Table 1 - Formatting style of fire occurrence records from ICMBio / CMIF. PMIF is the Planning of Integrated Fire Management

Date	UC name	Observations	Coordinates
1/7/2022	Veredas do Oeste Baiano Wildlife Refuge	Prescribed burns keeping in the portion of the unit. The burns are part of the prevention activities planned in the Wildlife Refuge PMIF*.	QC1: -1396433 - 4514504 QC2: -1398329 - 45.18494
1/7/2022	Serra da Canastra National Park	Controlled burn in the central zone of the unit. Fire without combat to the center-east and east of the park. Management is monitoring.	QC : -20.34764 - 46.60611

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1/7/2022	Serra Geral do Tocantins Ecological Station	Prescribed burn in the central-west zone of the unit keep active. Management crew is monitoring. The burns are part of the activities planned in the park's PMIF*.	QC -10.70718 -46.91044
1/7/2022	Chapada das Mesas National Park	Controlled burns by community members and authorized by management in the central-east, south, and northwest portions on the 2nd and 3rd of July.	QC: -7.16552 -46.97544 QC2: -7.2233 -47.24215 QC2: -6.916 -47.35098

Source: ICMBio (2023).

INSERTION INTO POSTGRESQL DATABASE

Once the initial parameters were defined, vector layers were created in the native "shapefile" format in the QGIS geoprocessing software (QGIS Development Team, 2023). Subsequently, the coordinates of the records were inserted to provide fire information in the local PostgreSQL database (PostgreSQL Developers, 2023). Next step, the PostGIS object-relational database system extension was installed, allowing the storage of information with the corresponding geometry type (point, line, polygon) in a "dataset", aiming to represent the data spatially in an object-based database (PostGIS Developers, 2023).

VALIDATION AND SPATIALIZATION OF FIRE OCCURRENCES

Once the data insertion was completed, four models were developed: three for the validation of occurrence records and one for the cross-referencing with fire events, as shown in Figure 2. The figure intends to show the entire methodological and data processing flow. For the validation of ICMBio's fire occurrences (Figure 2 - A), it was necessary to intersect the occurrences that fell within the Conservation Units (UCs). For this, a buffer was applied using the 'ST Buffer (geom: geography,10000)' function with a radius of 10 km around the UCs. This is necessary due to the data collection method being conducted outside the vicinity of the fire occurrence.

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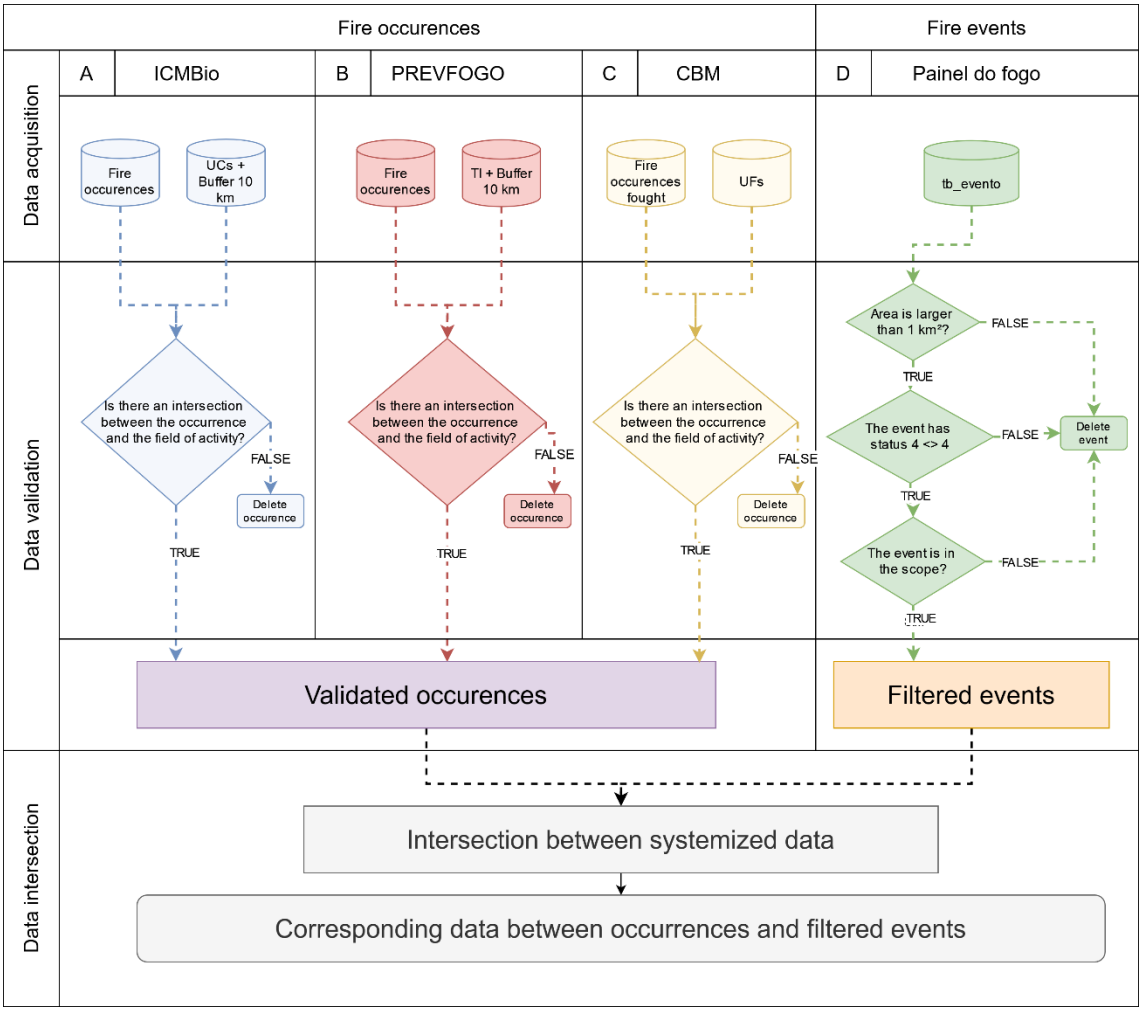

Figure 2 - Flowchart of the methodology employed. Validation rules for fire occurrences and data cross-referencing with the Fire Panel. (Source: the authors,2024).

The next step involved comparing the names of the Conservation Units (UCs) reported in the fire occurrence reports with those filled in the official vector layer of Federal UCs in Brazil. Parameters were defined as 'UC Name = UC Name (Buffer 10 Km)', and the parameter 'where 'Inside UC' = true' was used to intersect the records contained within the 10 Km buffer. Similarly, to validate the fire occurrences from PREVFOGO (Figure 2 - B) and CBM data (Figure 2 - C), the procedures illustrated in each of the data validation rules in this research were followed.

It is worth noting that for PREVFOGO data, the official vector layer of the National Indigenous Foundation (FUNAI) was used to cross-reference the occurrence records within Indigenous Lands (TIs), while for CBM records, the Brazilian Institute of Geography and Statistics (IBGE) vector layer of Federal Units (UFs) allowed intersecting the records reported within the Brazilian UFs.

MATCH UP OF COMBATED OCCURRENCES WITH DETECTED EVENTS FROM THE FIRE PANEL

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Even in the validation of spatialized information, a model was developed to create match up of combated occurrences with fire events (Figure 2 - D) that have been made available in near real-time on the Fire Panel platform. In this context, it is necessary to consider that the cross-referencing with fire data is based on parameters as shown in Table 2.

Table 2 - Assumptions for match up with Fire Panel events.

Match up Parameters	Description
Inside_Event	'True' or 'False' if there is an intersection of the occurrence with the detected fire event (Different Event <> 4) on the same date (occurrence_date >= min_date AND occurrence_date <= max_date).
Event_ID	ID of the fire event that intersects the occurrence on the same date (where Inside_Event = True).
Area_larger_than_1km²	'True' or 'False' if the area of the detected fire event intersecting the combated occurrence is larger than 1 km² (where Event_ID IS NOT NULL).
Inside_Scope	'True' or 'False' if the detected fire event intersecting the combated occurrence is within the scope table (Where Area_larger_than_1km² = TRUE).

Source: the authors (2024).

Based on the fire event status condition ('id_status <> 4'), it was possible to define that fire occurrences intersecting within the Fire Panel events (tb_events) and had status: active (id_status = 1, fire detections from active fire in the last 24 hours), under observation (id_status = 2, more than 24 hours without fire detection since the last fire detection), extinguished (id_status = 3, no fire detections for 5 days), and extinguished by merging (id_status = 4, when two or more fire events overlap) that met this condition were considered within the analysis.

Additionally, it was considered that the cumulative size of the event's vector perimeter is greater than 1 km² since during periods with a high number of fires and burnings, smaller events do not weigh in the decision-making process for fire combat. In this case, fire events that do not meet this condition were excluded from the analysis. It is important to note that in a preliminary analysis, there were no occurrences intersecting with this subset of smaller fire events.

Finally, occurrences within the scope of spurious areas (Antunes et al., 2023) were excluded from the model, considering that the objective of the Fire Panel is the monitoring of fires and burnings in rural areas. It is emphasized that this point is highly relevant in match up fire events with CBM information, as historically in Brazil, military firefighters are also responsible for this part of fire occurrence.

III. RESULTS AND DISCUSSION

REVIEW OF FIRE INCIDENTS REPORTED

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As cited above, the reports received correspond to three institutions involved in this research. Regarding the Military Fire Departments (CBM), reports were received from brigades in 12 states: Alagoas (CBM_AL), Pará (CBM_PA), Sergipe (CBM_SE), Mato Grosso do Sul (CBM_MS), Espírito Santo (CBM_ES), Tocantins (CBM_TO), Roraima (CBM_RR), Rio Grande do Sul (CBM_RS), Amazonas (CBM_AM), Pernambuco (CBM_PE), Paraná (CBM_PR), Santa Catarina (CBM_SC), and Minas Gerais (CBM_MG).

From the information received by CBM's in Brazil, the majority consisted of the date, city, observations, and brigade number associated with the incident. It was observed that some provided reports missed basic parameters for spatialization (especially geographical coordinates) and thus could not be associated with the exact fire occurrence location. This is one of the primary limitations discussed by the authors, as failure to capture location data at the time of the wildfire event, particularly when not done near the fire incident, hampers mapping a significant portion of the records in this study.

In terms of analysis, a total of 80,036 fire incidents were registered by the firefighting brigades between 2020 and 2022. Over 50% (47,341) of these records were from just three states (RS, AM, and PE) which had limitations in mapping due to the lack of geographical coordinates in their reports (Figure 3). Nonetheless, approximately 32,695 fire incident records met the initial parameters for spatialization, representing 40% of the total data received.

Regarding spatialized data, Figure 3 reveals that Espírito Santo (ES) and Paraná (PR) states recorded the highest number of fire incidents, with 15,790 and 8,110 respectively. Notably, in Espírito Santo, many incidents were linked to urban areas and were excluded due to their presence within the spurious areas mask of the Fire Panel. Therefore, these records were not included in the subsequent methodology step (intersections with fire events).

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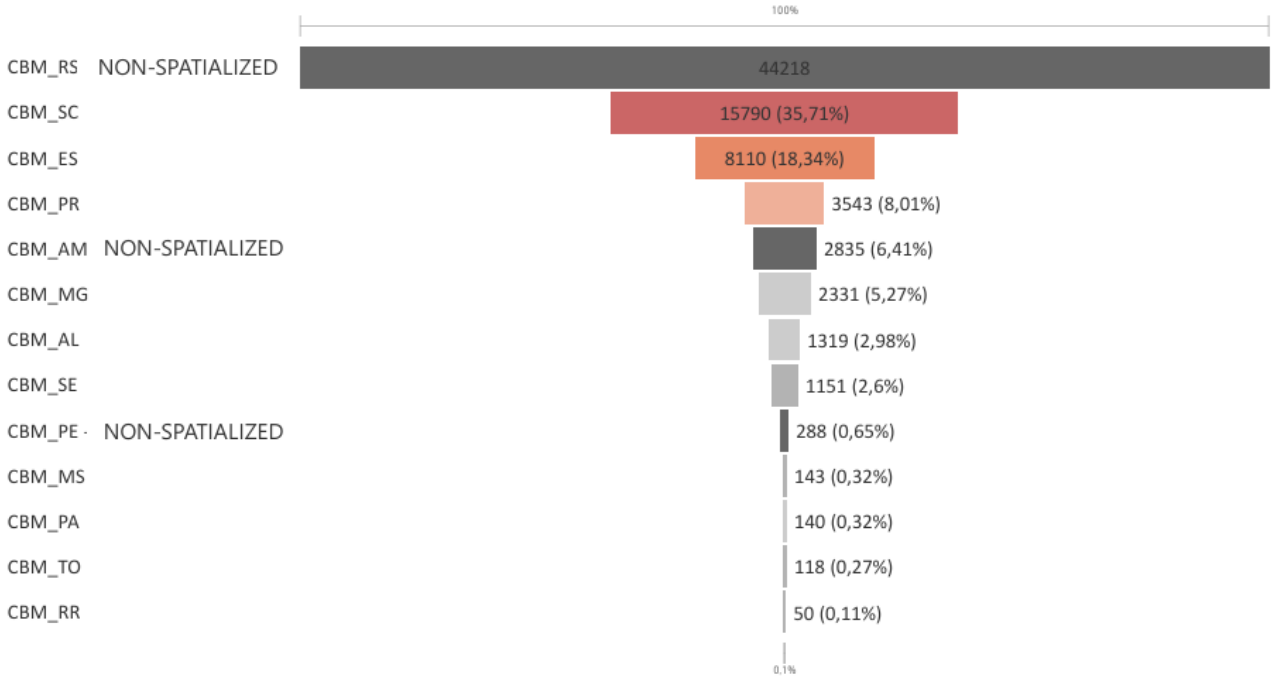

Figure 3 - Comparison between the number of records per unit of Military Fire Departments (CBM) between the years 2020 - 2022. (Source: the authors,2024).

Subsequently, similar to the other datasets, the data received from ICMBio included records from 2020 to 2022. However, ICMBio began recording the locations of fire incidents with geographical coordinates in Conservation Units (CUs) only in 2022. As a result, out of 5,215 fire occurrence records tallied between 2020 and 2022 (Figure 4), 3,702 (approximately 70%) records had limitations for spatialization in the years 2020/2021. Focusing on protected areas, National Parks (PARNA) had the highest quantity of spatialized incidents with 885, followed by Ecological Stations (ESEC) with 253. In contrast, Extractive Reserves (RESEX) and Wildlife Refuges (REVIS) had fewer occurrences.

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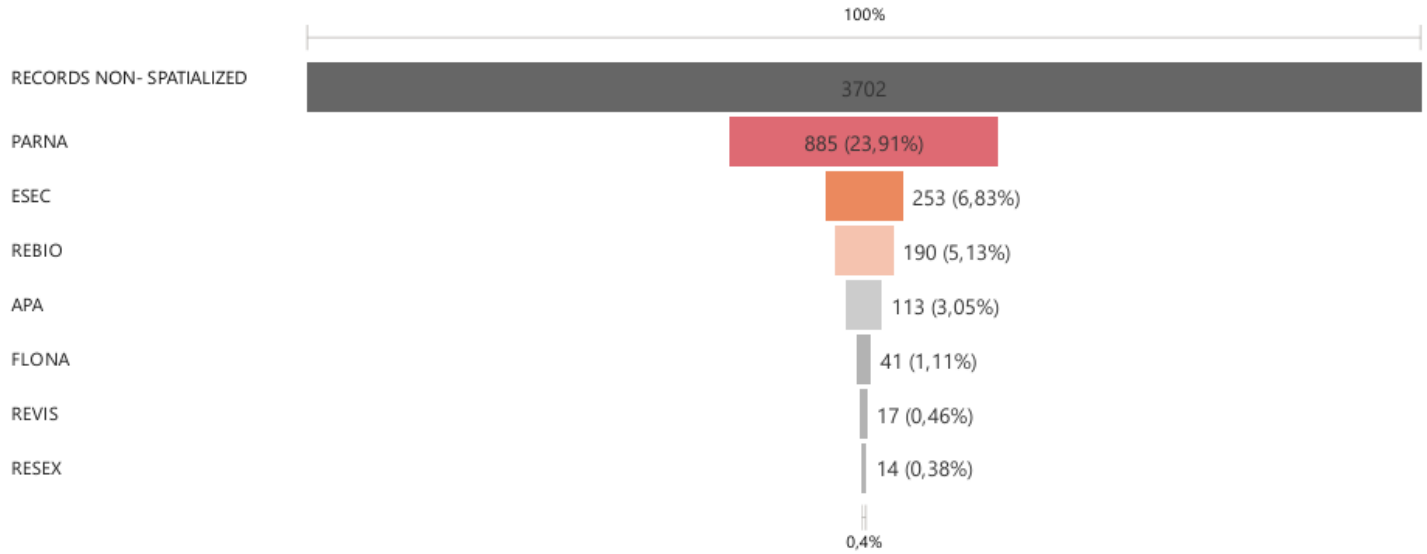

Figure 4 - Comparison between of the number of records per Conservation Unit in the year 2022. (Source: the authors,2024).

Regarding the Prevfogo occurrence data, 4,056 fire incident records between 2018 and 2022 were received. However, only records from April 2020 onwards were considered for analysis. As previously highlighted, this research aimed to intersect fire incidents with fire events detected by the Fire Panel, a platform that has been operational since 2020.

Fire incidents within indigenous territories (TI) were reported for the temporal scale of 2020 to 2022 (Figure 5), involving fire use practices and prescribed burning activities. In contrast to the analysis conducted with CBM and ICMBio datasets, Prevfogo records included geographical coordinates, facilitating the spatialization of all records (since 2020), totaling 3,381 (83%) fire incidents between 2020 and 2022.

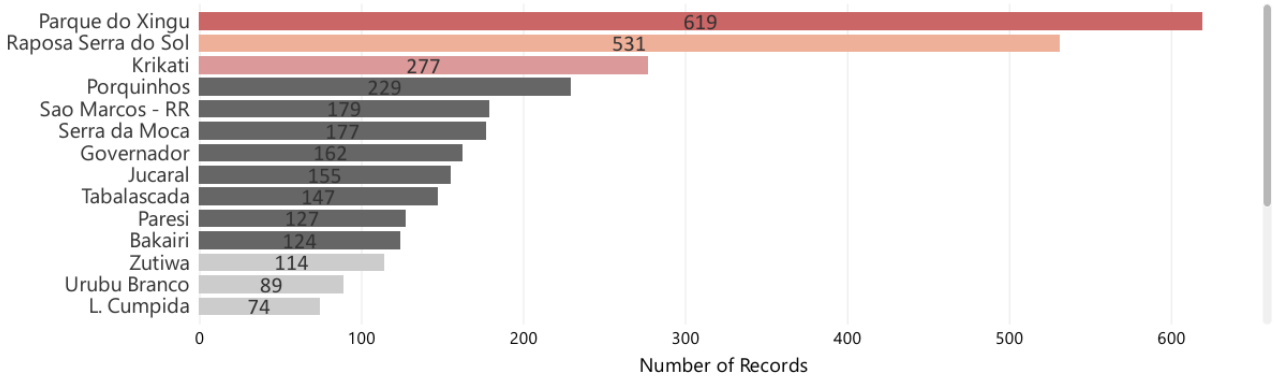

Figure 5 - Comparison of the number of records per Indigenous Territory between 2020 and 2022. (Source: the authors,2024).

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In indigenous territories, the highest number of fire incidents corresponded to Parque do Xingu (619) in Mato Grosso, followed by TI Raposa Serra do Sol (531) in Roraima. Additionally, Krikati (277) and Porquinhos (229) indigenous territories had a higher number of fire occurrences in Maranhão. It is noteworthy that these territories have the Federal Brigades Program (PBRIF), which is the primary policy to prevent wildland fires in indigenous territories, seeking a rapid response to fires and mitigating fire risk through prescribed burning.

VALIDATION RULES APPLICATION AND SPATIALIZATION OF FIRE INCIDENTS

MILITARY FIRE DEPARTMENTS (CBM)

With the information loaded into PostGIS, it was possible to apply data validation rules, validating the 32,695 records that met the initial parameters for incident spatialization. These validated records allowed the understanding that the total number of data remained unchanged. In Figure 6, red colors represent the states with the highest number of incidents: CBM_SC (15,790) and CBM_ES (8,110), while orange and yellow colors denote states with a lower number of reported incidents within the analysis scale, such as CBM_PR (3,540) and CBM_MG (2,330).

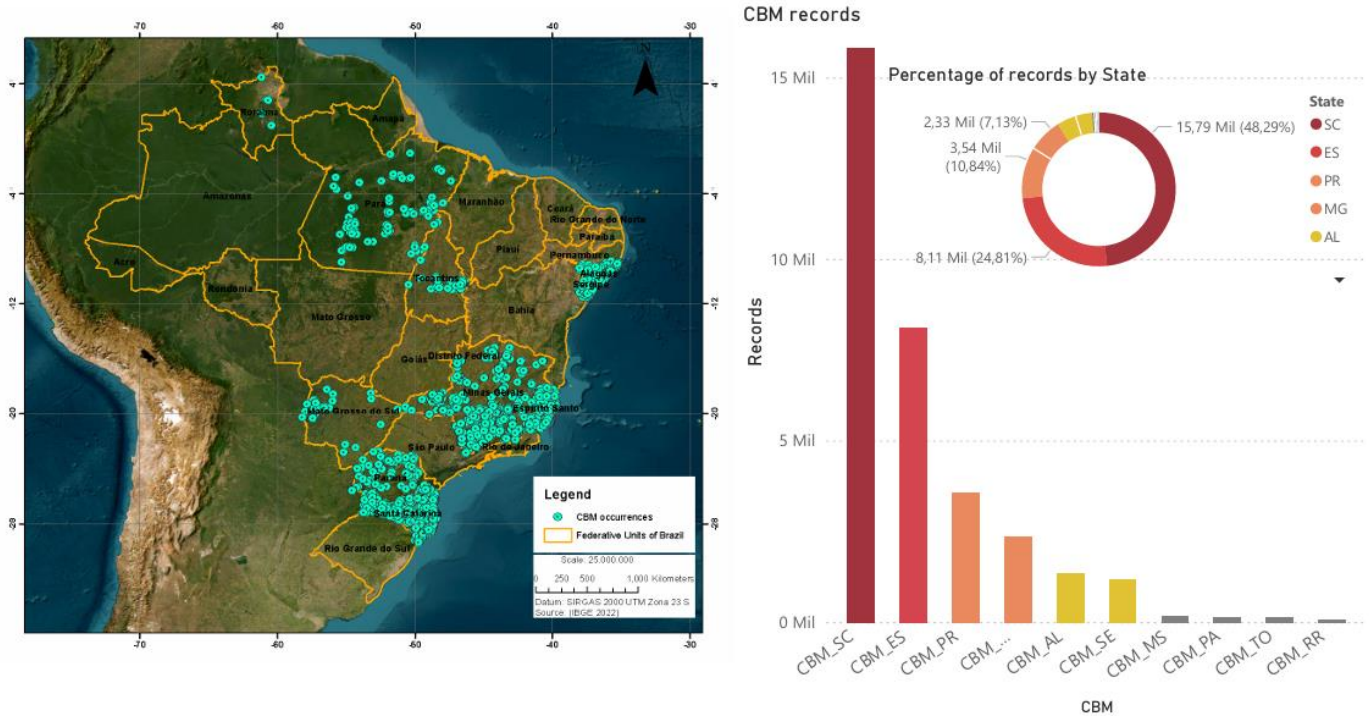

Figure 6 - Spatialization of fire incidents between 2020 and 2022 received from CBM. (Source: the authors,2024).

CHICO MENDES INSTITUTE FOR BIODIVERSITY CONSERVATION (ICMBIO)

Out of the total of 5,215 fire incident records received, 1,513 of them have complied with the validation rule parameters. This means an equivalent of 29,01% of the total received data. According to the Integrated Fire

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Management Coordination (CMIF) at ICMBio, some records are not collected within the incident perimeter due to terrain conditions and the risk faced by brigade members during the incident.

For this reason, a significant portion of the intersected records was based on the methodological rule of a 10 km buffer around Conservation Units (CUs). The results obtained reveal that the Serra Geral do Tocantins Ecological Station and Chapada das Mesas National Park recorded 191 and 139 fire incidents respectively. This scope includes prescribed burns and wildfires with 12.62% and 9.19% respectively in the year 2022 (Figure 7).

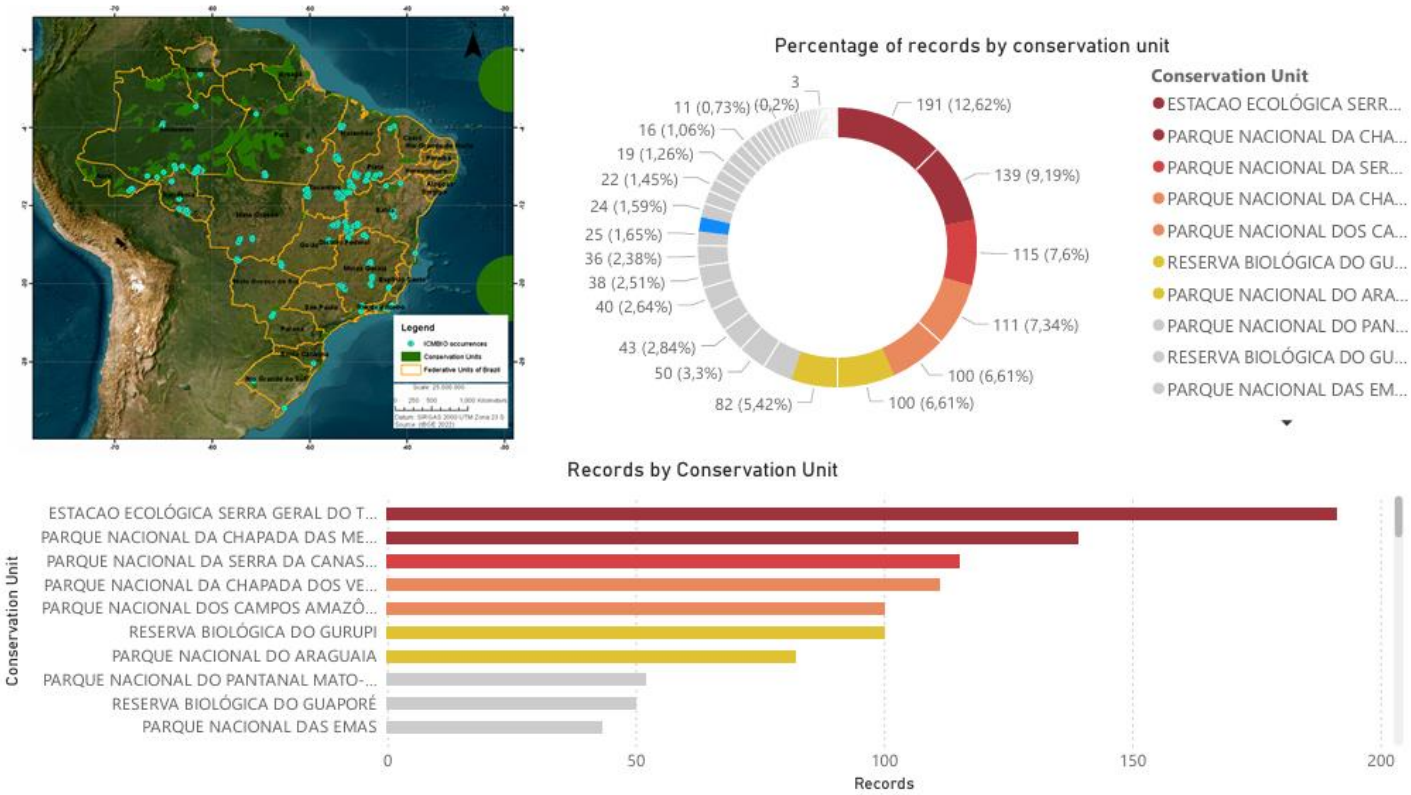

Figure 7 - Spatialization of fire incidents in 2022 received from ICMBio. (Source: the authors,2024).

NATIONAL CENTER FOR PREVENTION AND COMBAT OF FOREST FIRES (PREVFOGO)

During the initial review of 3,381 records, 2,806 met the validation rules. Only 17% (575) of the incidents were outside the official polygon of indigenous territories and did not match the name provided in the official layer from the National Indigenous People Foundation (FUNAI). Indigenous territories with the highest number of spatialized incidents (Figure 8) were Parque do Xingu (615) in Mato Grosso and Raposa Terra do Sol (530) in Roraima, followed by Krikati (274) and Porquinhos (229) in Maranhão.

From this temporal scale, approximately 36.74% of fire incidents between 2020 and 2022 were reported in the state of MG with 1,031 incidents. The state of RR presented 1,065 fire incidents, accounting for 37.95%,

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while MA reported 664 incidents, representing 23.66%. Notably, the reports from these three states suggested that the use of fire was related to preventive actions taken by CBM and ICMBio incidents.

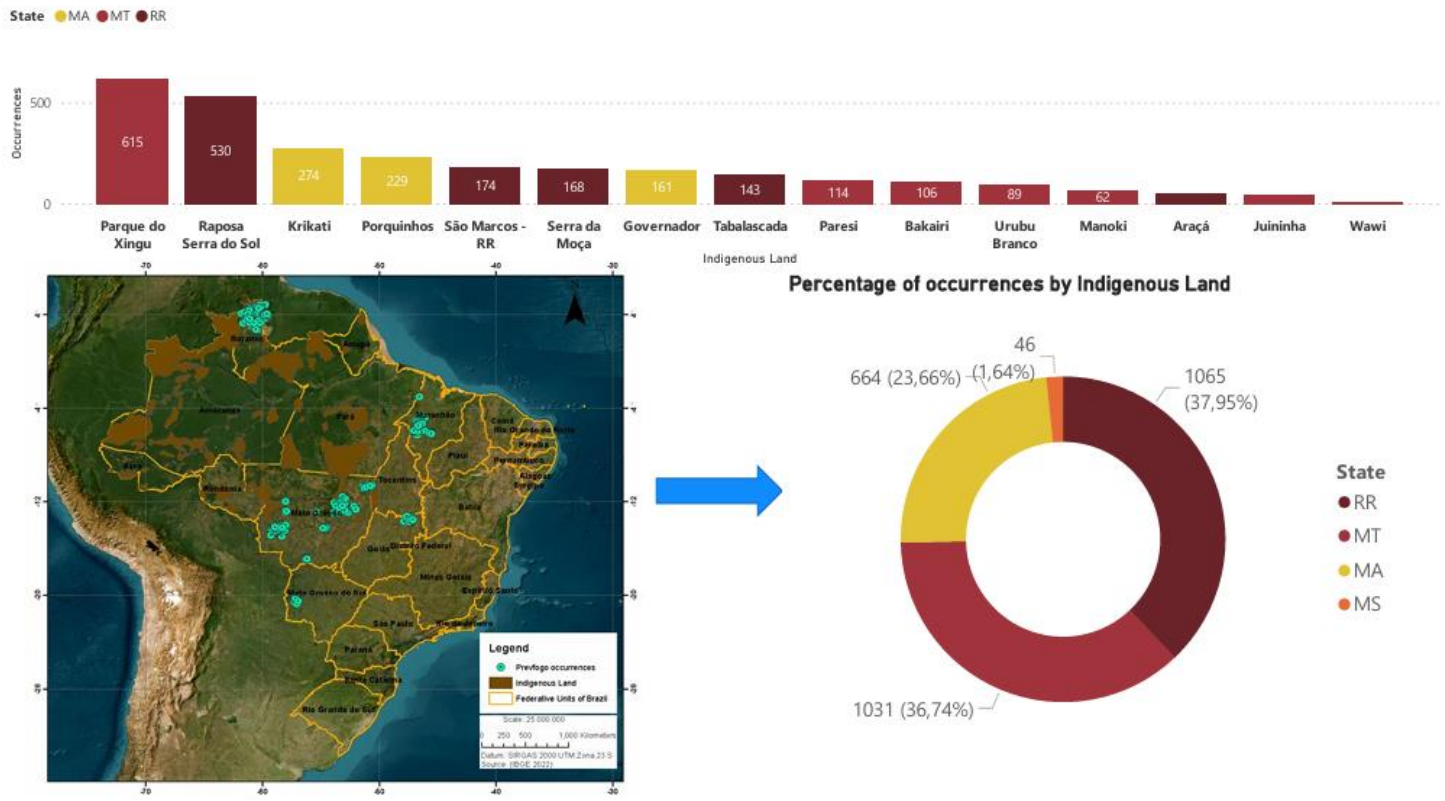

Figure 8 - Spatialization of fire incidents between 2020 and 2022 received from Prevfogo. (Source: the authors,2024).

MATCH UP OF FIRE INCIDENTS WITH DETECTED EVENTS FROM THE FIRE PANEL

CBM FIRE INCIDENTS WITH FIRE PANEL EVENTS

The intersection contributes to identifying the events detected by the Fire Panel platform that overlap with fire incidents between 2020 and 2022. In the case of CBM, 32,695 spatialized incidents were used, and intersection rules were applied using the PostGIS code proposed in this study. A total of 136 fire incidents overlapped with fire events detected by the Fire Panel. It was observed that 0.42% of spatialized incidents coincided with Fire Panel events, with the state of MS having 97 intersected fire events, representing 0.3%, followed by PA (24) with 0.07%, and MG (9) with 0.03% (Figure 9). The states of ES, SC, AL, and SE had a lower number of intersected fire events.

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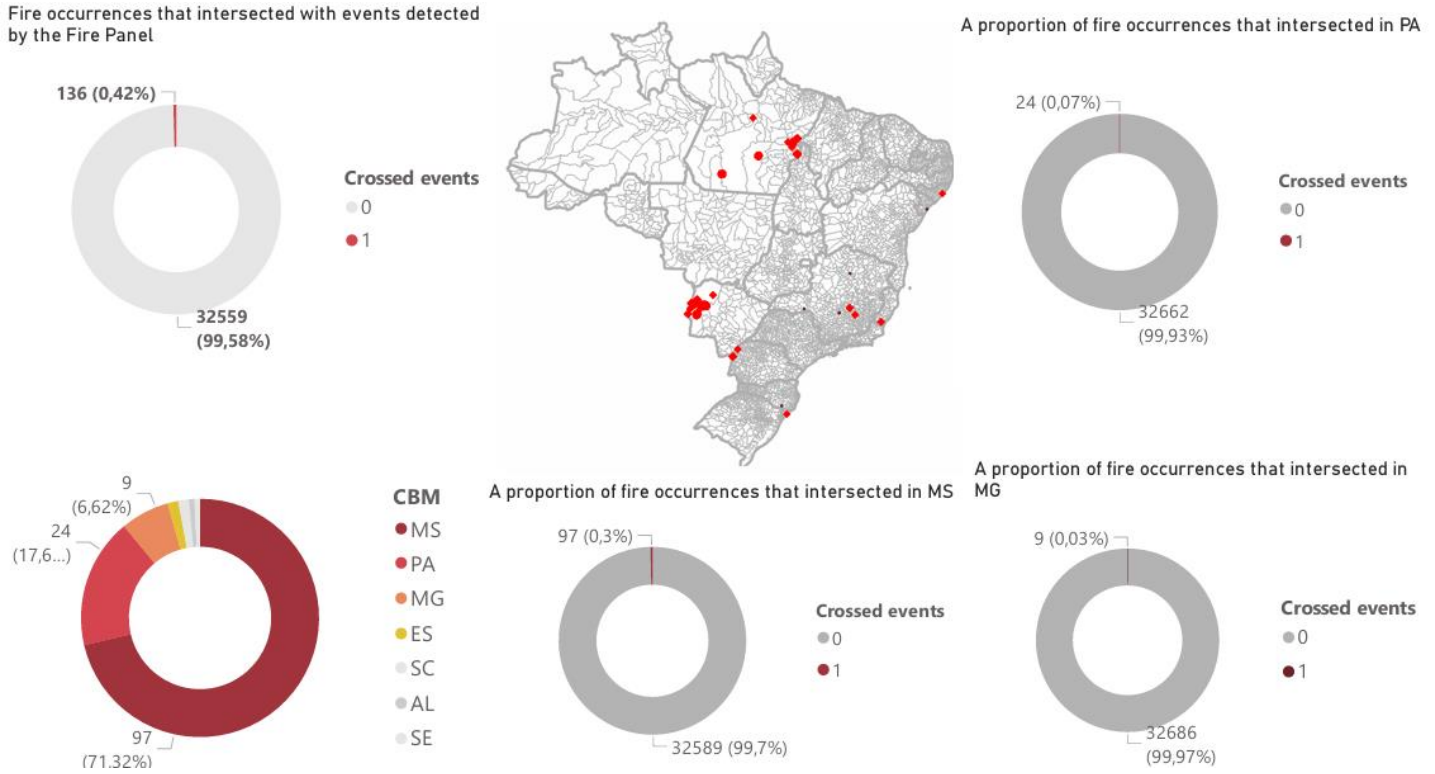

Figure 9 - Intersection between CBM fire incidents with Fire Panel events. (Source: the authors,2024).

Among the involved stakeholders, it is important to note that CBM has brigades for quickly dispatching, with vehicles, tools, firefighting equipment and accessories, search and rescue, available for activating by dialing the three-digit code 193. This condition enables almost instantaneous response between the time from notification of a wildland fire to the firefighter crew, thereby ensuring its fast containment and extinguishment.

Aware of this condition, it must be kept in mind that some short-duration incidents, even those with significant heat emission, when the fire outbreaks and is fought within the satellite pass-over window, will not be detected by the satellite sensor, and will only be registered historically within CBM systems.

Another important factor is joint action in large-scale events, which necessitates resource allocation from various entities, whether specialized in wildland fire combat or providing humanitarian support to affected teams and/or populations. However, when addressing specialized teams identified in this study as stakeholders, there is a gap in identifying fire events that may have occurred through joint action, which could lead to duplicated counting.

This condition underscores the importance of an integrated monitoring service for prescribed or controlled burns, and wildland fires, through a single situation room and unified command between national

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and state levels, sharing information about their operations, and facilitating collaborative solutions for fire combat. Even though ES was the state with the highest number of spatialized incidents, they were excluded from the match up model since they are urban area records, indicating that Military Firefighters have a higher demand outside the scope monitored by the Fire Panel.

ICMBIO FIRE INCIDENTS WITH FIRE PANEL EVENTS.

The match up with ICMBio data showed the highest coincidence with Fire Panel events. Out of 1,513 incident records in 2022 from ICMBio, it was observed that 369 intersected with detected fire events, suggesting that 24.39% of data collection allowed direct comparison with fire events. States outside the Legal Amazon with the highest number of match up were MG with 48 intersected fire incidents, including 19 combat and 19 prescribed burns, followed by Goiás with 41 intersected events, including 18 combat, 14 prescribed burns, and 8 controlled burns (Figure 10).

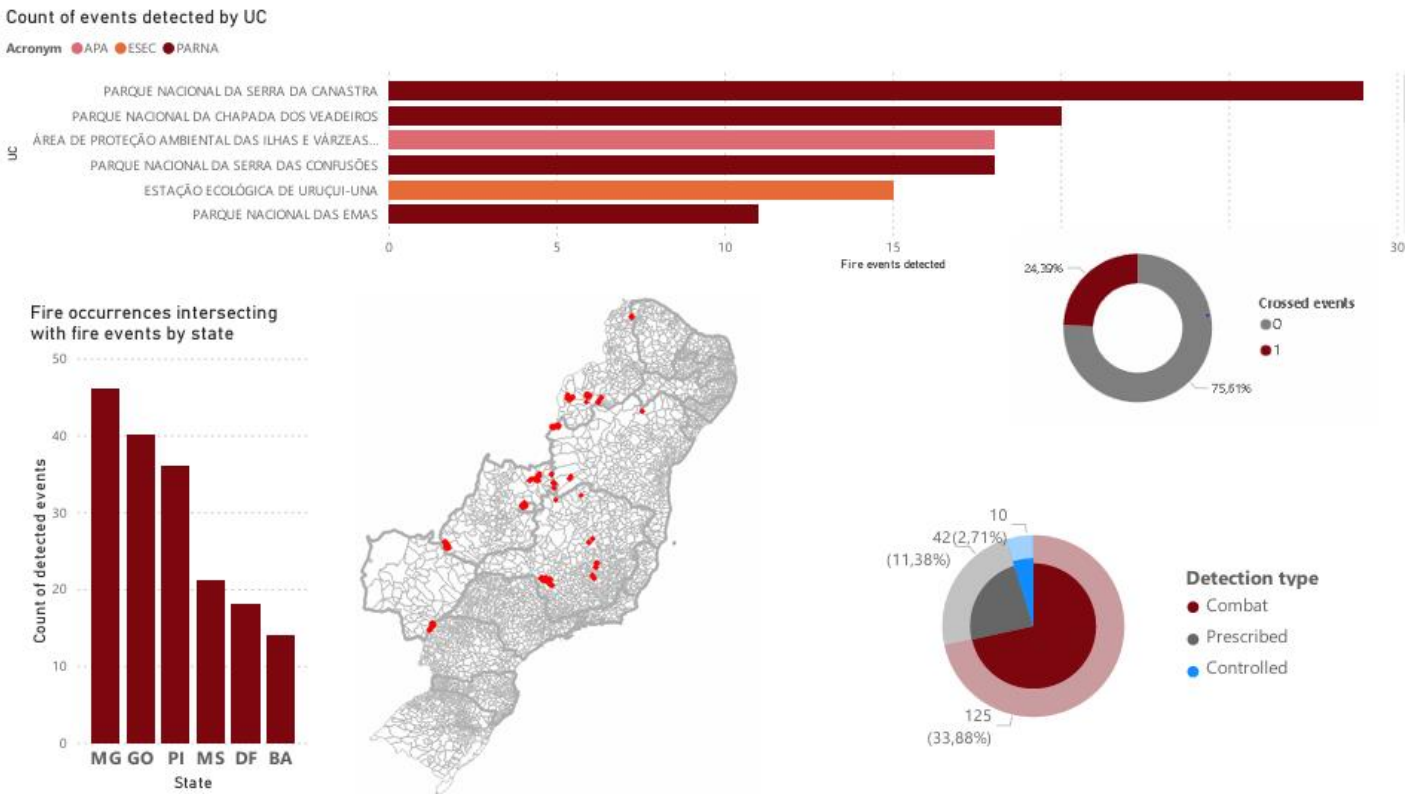

Figure 10 - Intersection between ICMBio fire incidents with Fire Panel events. (Source: the authors,2024).

In total, 177 events (47%) intersected with Fire Panel events in states outside the Legal Amazon. National Parks (PARNA) and Environmental Protection Areas (APA) had the highest number of fire incidents that

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intersected with Fire Panel events, particularly those related to prescribed burning activities, firefighting incidents, and controlled burns. Whereas Ecological Stations (ESEC) showed fewer intersected incidents.

Within the Legal Amazon, there were 192 intersected incidents with fire events. The state of Tocantins reported 56 intercepted incidents, including 31 firefighting and 25 prescribed burning, while MT reported 37 intercepted firefighting incidents, and PR reported 29 firefighting incidents crossing with the Fire Panel. In the state of AM, there were a total of 18 incidents, with 12 being firefighting and 6 prescribed burning incidents (Figure 11).

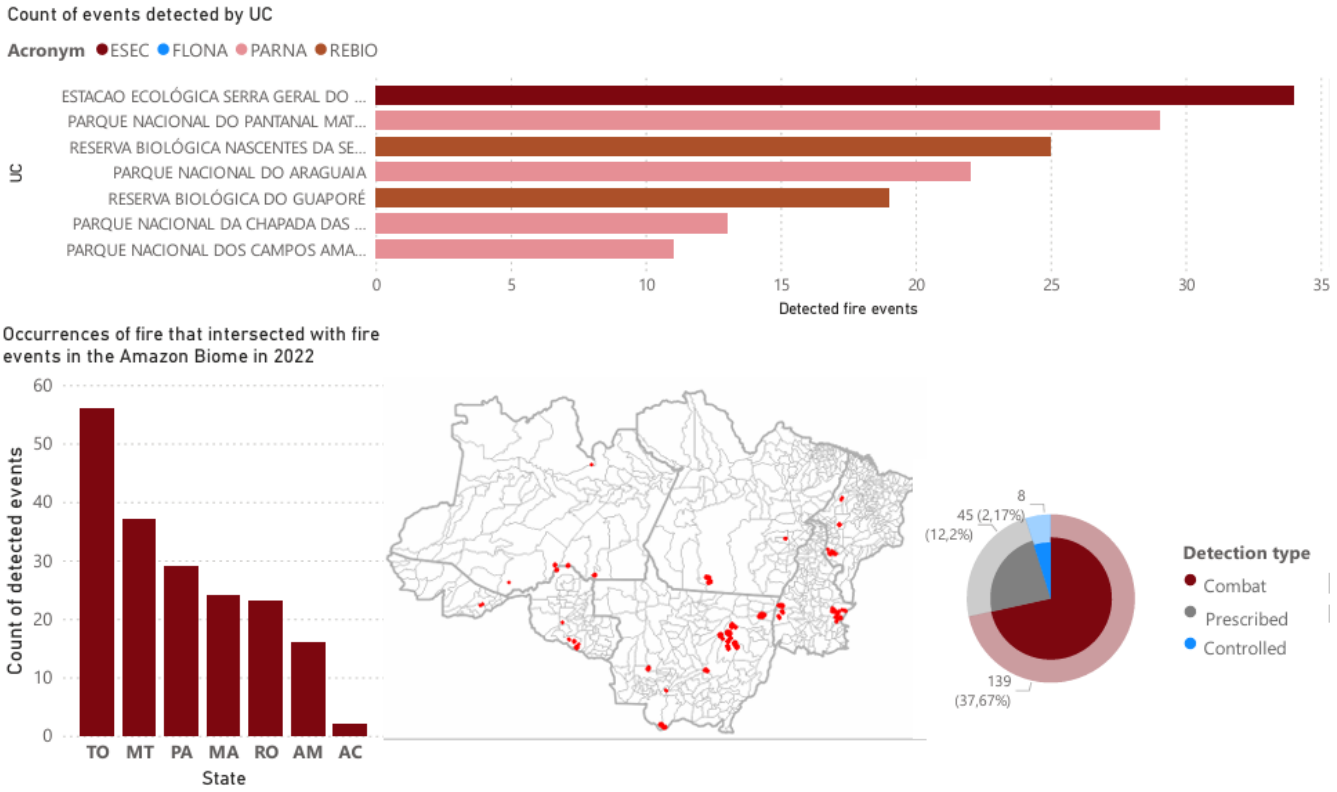

Figure 11 - Match up between ICMBio fire incidents with Fire Panel events in the Amazon biome. (Source: the authors,2024).

In contrast, in the Legal Amazon, Ecological Stations (ESEC) had the highest number of fire occurrence's intersected by the fire event. According to ICMBio, the database used to construct the reports allowed for more accurate geographical coordinate information, which contributed to achieving better results in the intersection process, suggesting an improved standardization among the various data collection teams involved.

However, considering the percentage of intersections, it showed that it is still a relatively low percentage in terms of correspondence between the data reported by the entities involved in fire control and the fire events monitored by the Fire Panel (Figure 11). Furthermore, one must consider the limitations mentioned by CMIF

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regarding the quality of collected data, which may lead to low reliability due to field conditions affecting brigade decisions when combating fires in UCs, thereby influencing geographical coordinate collection and impacting the comparisons with the fire event.

PREVFOGO FIRE INCIDENTS WITH FIRE PANEL EVENTS.

For Prevfogo, out of the 2,806 spatialized incidents, only 47 fire events were intersected, representing 1.67% of the total dataset (Figure 12). The results highlight that the Indigenous Territories with the highest number of match up were Parque do Xingu in the state of MT (26) and Bairiki with 5 fire occurrences. This outcome confirms that the collection of fire incidents lacks standardization and was not intended for comparison with data reported by fire event monitoring platforms in Brazil, highlighting the primary limitation discussed in this study.

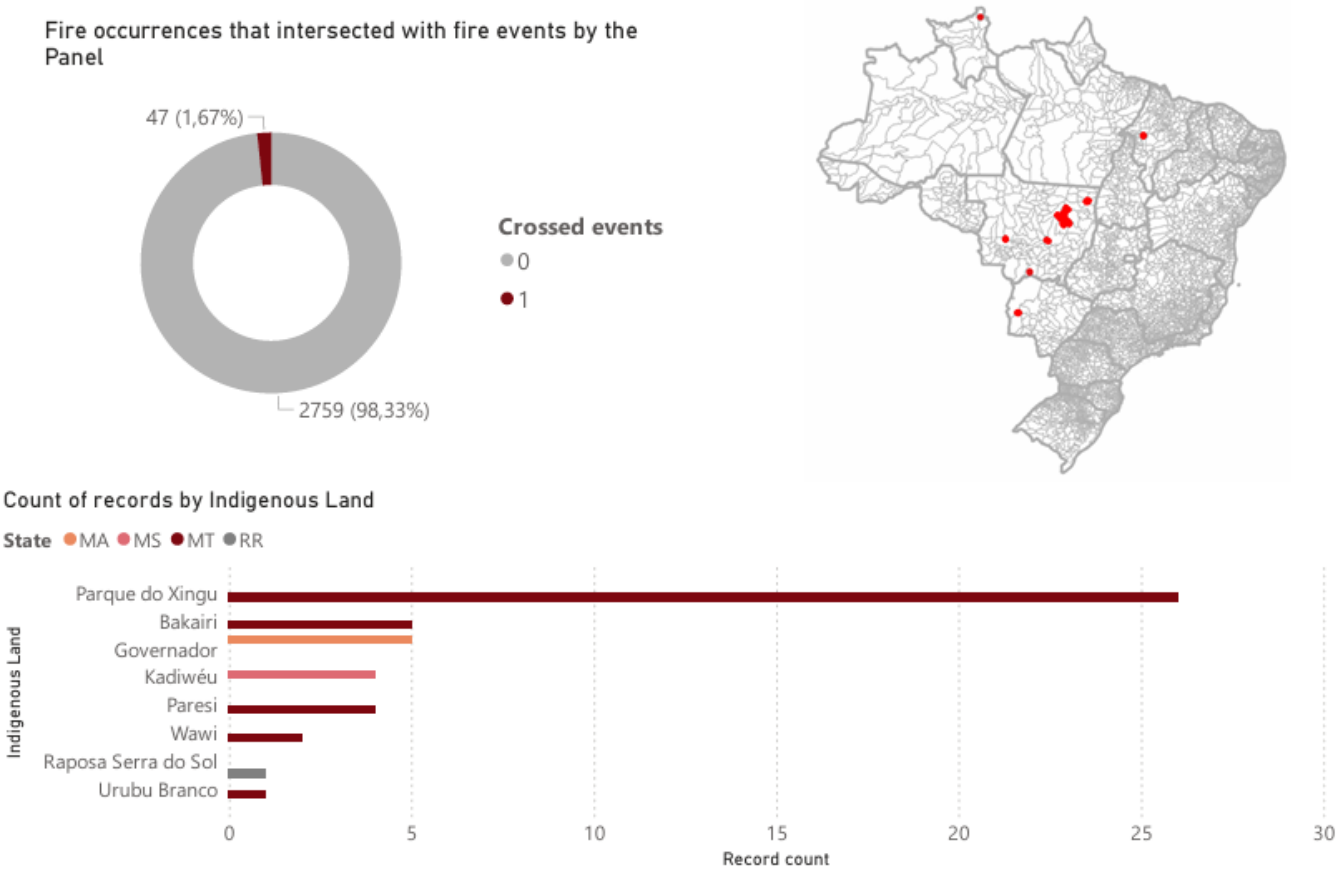

Figure 12 - Intersection between extinguished incidents from PREVFOGO and events from the Fire Panel. (Source: the authors,2024).

EXPLORATORY ANALYSIS OF FIRE EVENTS INTERSECTED BY DATA SPATIALIZATION

The purpose of this exploratory analysis is to demonstrate that, when the field and remote sensing data are blended, it's possible to analyze fire occurrences with a higher level of details. The algorithm that produces

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the fire event vector layer gathers qualified information about the event properties and its fire detections, which are tabulated in near real-time (CENSIPAM, 2023). The event properties classes pertain to intrinsic aspects of that event such as area, persistence (duration), quantity of detection, among others.

Additionally, fire events are matched with other thematic data to generate extrinsic information to the fire event, thus enhancing the response strategy during firefighting efforts. In this study, the attribute 'fire type ID ' was selected with the aim of typifying the occurrence. Currently, this attribute only considers the type of fire caused by deforestation and is restricted to the Legal Amazon. According to De Faria et al. (2023), the qualification of the type of fire occurrence is very useful information, which can be utilized by Brazilian Fire Departments for planning firefighting actions and contribute to the safety of wildfire fighting brigades.

From the results of these attributes contained in Table 3, it was possible to conclude that ICMBio presented the highest accumulated area of events (3728.28 km²), followed by CBM, which fought fires in an area of influence of 1881.44 km² corresponding to the fire events intercepted by fire occurrences. In the case of PREVFOGO, the intersected events totaled a smaller area (859.94 km²), although the average per event was higher (17.19 km²). It is noteworthy that ICMBio presented the highest accumulated area of events (3728.28 km²) and a greater dispersion of data (89.10 km²) in the quantity of satellite detections, hence greater heterogeneity compared to CBM and PREVFOGO.

Table 3 - General statistics of fire events intercepted by CBM, PREVFOGO, and ICMBio occurrence.

	Min	Max	Mean	Median	Sum	Standard Deviation
CBM						
Area (km²)	1.081	293.07	19.39	5	1881.4	50.78
Persistence (days)	0	298	9.69	3	940	31.23
Detection Quantity	1	520	34.43	8	3340	77.05
ICMBIO						
Area (km²)	0.49	412.40	16.42	4.12	3728.2	46.06
Persistence (days)	0	65	3.85	1	875	8.35
Detection Quantity	1	882	25.72	6	5820	89.10
PREVFOGO						
Area (km²)	1.13	273.42	17.19	4.63	859.94	46.30
Persistence (days)	0	22	3.36	2	168	5.65
Detection Quantity	1	227	18.08	4.50	904	44.89

Source: the authors (2024).

Regarding persistence, ICMBIO and PREVFOGO performed lower means and medians values since they deal with prescribed burns, which corroborates with this type of fire being linked to the prevention phase of the

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MIF in Brazil. In relation to CBM, the maximum value of persistence stands out, reaching 298 days, and is linked to large fires that occurred in the Brazilian Pantanal. Similarly, the average quantity of detections also suggests that the fires fought by CBM are slightly more intense.

As mentioned, for the Legal Amazon, the fire event vector layer has a specific attribute called 'fire type ID', which dissociates fire events linked to deforestation (type 1) from other types of fires. The result in Table 4 aims to demonstrate how this typification can reveal different details from the overall picture and consequently be evaluated uniquely in a firefighting strategy.

The result contained in Table 4 reveals that all institutions deal with occurrences involving deforestation (type 2), which is considered a type of environmental crime. Overall, 15% of the occurrences attended by CBM were classified as deforestation, suggesting a higher degree of security risk since deforestation, in many cases, is linked to land grabbing processes and other forms of environmental crime. Due to a smaller quantity, the total area was also smaller. Regarding the 'Persistence' variable of the fire events, the result suggests that this type of fire occurrence in protected areas shows greater persistence as revealed by the results for ICMBIO and PREVFOGO.

Table 4 - General description of fire types crossed by fire occurrences.

fire type ID	Total number of intercepted events	Area_ km²	Persistence (Mean)
		CBM	
1	83	1609.91	9.96
2	14	271.53	8.07
		ICMBIO	
1	202	3259.26	3.54
2	9	499.26	17.66
		PREVFOGO	
1	48	595.04	2.58
2	2	264.90	22.00

Source: the authors (2024).

On one hand, there is the possibility of increasing the amount of information from remote sensing considering the institutional profile; on the other hand, the same can occur from the perspective of the type of fire occurrence. Such a possibility can generate essential information for managing activities linked to the MIF. To exemplify, Figure 13 shows the accumulated value of the three remote sensing parameters by type of occurrence, here represented by combat, controlled and prescribed burning.

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The occurrence type of controlled burning, linked to land management, represented less significance in relation to the variables observed in this research, with an area of 163.13 km² (Figure 13 -A), 236 detections, and a total duration of events of 49 days (Figure 13 -B). A similar behavior is observed for prescribed burns, which have slightly higher values compared to controlled burns.

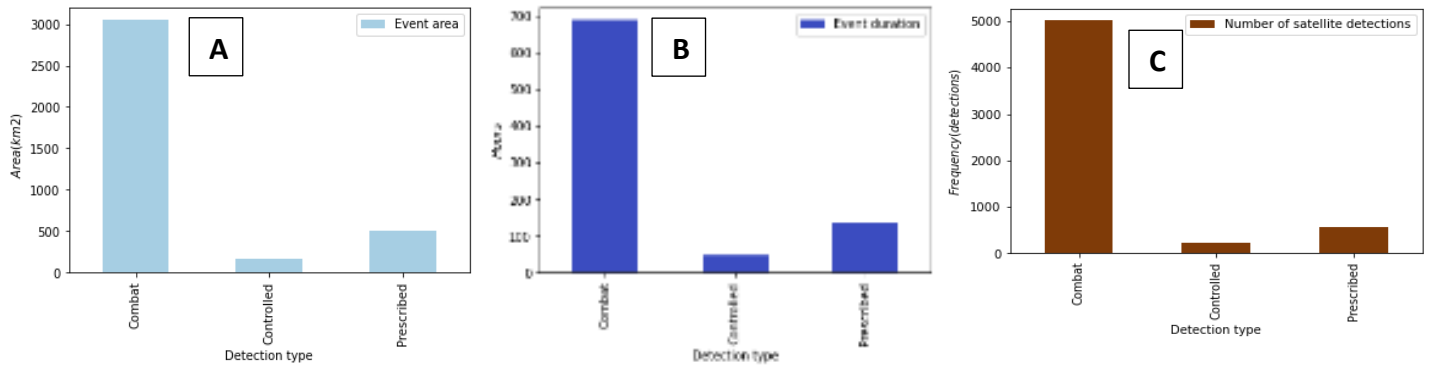
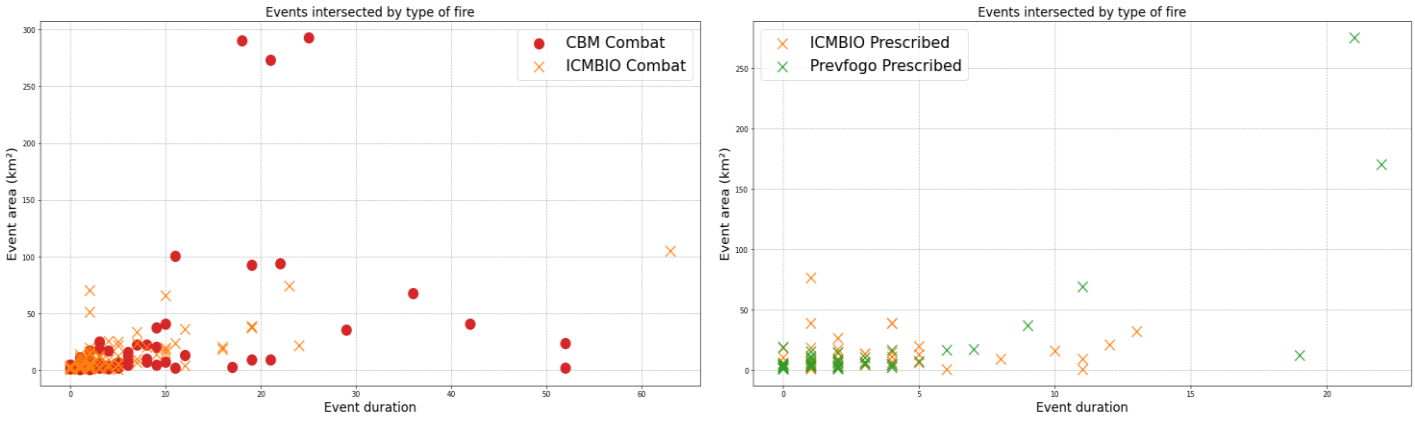


Figure 13 - Fire typification in relation to the variables of fire events intercepted by ICMBio fire occurrences. (Source: the authors,2024).

However, data on firefighting revealed significantly higher values, which are justified by being directly related to wildland fires. In the scatter plots, there is no clear pattern between the size of fire events and duration. In terms of firefighting, Figure 14-A shows that an occurrence can last for more than two months but not exceed 20 km². On the other hand, events that exceeded 200 km² in just over 10 days were extinguished. It is important to highlight that variables such as the firefighters employed can contribute to explaining this behavior.



a) b)

Figure 14 - Relationship between the duration and area of fire events intercepted by firefighting occurrences. (Source: the authors, 2024).

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The prescribed burns that intersected fire events were mostly conducted over a shorter period of time and area for both institutions (ICMBio and PREVFOGO), as shown in Figure 14-B. In general, prescribed burns should not exceed one or two days. However, there are cases where the burn can become uncontrolled and turn into a wildfire, resulting in a larger duration and area.

IV. CONCLUSIONS

This study aimed to analyze how different sources of data on fire occurrence in Brazil are collected and how they correlate with remote sensing data. The apparent lack of standardization in data collection in the field among the entities involved in firefighting and information management about fire allowed us to understand that the quality of the received data largely determined the outcome of the analysis. It was noticed, therefore, that not all entities (especially CBM) have management capable of providing data for an analysis like the one presented in this study. Of the 26 states plus the federal district, 44% were able to share their field records.

It is worth noting that the universe of nearly 90,000 fire occurrences registered in the field, a vast majority (over 85%), was collected by the Military Fire Departments, suggesting that these state entities play a significant role in firefighting. Further, it is important to emphasize that, in terms of fire occurrence, burnings and wildland fires outside protected areas are more frequent due to the extensive use of fire in rural activities, impacting the number of occurrences attended by CBM.

However, from this CBM sample universe, 40% complied with the initial parameters for the spatialization of the records used in this study. It is important to highlight that the result is a consequence of the first challenge for merging the databases, which is the separation between fire occurrences in urban and rural areas, considering that only rural areas are the focus of this spatial analysis. Regarding IBAMA, it is concluded that the collection of coordinates is a relevant parameter for PREVFOGO, and the lack of standardization in filling out the information compromised 83% of the analyzed data.

The lack of standardization also reflected in the stage of spatialization of the filtered data. At this point, ICMBio was the institution with the lowest number of fire occurrences spatialized (30%), although when crossed with the events of the Fire Panel, 362 fire events intersected, being the most accurate among the evaluated institutions. This suggests that, for ICMBio, the lack of standardization promotes the absence of geographical coordinates, which should be regarded as a key parameter for the match up. It is noted that this result is also restricted to a few Conservation Units (UCs), indicating that the lack of standardization may also be due to the absence of a standard protocol guiding the agents involved in the work.

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In terms of intersecting with fire events, CBM and IBAMA achieved even lower levels, with 136 and 50 intersected events, respectively. The low match up between spatialized fire occurrences and Fire Panel events suggests the need for a common protocol for fire data collection, allowing for direct comparison and interoperability between the fire data generated by wildland fire monitoring and surveillance platforms in Brazil.

One way to direct efforts of the Brazilian state towards improving data collection can be through Law Bill 1,818/2022, which institutes the National Integrated Fire Management Plan. Such a policy can provide for integrated monitoring mechanisms that should be implemented through normative instructions that guide the methods employed for this purpose. The results presented here suggest that there is a latent need for data to follow collection standards.

Note that, after analyzing nearly 90 thousand fire occurrences, less than 1% were spatialized, becoming insignificant for a situational analysis of the MIF in Brazil. Therefore, the results presented after the data intersection should not be interpreted as a standard behavior, as a more representative database needs to be analyzed. This conclusion should be pointed out in future work.

Additionally, the results show the potential for analysis when is made the match up with fire events. The exploratory analysis conducted in this study identified the similarities and differences between the total area fought, as well as the pattern of fire persistence and detection quantity. In this topic, for example, it is possible to identify that the extensive use of fire for mitigating the risks of forest fires produces lower persistence for IBAMA and ICMBio than for CBM.

Furthermore, it was possible to identify that the challenge of deforestation is inherent to all institutions. When considering the type of reported fire, such as ICMBio and IBAMA, all these parameters derived from geospatial data can also represent the behavior of each parameter available through the fire event. This should expand knowledge about the activities performed and provide new insights for implementing the MIF, taking into account that each state, Conservation Unit, and Indigenous Land presents its own contextual characteristics, as it can be inferred that each occurrence allows identifying factors that influence the increase of the problem.

Finally, the methodology employed in this study can be used to validate reports of burns reported by the institutions involved in fire control. Therefore, it becomes important for future research to ensure that the data is with the initial parameters, such as coordinates, date of the fire occurrence, type of burning, which helps contextualize the occurrence of combat, even actions to monitor and enforce more efficiently the areas with the highest recurrence of events during the burning period in Brazil.

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