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# Wildfire protection in indigenous lands of Brazil: the role of fire brigades programs

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Brazil's indigenous lands (ILs) are important for global environmental sustainability. Despite this, ILs are increasingly threatened by wildfires, largely driven by climate change. The main public policy implemented by the Brazilian government to protect ILs has been the Federal Brigades Program (BRIFs), created in 2013 within the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama). Coordinated by the National Center for Prevention and Suppression of Wildfires (Prevfogo), with the support of the National Indigenous Peoples Foundation (Funai), the BRIFs are the result of a long learning process, which led to the integrated fire management (IFM). Since then, protection strategies have begun to value social participation, traditional knowledge, and landscape management with prescribed burning. After a decade of operation, now is an opportune moment to evaluate the results of the BRIFs and the paradigm shift it represented. This study evaluated 42 ILs encompassing 25,355,413.6 hectares. Active fire satellite data, captured from outside the prescribed burning season, allowed estimation of wildfire occurrences. Using a before–after-control-intervention approach, ILs covered and not covered by BRIFs were compared before (2003–2012) and after (2014–2023) the program's implementation. These treatments were evaluated both collectively and separately by ecosystems: fire-prone savannas (Cerrado biome) and fire-sensitive forests (Amazon biome). The data was analyzed using the Chi-Square Adherence test, graphs, and trend lines. Results show that ILs covered by BRIFs presented a significant reduction of 22.7% in the number of active fires following program implementation, whilst those not covered showed an increase of 12.3%. In the Cerrado biome, the reduction in the ILs covered by BRIFs was evident soon after program implementation. In the Amazon biome, this reduction took longer, but the differences are highlighted by the trend curves. These results were achieved with an annual investment of USD 1.02 per hectare protected. We conclude that BRIFs have been effective in protecting Brazil's ILs from wildfires. Due to its efficiency, combined with low financial cost and equitable gains, the BRIFs Program offers a model for the protection of regions with ecological and social similarities, such as many tropical countries.

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## Introduction

The Indigenous peoples play a prominent role in the stability of the global climate and protect a large part of the world's biological and cultural diversity (FAO 2021). Like other traditional, tribal, and local communities, Indigenous peoples are key players in addressing the climate crisis (FAO 2021; IPCC 2023). Among the countries with the greatest potential to take advantage of the consonance between these peoples and the protection of ecosystems, Brazil stands out, both for its size and bio-cultural diversity.

The Brazilian indigenous lands (ILs) cover 117,361,064.51 ha (Funai 2025), where 689,532 people from 305 different ethnic groups live, speaking 274 native languages (IBGE 2025). An example of the complexity and richness of the indigenous issue in Brazil is the existence of 119 groups in voluntary isolation (Loebens and Neves 2024).

This rich natural and cultural heritage is under increasing and multiple threats, including wildfires, which are advancing across Brazil's biomes, driven by climate change (Bilbao et al. 2020; UNEP 2022). In fire-prone savannas, changes in rainfall and temperature patterns have threatened management practices based on traditional knowledge. In fire-sensitive rainforests, flammability and forest degradation are rapidly increasing (Pivello 2011). Indigenous peoples, who have contributed least to climate change, are suffering the depletion of essential natural resources and urgently demand mitigation and adaptation policies (Bilbao et al. 2020; FAO 2021).

Wildfire control policies are being challenged around the world, and even the most structured countries are failing to succeed on a warmer and more unstable planet (UNEP 2022). Brazil, with fewer financial resources and many differences compared to these countries, has opted for strategies based on hiring local labor and known as the Fire Brigade Programs. These programs were expanded and improved over time, culminating in the Federal Brigades Program (BRIFs). The BRIFs are based on the principles of Integrated Fire Management (IFM) and were the first public policy aimed at controlling wildfires in ILs (Myers 2006; Falleiro et al. 2021). However, before reaching ILs and IFM, Brazilian public policies for wildfire protection had come a long way. This history, rich in positive and negative experiences, is detailed in the first part of this study and relates to paradigm shifts in fire management around the world.

**History of federal fire brigade programs and fire management in Brazil**. Although Brazil's first wildfire protection laws were enacted during the colonial period, structured public policies only began to be implemented in 1998, after the worst fire season ever recorded, which mainly affected the Amazon biome (Falleiro et al. 2021). At this time and in direct response, the National Center for Prevention and Suppression of Wildfires (Prevfogo) was created within the structure of the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama).

Aimed at developing programs to address the problems of controlled burning and wildfires, Prevfogo/Ibama led to important changes in fire management. The most significant were the Fire Brigade Programs, which provided qualified professionals for wildfire control (Falleiro et al. 2021).

Before Fire Brigade Programs, only some cities and famous National Parks had any kind of protection system, and these drew on military firefighters and volunteers. Over time, the increasing occurrence of large wildfires demonstrated the fragility of this strategy and motivated the hiring of local labor through a series of Fire Brigade Programs: Brigades in Conservation Units (BCU), Brigades in Critical Municipalities (BCM), and, most recently, Federal Brigades (BRIFs) (Falleiro et al. 2021; Ibama 2024).

The BCU Program hired mainly brigade members from traditional and rural communities to protect Nature Conservation Units, and the BCM Program hired mainly brigade members from rural and urban communities to protect critical municipalities. It was only with the BRIFs Program that Indigenous people began to be hired in significant numbers, as its focus was the protection of ILs from wildfire (Falleiro et al. 2021; Ibama 2024).

The summarized history of the Brazilian Federal Fire Brigades Programs and some highlights since the creation of Prevfogo/Ibama are shown in Fig. 1. It's worth noting that the variations in active fires may be more related to changes in land use or climatological conditions, such as the occurrence of the *El Niño* phenomenon and climate change, than to the number of brigade members hired.

The BCU was created in 2001 by Prevfogo/Ibama and continues today, helping to protect National Parks, Ecological Stations, Biological Reserves, and other categories of Nature Conservation Units throughout Brazil. Despite its importance, relatively few empirical studies have focused on its performance, and there is little data available, especially from the early years (Falleiro et al. 2021).

However, there is a consensus that among the benefits of BCU, the hiring of local communities as brigade members was one of the most important. Hiring local members brought a positive impact on the management of Conservation Units, improving the relationships with traditional and rural communities, in addition to social benefits. Important policies for these often poor and marginalized communities, including income generation, as well as participation in the management of the protected areas that surround them, were implemented through this program (Falleiro et al. 2021; Ibama 2024).

On the other hand, a key feature of the program's first years was top-down technical management, accompanied by zero-fire policies, even in fire-prone ecosystems (Durigan and Ratter 2016; Moura et al. 2019). At that time, fire protection techniques in Brazil were not yet integrated with the ecologies and cultures of fire, as advocated by IFM (Myers 2006; Falleiro et al. 2021).

In this context, the brigades implemented prevention activities, such as firebreaks and environmental education, in addition to monitoring and preparation to reduce the response time to fighting wildfires. Over this period, the use of fire was suppressed. For example, controlled agricultural and pasture burning were inhibited, with the support of environmental law enforcement, and prescribed burns for landscape management had not yet been implemented (Pivello 2011).

These strategies generated a disruption to the traditional practices of local communities, which had historically maintained a cultural fire management system (Falleiro 2011; Moura et al. 2019). The combination of abandonment of traditional management practices, accumulation of fine fuel in savannas and pastures, and conflicts with environmental agencies generates an even more serious problem. Just a few years after the implementation of the BCU Program, large wildfires hit several protected areas, especially National Parks with fire-prone ecosystems (Durigan and Ratter 2016; Moura et al. 2019). In 2007, the Chico Mendes Institute for Biodiversity Conservation (ICMBio) was created and took over the BCU, a structure that remains in place to this day. Over time, ICMBio also changed the zero-fire approach to IFM, but that is another story (Berlinck and Lima 2021).

The year 2008 was important for fire policies in Brazil. With the transfer of BCU from Ibama to ICMBio, Prevfogo/Ibama began to direct its operations to other regions of the country, where there was a growing demand for public fire management

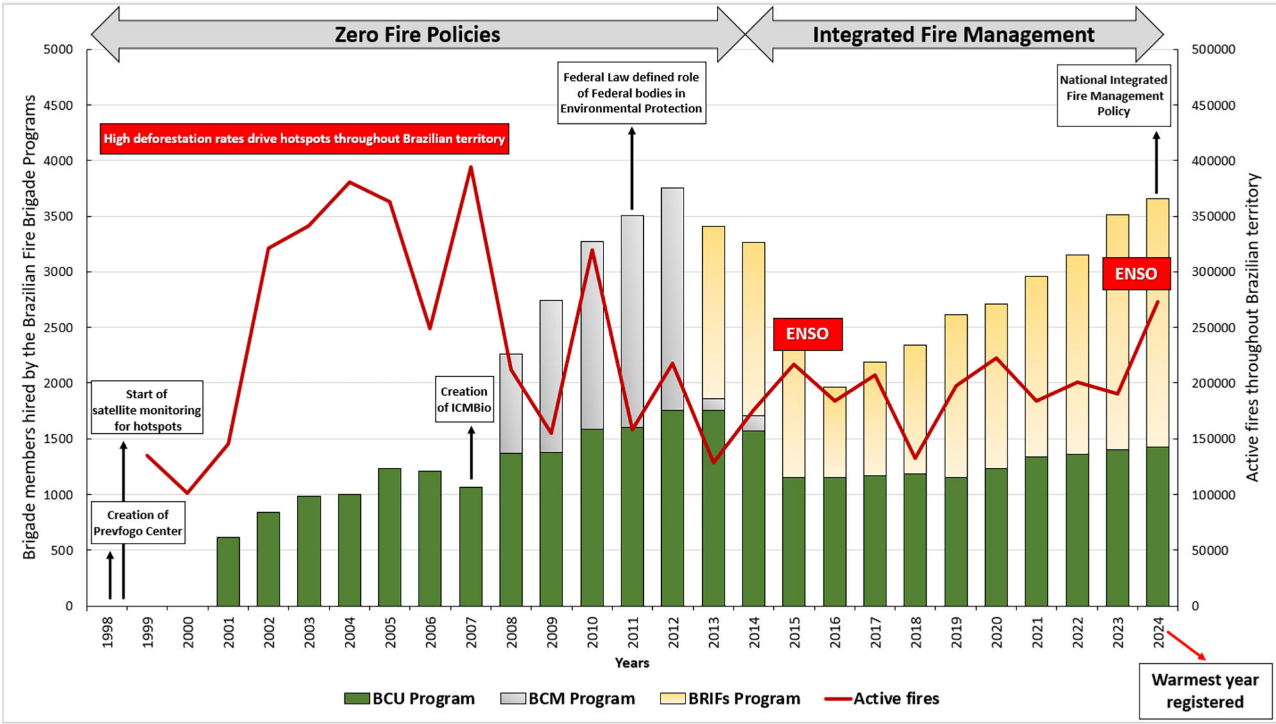


**Fig. 1** Number of active fires captured annually by reference satellites across the country (not only the territories protected by the Fire Brigade Programs) between 1998 and 2024, the highlights on fire public policies in Brazil, occurrences of the strongest El Niño Southern Oscillation (ENSO), and the number of brigade members hired by Federal Fire Brigade Programs.

policies. At this time, there was a confluence of factors, such as high records of active fires in 2007, unemployment caused by environmental law enforcement in the Amazon, and the need to protect other federal areas, such as Agrarian Settlement Projects, Traditional Territories, and ILs (Falleiro et al. 2021).

In this context, a new fire brigade program, which would bring together economic, social, and environmental benefits, appeared to be a promising solution. In this sense, the Brigades Program for Critical Municipalities (BCM) was created in 2008, with the aim of generating jobs and environmental protection for the Amazon municipalities most impacted by environmental law enforcement and wildfires (Falleiro et al. 2021).

Although ILs were one of the priority areas of action of the BCM, the program did not provide for the hiring of Indigenous people as members of the brigades. There was also no participation of the National Foundation of Indigenous Peoples (Funai) in the development and planning of the program (Falleiro et al. 2021).

The managers of Ibama/Prevfogo and the members of the Fire Brigades were not prepared for the particularities of working with indigenous communities and had very limited action in these areas. Although ILs gradually increased their participation in the BCU, the top-down model and prejudices against indigenous peoples prevented the program from breaking the paradigms that obstructed the implementation of the IFM in Brazil (Ibama 2024).

In 2011, the Complementary Law 140/2011 was published, which better defined the role of Federal entities in environmental protection. Then, the BCM came to be strongly questioned, opening space for its replacement by the BRIFs in 2013. In many ways, the BRIFs Program is an extension of the BCM Program, even sharing the same administrative processes, and many Federal Brigades were created from the migration of municipalities into ILs, Agrarian Settlements, and Quilombola (*maroon* communities) Territories (QTs) (Ibama 2024). However, in terms of fire management, BRIFs have made great advances and brought about a shift toward IFM.

**The transition to the BRIFs and the paradigm shift it represented**. Despite being an extension of the BCM program, the BRIFs brought changes that radically impacted the way environmental agencies operated in Indigenous, traditional, and rural communities. The top-down approach to fire governance, typically based on centralized decision-making and technical-scientific knowledge, required incorporating many bottom-up principles, such as decentralized decision-making, community involvement, valuing local knowledge, and adaptive management. In this way, the principles of IFM (Myers 2006) and other innovations such as participatory land management (Brazil, 2012), community-based fire management (FAO 2011), and the use of prescribed burning in savannas and grasslands (Durigan and Ratter 2016) could be adopted.

Breaking the "zero fire paradigm" and implementing protection strategies broadly based on the use of fire was the biggest challenge. To reverse large wildfires, it was necessary to reduce conflicts and address the fuel accumulation in open-canopy landscapes (Durigan and Ratter 2016). In 2014, one year after the start of the BRIFs Program, the first official prescribed burnings were carried out in Brazilian protected areas (Falleiro et al. 2016; Schmidt et al. 2018). In tropical forest ecosystems, where prescribed burns are not recommended, the alternative has been to improve the prevention and fighting of wildfires, in addition to supporting controlled burning in swidden agriculture (Ibama 2022).

Prescribed and controlled burns are conducted based on traditional knowledge learned from elders, shamans, and other knowledge-holders (Falleiro 2011; Bilbao et al. 2025). Many of them were hired as members of fire management brigades. To

| Year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Program BRIFs[1] | | | | | | | | | | | |
| Area of operation ($Km^2$) | 105,788.06 | 180,788.16 | 204,726.60 | 180,482.22 | 195,594.00 | 235,426.45 | 203,161.68 | 188,600.56 | 196,647.19 | 192,644.49 | 201,704.59 |
| Brigade members | 1,593.00 | 1,706.00 | 1,413.00 | 965.00 | 1,079.00 | 1,525.00 | 1,459.00 | 1,480.00 | 1,627.00 | 1,788.00 | 2,117.00 |
| Area/brigade member | 66.41 | 105.97 | 144.89 | 187.03 | 181.27 | 154.38 | 139.25 | 127.43 | 120.86 | 107.74 | 95.28 |
| Support area ($Km^2$) | ND | 191,902.44 | 297,215.07 | 151,082.61 | 113,073.74 | 72,584.56 | 216,799.14 | 393,658.29 | 425,367.04 | 450,859.03 | 610,712.85 |
| Indigenous Brigades (ILs): BRIFs-I | | | | | | | | | | | |
| Area of operation ($Km^2$) | 64,252.59 | 145,080.28 | 171,402.65 | 170,309.52 | 174,369.33 | 204,427.45 | 172,772.69 | 170,268.22 | 178,026.85 | 173,985.00 | 174,520.72 |
| Brigade members | 412.00 | 548.00 | 608.00 | 496.00 | 426.00 | 696.00 | 729.00 | 651.00 | 860.00 | 923.00 | 1,059.00 |
| Area/brigade member | 155.95 | 264.75 | 281.91 | 343.37 | 409.32 | 293.72 | 237.00 | 261.55 | 207.01 | 188.50 | 164.80 |
| Agrarian Settlement Brigades: BRIFs-A | | | | | | | | | | | |
| Area of operation ($Km^2$) | 38,865.48 | 33,407.88 | 30,673.99 | 7,522.71 | 7,649.36 | 28,349.01 | 27,718.99 | 15,662.34 | 15,950.35 | 15,659.12 | 22,232.94 |
| Brigade members | 502.00 | 621.00 | 447.00 | 232.00 | 188.00 | 387.00 | 336.00 | 225.00 | 240.00 | 313.00 | 343.00 |
| Area/brigade member | 77.42 | 53.80 | 68.62 | 32.43 | 40.69 | 73.25 | 82.50 | 69.61 | 66.46 | 50.03 | 64.82 |
| Traditional Maroon Brigades: BRIFs-Q | | | | | | | | | | | |
| Area of operation ($Km^2$) | 2,670.00 | 2,300.00 | 2,650.00 | 2,650.00 | 2,370.00 | 2,650.00 | 2,670.00 | 2,670.00 | 2,670.00 | 2,670.00 | 4,950.92 |
| Brigade members | 15.00 | 30.00 | 15.00 | 13.00 | 26.00 | 45.00 | 45.00 | 45.00 | 34.00 | 32.00 | 112.00 |
| Area/brigade member | 178.00 | 76.67 | 176.67 | 203.85 | 91.15 | 58.89 | 59.33 | 59.33 | 78.53 | 83.44 | 44.20 |

**Fig. 2** Summary of the BRIFs Program features in terms of area of operation, number of brigade members hired annually, ratio of area per brigade member, and the support areas (including data from reinforcement BRIFs).

this end, they underwent special selection and training procedures. Many of them are local leaders and organize meetings with communities to develop and discuss fire plans and schedules (Falleiro et al. 2016; Falleiro et al. 2021; Ibama 2022).

Along with the increase in prescribed burning in savannas, there has been a reduction in large wildfires and the large-scale suppression operations needed to control them in these ecosystems (Falleiro et al. 2021; Ibama 2024). The introduction of fire into landscape management and its first results quickly aroused the interest of researchers. Scientific studies conducted with the involvement of local brigade members have shown that prescribed burns have benefited the production of important natural resources, such as edible native fruits (Falleiro et al. 2024; Bilbao et al. 2025).

In addition to environmental protection, the program has brought food security, income opportunities, training, and citizenship to some of the most remote and marginalized communities in the country. As a result, it has reduced conflicts with environmental agencies and led to several synergies. Currently, the BRIFs have become an essential public policy for controlling wildfires in Brazil, operating in approximately 20 million hectares, around 90% of which are within ILs. The Program also helps protect tens of millions of hectares of support areas, which are served indirectly, depending on the availability of resources (Fig. 2).

Despite its importance, there are few studies of BRIF's impacts on these communities and territories, and it is likely that many problems and colonial legacies remain. In this sense, many other studies in diverse areas of knowledge need to be carried out to obtain a more comprehensive diagnosis of what the implementation of BRIFs has meant. Here, we take advantage of the first decade of BRIF's operation and quantitatively evaluate the results of the program in terms of reducing wildfires, which is its main objective.

## Methodology

**Selection of biomes**. This work builds on an earlier evaluation of the BRIFs carried out by the Ibama/Prevfogo (Ibama 2024). That study identified that ILs located in the Atlantic Forest, Caatinga, and Pantanal biomes presented methodological problems for being assessed using active fires due to their often small size. Thus, only the ILs located in the Cerrado and Amazon biomes had the necessary dimensions to be analyzed by active fires. Before moving on to the selection of ILs within these biomes, some general characteristics and fire regimes are presented:

- Cerrado biome: predominantly features fire-prone savanna and grassland ecosystems, although it may present several fire-sensitive forest ecosystems. The climate is semi-humid tropical, and the dry season can last from 4 to 5 months, depending on the region. The natural fire regime consisted of periodic lightning wildfires that hit larger areas during the transition between the dry and rainy seasons. Traditional burning practices of most indigenous peoples set fires during the early dry season or just after the rains, except in some cases of collective hunting. Currently, wildfires in the biome are concentrated at the end of the dry season, caused by humans for various reasons, ranging from accidental to criminal (Pivello 2011; Bilbao et al. 2025; Moreira et al. 2024).
- Amazon biome: predominantly features fire-sensitive forest ecosystems, although it may present some fire-prone savanna ecosystems. The climate is humid tropical, and the dry season may be non-existent or last up to four months, depending on the region. Wildfires, once rare in these forests, accompany the dry season and have been increasing rapidly (Pivello 2011; Moreira et al. 2024; Tyukavina et al. 2022).

**Selection of ILs**. Only homologated ILs were considered. Those with an area <25,000 hectares were discarded, as smaller areas present many errors associated with the detection of active fires by satellites.

In the Cerrado biome, only ILs with more than 70% of their area covered by savanna and grassland physiognomies were selected. The objective was to evaluate the program in fire-prone ecosystems, where landscape management with prescribed burning is the most efficient protection strategy against wildfires.

In the Amazon biome, only ILs with more than 70% of their area covered by forest physiognomies were selected. The objective was to evaluate the program in fire-sensitive ecosystems, where prescribed burning management is not recommended, and there is a need for several integrated strategies, such as support for controlled burning (slash and burn agriculture), rapid suppression, and prevention of wildfires.

Within each biome, areas covered (BRIFs) and not covered (No BRIFs) by the Program were selected (Falleiro et al. 2021; Ibama 2024), as shown below:

- BRIFs: only ILs with a long history of program coverage, without interruptions.
- No BRIFs: only ILs that have never been covered by the program.

**Table 1 Summary of data for the selected ILs within each biome (Tables 3–6).**

| Biome | Program | N° ILs | Area (ha) | N° ethnic groups | Population size | Active fires 2003–2012 |
|---|---|---|---|---|---|---|
| Cerrado | BRIFs | 11 | 2,971,334.8 | 14 | 20,362 | 23,353[a] |
| | No BRIFs[a] | 14 | 2,156,604.6 | 12 | 23,469 | 23,329[a] |
| Amazon | BRIFs | 7 | 10,179,566.1 | 26 | 26,028 | 8984[a] |
| | No BRIFs[a] | 10 | 10,047,908.1 | 18 | 26,069 | 9025[a] |

Equal lowercase letters within the same biomes indicate that the differences in active fires are not significant between the treatments (BRIFs or no BRIFs) according to the Chi-Square Adherence test ($P < 0.05$) (Table 11).
[a] These areas may have received other protection programs, mainly volunteer brigades, or possibly even support from BRIFs at some specific time. But they were not directly and continuously covered by BRIFs.

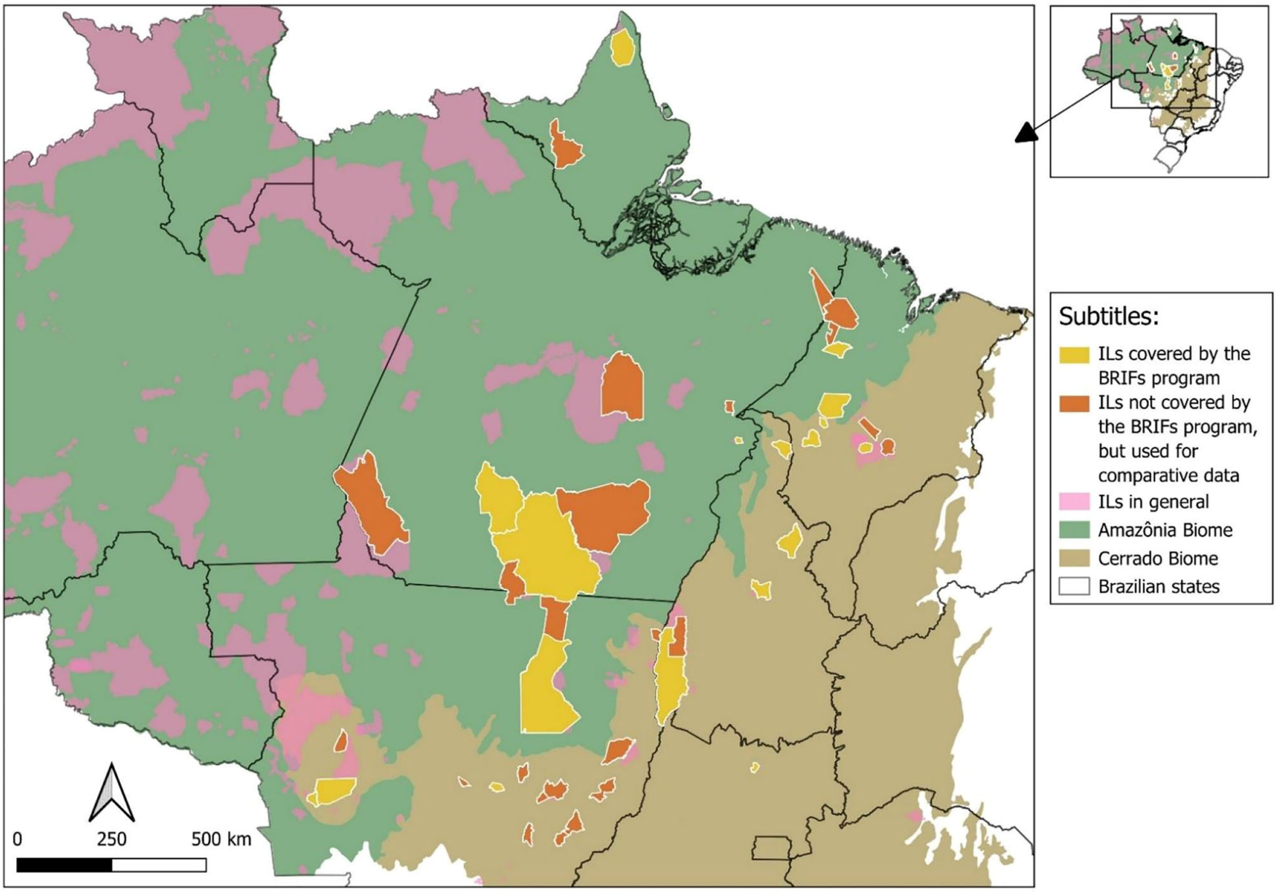


**Fig. 3** Map of ILs in the Amazon and Cerrado biomes, highlighting the areas selected for comparison (covered or not by the BRIFs).

The ILs were tested until the BRIFs, and no BRIF groups presented similarity in terms of geographic proximity, climate, fire seasons, ethnic groups, population, and area size (Tables 3–6). The groups were then tested again, this time statistically, until they showed statistical similarity within each biome. The result was two groups (BRIFs and No BRIFs) per biome, as similar and close as possible (Table 1 and Fig. 3).

**Statistical analysis**. The BRIFs Program was evaluated by comparing the number of active fires captured by the AQUA_M-T reference satellite, to estimate wildfires between the years 2003–2012 and 2014–2023. The year 2013 was discarded as it was considered a transitional phase between treatments.

Only active fires (hotspots captured by satellites) during the wildfire season were considered (Tables 3–6), to avoid including those generated by early-season prescribed burnings. Using active fires may not be ideal, as this methodology can overlook small fires and may result in false negatives, or positives. Furthermore, it underestimates the results of wildfire reductions, as controlled agricultural burns of swidden agriculture may have been included as wildfires. However, active fires are the only data available in Brazil for the 20-year period and, considering that all areas are subject to the same error, it is an efficient system for comparisons made (INPE 2024).

The assessments were conducted for all ILs as a whole and separately by biome. This made it possible to verify the Program's results in both forests of the Amazon biome (fire-sensitive ecosystems) and savannas of the Cerrado biome (fire-prone ecosystems). Comparisons between treatments were carried out with the aim of finding Before-After-Control-Impact (BACI) response units.

To investigate if the BRIFs program affects fire occurrence in the ILs it has been implemented, two treatments were considered:

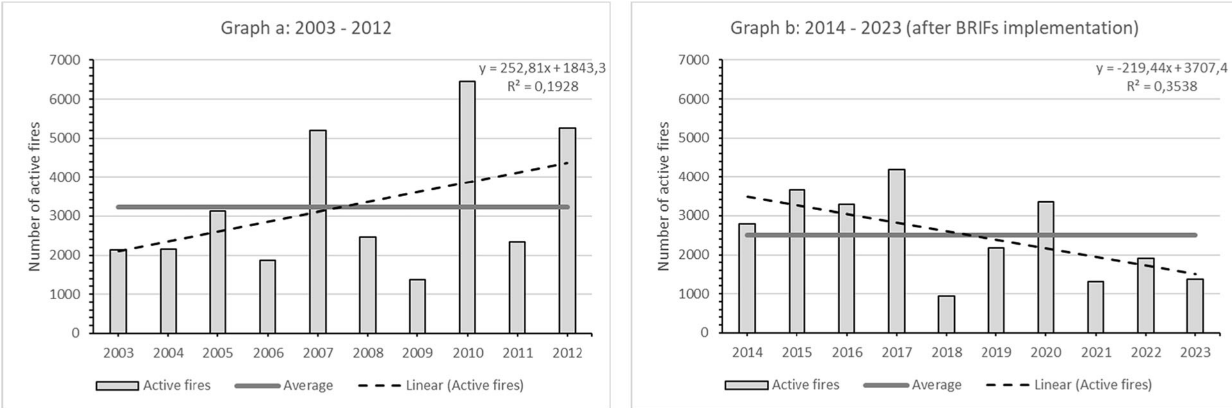


**Fig. 4 Annual quantity of active fires in Indigenous Lands covered by BRIFs.** The graphs before (**a**) and after (**b**) implementation include the average value, the trend line and the respective y and $R^2$ values.

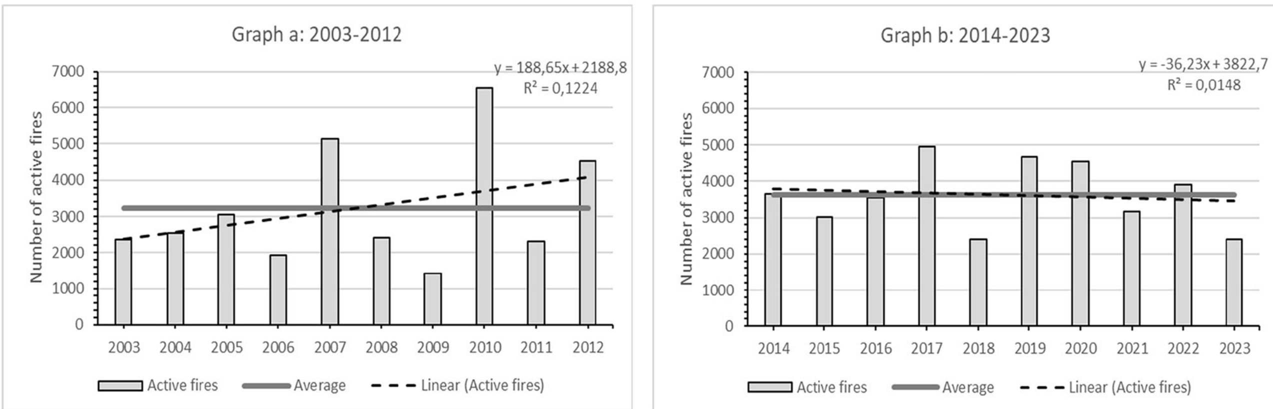


**Fig. 5 Annual quantity of active fires in Indigenous Lands not covered by BRIFs.** The graphs for the periods 2003-2012 (**a**) and 2014-2023 (**b**) include the average value, the trend line and the respective y and $R^2$ values.

Control, including all ILs that were never covered by the Program (No BRIFs), and Intervention, which includes all ILs consistently covered by the Program (BRIFs). Then, the number of active fires across these two treatments is considered 10 years before the program implementation (2003–2012) and also 10 years after the program implementation (2014–2023).

The numbers of active fires between treatments were compared, considering these two periods, applying the Chi-Square Adherence test, and considered that results with $P < 0.05$ indicate significant differences. The analyses were performed using R, version 4.3.0, using packages *stats*, *ggplot2*, and *dplyr*. Detailed data on each IL are presented in Tables 7–10, and statistical analysis data are shown in Table 11.

We performed simple linear regressions using the number of active fires throughout the years, considering ILs that received the program (BRIFs) and ILs that did not receive the program (No BRIF), and considering both periods of 10 years before and 10 years after the implementation of the BRIFs. The goal was to present the behavior of the areas over the evaluation period and identify potential trends. The analyses were performed using R, version 4.3.0, using packages *stats*, *ggplot2*, and *dplyr*.

In addition to statistical analyses, graphs were created using annual data on active fires. The aim was to present the behavior of the areas during the evaluation period and identify possible trends using simple linear regressions. The results were presented in graphs created using Excel, accompanied by the respective linear trend lines and equations.

At the end, in addition to active fire analysis, descriptive analyses were made on the structure and costs of the program. The proportion of area per member brigade (Table 2) and the financial costs of the BRIFs Program were estimated (Table 12), according to Prevfogo's 2023 budget control spreadsheet and technical-administrative reports (Ibama 2022), with the aim of evaluating the program structure and determining the costs per protected area (ha).

## Results and discussion

**Have BRIFs reduced wildfires across Brazil's ILs?** All ILs evaluated presented similar behavior during the period before the implementation of the program, with a rising linear trend (Figs. 4a and 5a) and no statistical differences in the number of active fires (Table 1). After 2014, ILs covered by BRIFs showed a significant reduction of 22.7% in the number of active fires, while the areas not covered showed a significant increase of 12.3% (Table 2), totaling an accumulated difference of 35.0% between them. The linear trend line reinforces this drop, demonstrating a greater inflection in the areas covered by BRIFs (Figs. 4b and 5b).

In fact, previous work carried out in some specific ILs covered by BRIFs already indicated a reduction in the number of wildfires (Andrade et al. 2021; Santos et al. 2021; Oliveira et al. 2022). However, the present work is the first to scientifically evaluate the BRIFs Program in its entirety.

Before BRIFs, the Brigades Program in Critical Municipalities (BCM) Program protected some of the ILs addressed in this

**Table 2 Biomes (Cerrado, Amazonia, and both), treatments (BRIFs × No BRIFs and before × after BRIFs), area (ha) per brigade member, number of active fires corresponding to each treatment, and the difference between them.**

| Biome | Program | Area (ha)/ brigade member | Active fires 2003-2012 | Active fires 2014-2023 | Difference in active fires (%) |
|---|---|---|---|---|---|
| Cerrado + Amazon | BRIFs | 46,283.4[a] | 32,337 Aa | 25,005 Ab | −22.7 |
| | No BRIFs | - | 32,264 Aa | 36,234 Bb | + 12.3 |
| Cerrado | BRIFs | 11,043.4 | 23,353 Aa | 16,190 Ab | −30.7 |
| | No BRIFs | - | 23,239 Aa | 25,866 Bb | + 11.3 |
| Amazon | BRIFs | 81,523.5 | 8984 Aa | 8815 Aa | −1.9 |
| | No BRIFs | - | 9025 Aa | 10,368 Bb | + 14.9 |

Different lowercase letters indicate significant differences between periods before (2003–2012) and after (2014–2023) the BRIFs, within the same treatments (BRIFs and No BRIFs), according to the Chi-Square Adherence test.
Different capital letters indicate significant differences between treatments (BRIFs and no BRIFs) within the same biomes or both.
[a]Average between the Cerrado and Amazon biomes.

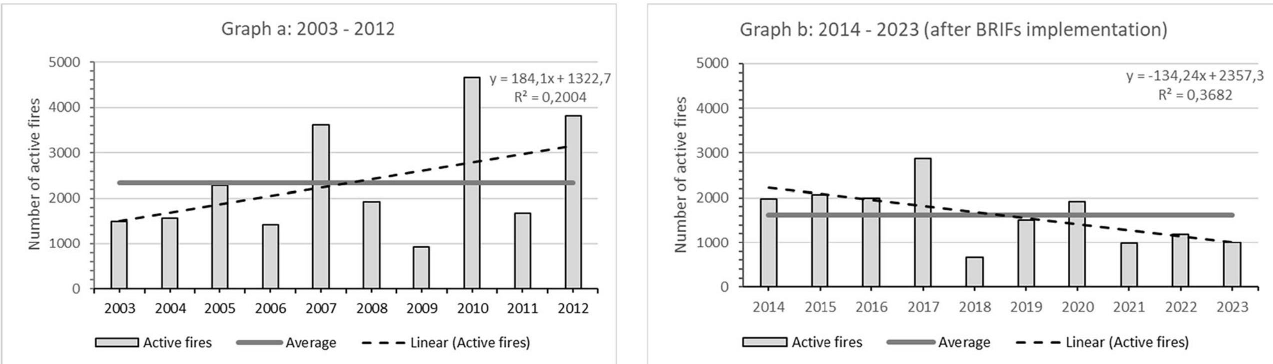


**Fig. 6 Annual quantity of active fires in Indigenous Lands of the Cerrado biome covered by BRIFs.** The graphs before (**a**) and after (**b**) implementation include the average value, the trend line and the respective y and R2 values.

study. In the only evaluation carried out (Ibama 2024), it was shown that there was an average increase of 5.7% in the number of active fires in these ILs after the implementation of the program. Afterward, replacing BCM with BRIFs resulted in an average reduction of 20.7% in the same areas, a result similar to that found in the present study. These results can be attributed to the paradigm shift that the replacement of BCM by BRIFs represented, with the adoption of IFM, in addition to technical advances (Falleiro et al. 2021).

The Brigades Program in Conservation Units (BCU) also has many similarities with BRIFs. According to some available studies (Berlinck and Batista 2020; Berlinck and Lima 2021), between 2011 and 2019, there were years in which BCU showed a reduction of up to 40% in wildfires in the Conservation Units of the Cerrado. However, the evaluation was made exclusively in relation to the critical years of 2010 and 2017, instead of comparing with the historical average. Furthermore, the study was more focused on specifically assessing the introduction of prescribed burnings, since the BCU had already been operating since 2001. Therefore, comparisons between these programs using these studies should be made with caution.

**International comparisons and management models**. Comparisons with other countries are even more difficult, due to the scarcity of publications, the particularities of context, and differences in evaluation methodology. Even so, comparing the available data can still be interesting. In Mexico, the wildfire protection system is much more organized, expensive, and structured than the Brazilian one (Conafor 2020; Conafor 2022). Although there was a rapid reduction in the occurrence of wildfires in the years following the implementation of fire brigade programs, the country has been registering recent increases in some regions (Rodríguez-Tejo et al. 2022). This has led to a reflection on spending cuts, recognition of the ecological, cultural, and social role of fire, and the creation of pyrobiocultural territories (Ponce-Calderón et al. 2022).

In Chile, which also has a well-structured protection system, the opposite occurred, with an increase in the area affected by wildfires recently (Conaf 2024). In the United States, the Bureau of Indian Affairs-BIA has a fire program similar to BRIFs, but with much more structure and resources (BIA 2018). Despite that, there has been an increase in wildfires in recent years, driven by climate change and the difficulties of reintroducing traditional fire management.

Overall, the BRIFs Program was efficient in protecting ILs from wildfire during its first ten years of implementation, even in the face of an unfavorable climate scenario (Fidelis et al. 2018; Pivello et al. 2021; UNEP 2022). These results are similar, or even better than, those observed in much more expensive, older, and structured programs, which demonstrate their potential for environmental protection. However, due to the distinctions between fire-prone ecosystems (savannas of the Cerrado biome) and fire-sensitive ecosystems (forests of the Amazon biome), it is necessary to evaluate performance in the biomes separately.

**In the savannas of the Cerrado biome, the results were sooner**. All ILs evaluated in the Cerrado biome presented similar behavior during the period before the implementation of the program (2003–2012), with a rising linear trend (Figs. 6a and 7a) and no statistical differences in the number of active fires (Table 1). After

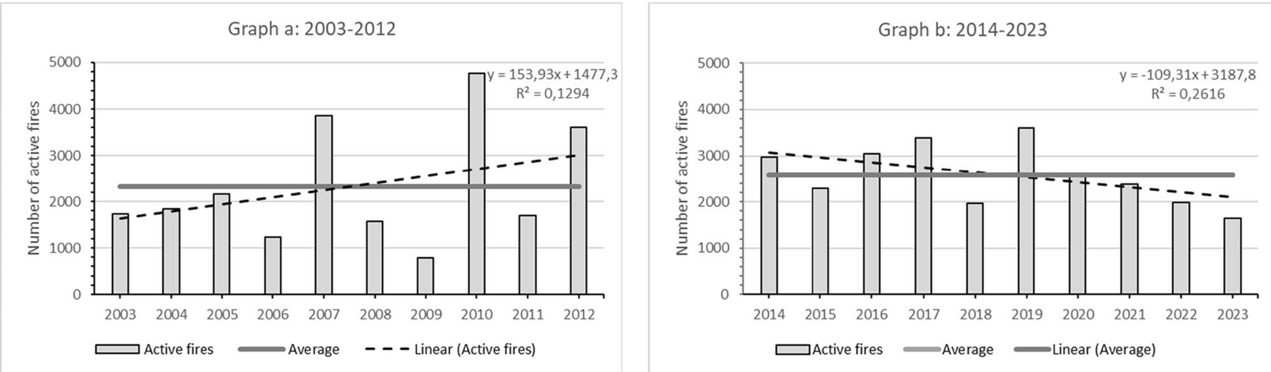


**Fig. 7 Annual quantity of active fires in Indigenous Lands of the Cerrado biome not covered by BRIFs.** The graphs for the periods 2003-2012 (**a**) and 2014-2023 (**b**) include the average value, the trend line and the respective y and $R^2$ values.

2014, these areas showed significant differences. In ILs covered by the BRIFs, the number of active fires decreased 30.7%, whilst the areas not covered by BRIFs recorded an increase of 11.3%, totaling an accumulated difference of 42.0% (Table 2 and Figs. 6b and 7b).

These reductions in active fires reflect the introduction of protection strategies based on the IFM approach. Risk reduction activities and a decrease in response time have certainly helped to reduce the number and size of wildfires. However, in savannas, protection strategies that do not include the use of fire tend to lead to fine fuel accumulation, increasing the risk of large wildfires (Durigan and Ratter 2016; Fidelis et al. 2018).

Therefore, it is likely that the management with prescribed burning was the most important activity to reduce large wildfires in these savannas. This is especially after 2018, when the BRIFs reached the necessary scale to create mosaics of different fire histories in the landscape (Falleiro et al. 2021; Ibama 2024). A study evaluating the activities carried out by BRIF members indicates that the number of burnings carried out is inversely proportional to the number of wildfires that need to be fought. In this sense, the use of fire is the activity in which indigenous brigades excel the most, compared to other types of brigades in the program (Falleiro et al. 2021).

In the Brazilian Conservation Units, the management using prescribed burnings is also an important strategy to protect the savannas located in the Cerrado biome. The evaluations made so far indicate a 33% average reduction in the areas affected by wildfires, but in some cases this reduction reached 72.5% (Berlinck and Batista 2020; Berlinck and Lima 2021). Nonetheless, the comparison was made in relation to the most critical years or during short periods, different from the methodology of this study, which covered the average of two long periods.

**Comparisons with tropical savannas in other countries around the world**. About 97% of the Cerrado biome is located in Brazil, which makes some international comparisons difficult, especially in ILs. But South America has other fire-prone tropical savannas, subject to different public policies and fire management models. In general, the IFM is still new on the continent, and despite some progress, the use of fire is not a consensus. Some countries still insist on top-down models and face the consequences of "zero-fire policies"(Falleiro 2011; Moura et al. 2019; Fidelis and Pivello 2025).

Between Colombia and Venezuela, there is a vast savanna region called "Llanos del Orinoco", with many fire-prone vegetation types. Although it also has indigenous and traditional populations with extensive knowledge of the use of fire for management, the public policies of the two countries are not yet aligned with the IFM, and large wildfires have been recorded (Silva and Bilbao 2025).

Also, in the north of the continent, another fire-prone ecosystem stands out, on the border between Venezuela, Brazil, and Guyana, known as "Lavrado Roraimense" or "Savana do Rupununi." These savannas have been the subject of several studies due to their close relationship with fire and the rich indigenous knowledge associated with them (Mistry et al. 2016; Bilbao et al. 2019). Among the advances and resistances in fire policies in the three countries (Eloy et al. 2019), the management of prescribed burns in ILs carried out on the Brazilian side stands out positively. Unfortunately, methodological problems in separating prescribed burning seasons from wildfires, combined with constant cloud cover, have impeded scientific evaluation using active fires. However, these ILs are considered the best managed in the BRIFs Program, with socio-environmental results reported in documents (Falleiro et al. 2020; Falleiro et al. 2021; Ibama 2022).

In the center of the continent, wet and dry fire-prone savannas alternate, mainly in the Pantanal and Chaco biomes (Fidelis and Pivello 2025). The Pantanal recently faced the worst wildfire season in its history, driven by climate change and also by the lack of fire management, except for some ILs covered by BRIFs (Pivello et al. 2021; Oliveira et al. 2022). In the Chaco, Bolivia, Paraguay, and Argentina have not yet implemented public policies based on IFM, despite the worsening problem of wildfires. However, in northern Bolivia, non-governmental organizations and indigenous associations have attempted to implement IFM initiatives. But these are still too recent and localized to be evaluated or compared with the present study (Supayabe et al. 2022; Ibarnegaray et al. 2022; Rodríguez et al. 2023).

Moving southward, the climate becomes subtropical to temperate, and savannas and grasslands are dominated by agriculture and livestock farming. In these southern regions of Brazil, Argentina, and Uruguay, ILs are very small or even nonexistent. However, in some areas, the use of fire still plays an important role for indigenous and traditional communities, including in the prevention of wildfires (Millán et al. 2022). Despite this, recognition of the social, cultural, and ecological role of fire in these regions tends to be even lower than in the north of the continent (López-Mársico et al. 2025).

Public policies based on top-down models are not a characteristic unique to South America (Myers 2006; UNEP 2022; Pasiecznik and Goldammer 2022). The "zero-fire policies" have been implemented around the world and are difficult to change, despite consensus that their results have ranged from bad

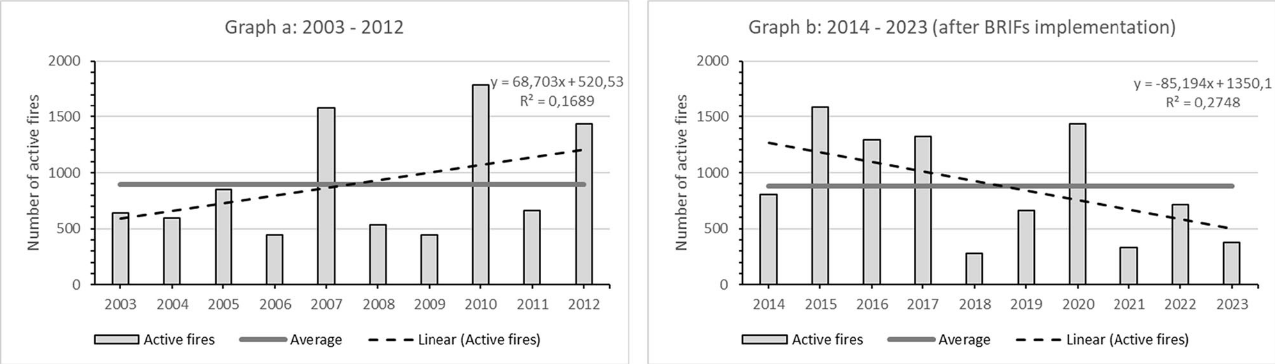


**Fig. 8 Annual quantity of active fires in Indigenous Lands of the Amazon biome covered by BRIFs.** The graphs before (**a**) and after (**b**) implementation include the average value, the trend line and the respective y and $R^2$ values.

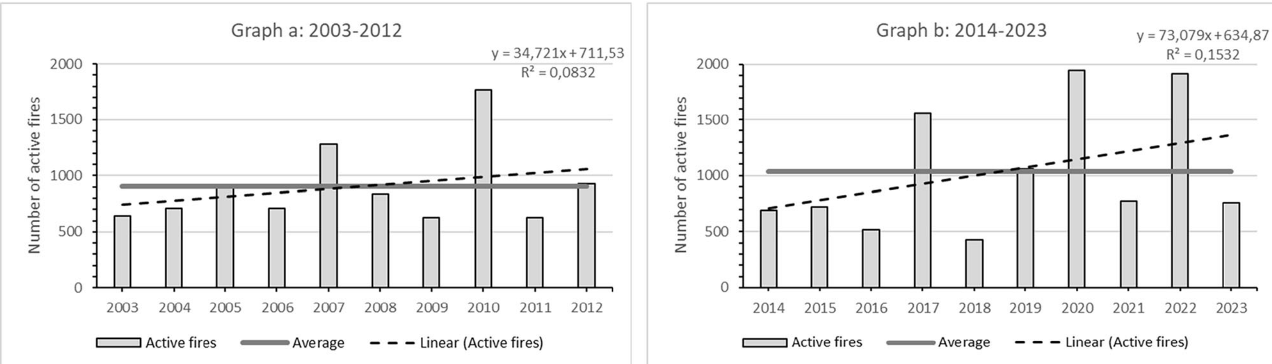


**Fig. 9 Annual quantity of active fires in Indigenous Lands of the Amazon biome not covered by BRIFs.** The graphs for the periods 2003-2012 (**a**) and 2014-2023 (**b**) include the average value, the trend line and the respective y and $R^2$ values.

to catastrophic (Pivello et al. 2021; UNEP 2022). However, there are positive experiences of IFM in tropical savannas around the world, particularly in Australia and some African countries.

In the African savannas, several protected areas have long-standing and highly advanced fire management programs, most notably Kruger National Park (Van Wilgen et al. 2014). Increasingly, the use of prescribed burning is being encouraged, generating changes in the fire regime and opportunities for local communities to pay carbon credits (UNU 2015; Pasiecznik and Goldammer 2022). The same is true in the Australian savannas, where an older and more structured IFM program has already achieved an average reduction of 37.7% in $CO_2$ emissions, generating carbon credits to pay Aboriginal communities that manage the landscape with fire (Russell-Smith et al. 2013).

In these contexts, the BRIFs Program in the ILs of the Cerrado biome achieved results similar to the best IFM programs implemented in tropical savannas around the world. The emission reductions generated can be an excellent financing opportunity for the program and to pay for environmental services provided by Indigenous communities, promoting financial sustainability for Brazilian environmental conservation (Russell-Smith et al. 2017; Franke et al. 2024).

In addition to reducing wildfires and their damage, prescribed burnings applied by BRIFs in fire-prone ecosystems help maintain ecological processes, biodiversity, and the environmental services (Honda and Durigan 2016; Abreu et al. 2017). In the Cerrado biome's ILs, they also play an important role in the production of natural resources and the preservation of the rich culture of Indigenous peoples (Falleiro 2011; Falleiro et al. 2024; Bilbao et al. 2025).

**In the forests of the Amazon biome, the results took longer**. All ILs evaluated in the Amazon biome presented a similar behavior during the period before the implementation of the program, with a rising linear trend (Figs. 8a and 9a) and without statistical differences in the number of active fires (Table 1). After BRIF's implementation, the areas covered by BRIFs showed a small reduction in the average of active fires (1.9%), which was not statistically significant. However, the trend curve showed a strong downward inflection in the areas covered by BRIFs, while those not covered extended the upward trend (Figs. 8b and 9b). Accompanying the upward trend, areas not covered by BRIFs showed a significant increase of 14.9% in the number of active fires in the period 2014–2023 (Table 2).

The ILs covered by BRIFs registered a pulse of more active fires shortly after the program implementation (Fig. 8b), mainly due to the large wildfires in the forests of the Xingu and Araribóia ILs (Falleiro et al. 2021; Ibama 2024). Driven by extreme weather events (Fig. 1), these wildfires in 2015 and 2016 affected the program's results in the period between 2014 and 2023. However, after these initial years, strong investments were made in protection strategies, such as risk reduction, preparedness, and suppression, as well as support for swidden agriculture (Falleiro et al. 2021). As a result, the number of active fires was reduced, affecting the trend curve.

These differences became even more evident in the extreme year of 2024, considered the warmest ever recorded and the worst for Brazilian ILs, in terms of wildfires. According to a report prepared specifically to verify whether the results of this study held up in that critical year, the differences between areas served and not served by BRIFs widened, reaching a staggering 435.7% (MPI 2025). This reinforces the importance of maintaining long-term protection strategies for controlling wildfires in the ILs.

There are no specific studies comparing the implementation of public policies in rainforests and wildfires, by other Brazilian agencies. However, there is undeniable evidence that there has been a significant increase in wildfires in the Amazon forest (UNEP 2022; Tuky et al. 2022; Silverio et al. 2025). Due to increased flammability and the immense logistical challenges of working in the vastness of the Amazon ILs, controlling wildfires in these areas is much more difficult and complex than in the rest of the country (Falleiro et al. 2021; Ibama 2024).

Most of the techniques and resources used around the world to protect forests from wildfires have been developed by countries with much stronger financial and material resources (Howard 2014; Hope et al. 2016). In this context, comparing the protection systems of rich temperate countries with poor tropical countries should be done with care. If possible, comparisons should be made as similar as possible.

**Comparisons with tropical forests in other countries around the world**. The other Amazonian countries generally have limited resources for environmental protection and poorly structured and heterogeneous fire protection systems. For this reason, we did not find any studies on public policies for IFMs such as BRIFs. In many cases, the absence of government programs opens space for local initiatives, that deserve to be mentioned (Pasiecznik and Goldammer 2022).

In Bolivia, several IFM-based projects have been carried out by civil society organizations and indigenous associations, in Indigenous Communal Territories and other protected areas. Some of these experiences appear to have significantly reduced conflicts with the government's environmental agency. However, they have not yet yielded significant results, partly due to their recent implementation (Supayabe 2022; Ibarnegaray 2022; Rodríguez 2022). In Ecuador, despite the implementation of the "Amazonia Without Fire Project", based on Brazilian experiences in recent years, the number of people affected, and the number of wildfires, have increased (Segura et al. 2022).

The lack of large-scale experiences in South America highlights the importance of analysis and comparison with other continents. However, countries in tropical and equatorial zones are generally characterized by precarious environmental protection structures and a scarcity of scientific reports and research. When available, these data usually refer to local initiatives promoted by non-governmental organizations and associated with specific protected areas (Pasiecznik and Goldammer 2022).

The tropical forests of the African continent are one example. Despite experiencing an increase in areas affected by wildfires in recent years, there is no information on large-scale public protection policies implemented (UNEP 2022; Tyukavina et al. 2022; FAO 2024). In addition to poverty and climate change, in some countries, wildfires are also being driven by wars, with devastating consequences for both local native peoples and ecosystems (Shapiro et al. 2021). This is concerning, as Africa's rainforests appear to be undergoing similar processes to those of the Amazon rainforest, with increasing severity, degradation, and flammability (Fischer 2021; Tyukavina et al. 2022).

Further east, on the Asian continent, despite the distances and cultural differences, there are also initiatives that deserve to be compared with the experiences of the BRIFs Program. Like the Brazilian Amazon, Indonesia's tropical forests had a history of few problems related to wildfires. However, since the early 1990s, and with an extreme year in 2015, the country has suffered a series of anthropogenic wildfires, which have humanitarian burdens for local populations and global impacts (Miettinen et al. 2016; Carmenta et al. 2017; Carmenta et al. 2021). An aggravating factor to the problem of wildfires in Indonesia, compared to Brazil, is that the peat soil itself is fuel for the fires, meaning their control is extremely difficult (Aminah et al. 2020).

Following the 2015 disaster, Indonesia invested a lot of resources in well-structured and highly technological protection systems. The burned area has decreased compared to 2015, but it remains high compared to the years before the disaster (Miettinen et al. 2016; Carmenta et al. 2021). Another Asian country, Vietnam, has recently seen a reduction in wildfires (Thuy et al. 2022), and is the only tropical country among those to have increased its forest area the most (FAO 2024). Therefore, some Asian countries are also making progress in protecting against wildfires. However, it seems that their systems are more expensive, top-down, and costly than the BRIFS applied in Brazilian ILs.

Protecting tropical forests and their rich social biodiversity is important for the entire planet (FAO 2024). Despite this, little progress has been made. In this context, Brazil's experience with ILs in the Amazon is especially important, as it has achieved positive results so far. However, controlling forest fires in the Amazon rainforest is still the biggest challenge for Prevfogo/Ibama (Falleiro et al. 2021). Protecting the world's largest rainforest is strategic for Brazil for reasons that go beyond socio-environmental issues, including international political leadership and maintaining essential ecological services, such as the water balance that sustains the country's main agricultural regions (Weng et al. 2017). To achieve this, it is necessary to expand the area served by BRIFs and improve infrastructure, as increased flammability, forest degradation, and climate change are getting harder to overcome.

**Implications, the BRIFs model, and long-term sustainability**. The BRIFs Program represented a break with prejudices against indigenous communities and the traditional use of fire in Brazil. Before it, Brazilian environmental agencies hiring indigenous labor was taboo, and the implementation of a protection system managed by them would have been unlikely. No less unlikely was the Brazilian government supporting the management of millions of hectares of protected areas based on traditional knowledge (Falleiro et al. 2021). These were precisely the pillars of the BRIFs Program, and the results presented here and in previous publications leave no doubt regarding their efficiency. For this reason, it could serve as a model for wildfire protection in the tropics.

Many tropical countries are economically poor and need models that are adapted to their reality. Therefore, costs are a fundamental part of evaluating the efficiency and viability of projects. In 2023, BRIFs directly protected 17,452,072.0 million hectares of ILs (Table 1), and the estimated total cost of the program was USD 17,803,727.0 (Table 12), resulting in a proportion of USD 1.02 per hectare protected. These values are compatible with estimates of the costs of ICMBio to protect Brazilian Nature Conservation Units and are much cheaper than the cost of protecting public-private partnerships (Oliveira et al. 2021).

On the other hand, the low costs also resulted in an excessive area of protection per brigade member, especially in the Amazon biome (Table 2), in addition to some structural problems not addressed in this study (Ibama 2024). Therefore, significant investment is still needed for the program to improve working conditions for brigade members, as well as to acquire the necessary scale in a continental country like Brazil. Currently, only 23.1% of the total IL area is covered by the program.

It is also necessary to monitor the program's progress over the long term, using multidisciplinary approaches. Integrated research should be conducted in the environmental, social, and cultural areas to develop more comprehensive and intercultural diagnoses as quickly as possible.

Brazilian Indigenous peoples are experiencing rapid climate and cultural changes. For them to continue protecting our natural heritage against wildfires, payment for environmental services and the implementation of more structured protection systems is essential. It is also important to implement other important public policies, such as the National Policy for Environmental and Territorial Management (Brazil 2012) and the National Policy for IFM (Brazil 2024). With the right framework, Indigenous peoples will have a better chance of dealing with the changes to come. This study showed that it is still possible to create efficient frameworks at low cost while respecting the rights of local people.

## Conclusion

The BRIFs Program reduced the number of active fires, captured by satellites in ILs during the wildfire season, by 35.0%. These results were achieved in a total area of 17,452,072.0 hectares, with investments of U$1.02/hectare. The responses were different between the ecosystems, with the savannas of the Cerrado biome showing faster and more evident reductions than the forests of the Amazon biome. These environmental results, combined with low costs, indicate that BRIFs could serve as a model for countries with similar socio-environmental conditions.

## Data availability

The data on active fires used in the survey is public and available at https://terrabrasilis.dpi.inpe.br/queimadas/bdqueimadas/.

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## Appendix

**Table 3 Name of the ILs, wildfire season, area, ethnic groups, population size, and number of active fires detected via reference satellite (2003–2012), in the ILs located in the Cerrado biome covered by BRIFs.**

| N° | Indigenous land | Climate[a] | Fire season | Area (ha) | Ethnic group | Population size | Active fires 2003-2012 |
|---|---|---|---|---|---|---|---|
| 1 | Krikati | Aw | Aug-Dec | 144,775.8 | Krikati | 1670 | 1111 |
| 2 | Porquinhos | Aw | Aug-Dec | 79,520.3 | Canela Apanyekrá | 892 | 539 |
| 3 | Governador | Aw | Aug-Dec | 41,643.0 | Gavião Pykopjê, Guajajara and Tabajara | 1360 | 480 |
| 4 | PI Araguaia | Aw | Aug-Dec | 1,358,499.5 | Avá-Canoeiro, Karajá, Javaé and Tapirapé | 4503 | 11,906 |
| 5 | Paresi | Aw | Jul-Dec | 563,586.5 | Paresi | 1266 | 2095 |
| 6 | Juininha | Aw | Jul-Dec | 70,537.5 | Paresi | 108 | 439 |
| 7 | Apinayé | Aw | Jul-Dec | 141,904.2 | Apinayé | 2731 | 1372 |
| 8 | Kraholândia | Aw | Jul-Dec | 302,533.4 | Krahô | 3691 | 2930 |
| 9 | Xerente | Aw | Jul-Dec | 167,542.1 | Xerente | 3336 | 1785 |
| 10 | Avá-Canoeiro | Aw | Jul-Dec | 39,387.0 | Avá-Canoeiro | 11 | 244 |
| 11 | Bakairi | Aw | Jul-Dec | 61,405.5 | Bakairi | 794 | 452 |
|  | Total | - | - | 2,971,334.8 | 14 | 20,362 | 23,353 |

[a]According to the Köppen-Geiger classification in (24).

**Table 4 Name of the ILs, wildfire season, area, ethnic groups, population size, and number of active fires detected via reference satellite (2003–2012) in the ILs of the Cerrado biome covered by BRIFs.**

| N° | Indigenous land | Climate[a] | Fire season | Area (ha) | Ethnic group | Population size | Active fires 2003-2012 |
|---|---|---|---|---|---|---|---|
| 1 | Cana-Brava Guajajara | Aw | Aug-Dec | 136,813.0 | Guajajara | 4510 | 2498 |
| 2 | Kanela | Aw | Aug-Dec | 125,941.0 | Canela Memortumré | 2103 | 880 |
| 3 | Pimentel Barbosa | Aw | Aug-Dec | 329,411.0 | Xavante | 2369 | 3225 |
| 4 | Tapirapé/ Karajá | Aw | Aug-Dec | 66,531.0 | Karajá and Tapirapé | 550 | 264 |
| 5 | Inãwébohona | Aw | Aug-Dec | 377,113.6 | Avá-Canoeiro, Karajá and Javaé | 388 | 2607 |
| 6 | Tirecatinga | Aw | Jul-Dec | 130,575.0 | Nambikwara and Paresi | 244 | 303 |
| 7 | Areões | Aw | Jul-Dec | 218,515.0 | Xavante | 1342 | 2809 |
| 8 | Parabubure | Aw | Jul-Dec | 224,447.0 | Xavante | 3819 | 4338 |
| 9 | Ubawawe | Aw | Jul-Dec | 52,296.0 | Xavante | 600 | 769 |
| 10 | São Marcos | Aw | Jul-Dec | 174,865.0 | Xavante | 3667 | 1971 |
| 11 | Merure | Aw | Jul-Dec | 82,279.0 | Bororo | 811 | 1108 |
| 12 | Sangradouro/ Volta Grande | Aw | Jul-Dec | 102,468.0 | Xavante and Bororo | 1817 | 1160 |
| 13 | Marechal Rondon | Aw | Jul-Dec | 99,879.0 | Xavante | 1043 | 1110 |
| 14 | Santana | Aw | Jul-Dec | 35,471.0 | Bakairi | 206 | 197 |
|  | Total | - | - | 2,156,604.6 | 12 | 23,469 | 23,239 |

[a]According to the Köppen-Geiger classification in (24).

**Table 5 Name of the ILs, fire season, area, ethnic groups, population size, and number of active fires detected via reference satellite (2003–2012) in the ILs of the Amazon biome covered by BRIFs.**

| N° | Indigenous land | Climate[a] | Fire season | Area (ha) | Ethnic group | Population size | Active fires 2003–2012 |
|---|---|---|---|---|---|---|---|
| 1 | Uaçá | Am | Jan–Dec | 470,164.0 | Galibi-Marworno, Karipuna do Amapá, and Palikur | 6105 | 1871 |
| 2 | Araribóia | Aw | Aug–Dec | 413,288.1 | Guajajara and Awá-Guajá | 10,318 | 2695 |
| 3 | Caru | Aw | Jan–Dec | 172,667.4 | Guajajara and Awá-Guajá | 779 | 251 |
| 4 | Sororó | Aw | Jan–Dec | 26,257.9 | Aikewara | 594 | 21 |
| 5 | Mekragnoti | Am | Jan–Dec | 4,914,254.8 | Mêbengrôke (Kayapó), Isolated Indigenous People from Rio Novo and Mengra Mirari | 1383 | 381 |
| 6 | Baú | Am | Jan–Dec | 1,540,930.0 | Mêbengrôke (Kayapó), Mekrãgnoti and Isolados Pu'rô | 672 | 69 |
| 7 | PI Xingu | Am, Aw | Aug–Dec | 2,642,003.9 | Aweti, Ikpeng, Kaiabi, Kalapalo, Kamaiurá, Khisetje, Kuikuro, Matipu, Mehinaco, Nahukuá, Naruvotu, Tapaiuna, Trumai, Wauja, Yawalapiti, and Yudja, | 6177 | 3696 |
| | Total | - | - | 10,179,566.1 | 26 | 26,028 | 8984 |

[a]According to the Köppen–Geiger classification in (24).

**Table 6 Name of the ILs, fire season, area, ethnic groups, population size, and number of active fires detected via reference satellite (2003–2012) in the ILs of the Amazon biome covered by BRIFs.**

| N° | Indigenous land | Climate[a] | Fire season | Area (ha) | Ethnic group | Population size | Active fires 2003–2012 |
|---|---|---|---|---|---|---|---|
| 1 | Alto Rio Guamá | Am | Jan–Dec | 279,897.0 | Awá-Guajá, Ka'apor and Tembé | 1727 | 1775 |
| 2 | Waiãpi | Am | Jan–Dec | 607,017.0 | Waiãpi | 1665 | 122 |
| 3 | Awá | Aw | Jan–Dec | 116,582.0 | Awá-Guajá | 279 | 1290 |
| 4 | Alto Turiaçú | Am | Jan–Dec | 530,525.0 | Awá-Guajá, Ka'apor and Tembé | 4183 | 577 |
| 5 | Mãe Maria | Aw | Jan–Dec | 62,488.0 | Gavião and Guarani | 1302 | 55 |
| 6 | Kayapó | Am | Jan–Dec | 3,284,004.9 | Mêbengrôke (Kayapó) Gorotire, Kôkraimôrô, Kuben Kran Krên, and Isolated do Rio Fresco | 6365 | 2796 |
| 8 | Munduruku | Am | Jan–Dec | 2,381,800.0 | Apiaká, Munduruku, and Isolated do Alto Tapajós | 6518 | 1357 |
| 9 | Trincheira/ Bacajá | Af, Am | Jan–Dec | 1,650,939.0 | Mêbengrôke (Kayapó), Xikrin Mêbengôkre, and Guarany Mbya | 1737 | 72 |
| 10 | Panará | Am | Jan–Dec | 499,740.0 | Panará | 704 | 149 |
| 11 | Capoto/ Jarina | Am | Jan–Dec | 634,915.2 | Mêbengrôke (Kayapó) and Tapayuna | 1589 | 832 |
| | Total | - | - | 10,047,908,1 | 18 | 26,069 | 9025 |

[a]According to the Köppen–Geiger classification in (24).

**Table 7 Name, average number of brigade members (2014–2023), area (ha) per brigade members, number of active fires (2003–2012 and 2014–2023), and difference in the number of active fires between the two time periods in the ILs of the Cerrado biome covered by BRIFs.**

| N° | Indigenous land | Brigade members/ year | Area (ha)/brigade members | Active fires 2003–2012 | Active fires 2014–2023 | Active fires difference |
|---|---|---|---|---|---|---|
| 1 | Krikati | 7.9 | 18,326.1 | 1111 | 1055 | −5.0 |
| 2 | Porquinhos | 15.0 | 5301.4 | 539 | 548 | +1.7 |
| 3 | Governador | 12.0 | 3470.3 | 480 | 521 | +8.5 |
| 4 | PI Araguaia | 70.1 | 19,379.5 | 1372 | 1249 | −9.0 |
| 5 | Paresi | 14.8 | 38,080.2 | 2.095 | 1267 | −39.5 |
| 6 | Juininha | 11.1 | 6354.7 | 439 | 151 | −65.6 |
| 7 | Apinayé | 20.7 | 6855.3 | 1372 | 1249 | −9.0 |
| 8 | Kraholândia | 26.8 | 11,288.6 | 2930 | 2754 | −6.0 |
| 9 | Xerente | 25.2 | 6648.5 | 1785 | 1302 | −27.1 |
| 10 | Avá-Canoeiro | 15.2 | 2591.3 | 244 | 146 | −40.2 |
| 11 | Bakairi | 19.3 | 3181.6 | 452 | 141 | −68.8 |
| | Average | 21.6 | 11,043.4 | 23,353 | 16,190 | −30.7 |

**Table 8 Name, average number of brigade members (2014–2023), area (ha) per brigade members, number of active fires (2003–2012 and 2014–2023) and difference in the number of active fires between the two time periods in the ILs of the Cerrado biome covered by BRIFs Program.**

| N° | Indigenous land | Brigade members/ year | Area (ha)/brigade members | Active fires 2003–2012 | Active fires 2014–2023 | Active fires difference |
|---|---|---|---|---|---|---|
| 1 | Cana-Brava Guajajara | 0 | - | 2498 | 3728 | +49.2 |
| 2 | Kanela | 0 | - | 880 | 905 | +2.8 |
| 3 | Pimentel Barbosa | 0 | - | 3225 | 3480 | +7.9 |
| 4 | Tapirapé/Karajá | 0 | - | 264 | 506 | +91.7 |
| 5 | Inãwébohona | 15[a] | 25,140.9 | 2607 | 3363 | +29.0 |
| 6 | Tirecatinga | 0 | - | 303 | 140 | −53.8 |
| 7 | Areões | 0 | - | 2809 | 3866 | +37,6 |
| 8 | Parabubure | 0 | - | 4338 | 4403 | +1.5 |
| 9 | Ubawawe | 0 | - | 769 | 620 | −19.4 |
| 10 | São Marcos | 0 | - | 1971 | 1683 | −14.6 |
| 11 | Merure | 0 | - | 1108 | 1061 | +4.2 |
| 12 | Sangradouro/Volta Grande | 0 | - | 1160 | 1126 | −2.9 |
| 13 | Marechal Rondon | 0 | - | 1110 | 934 | −15.9 |
| 14 | Santana | 0 | - | 197 | 51 | −74.1 |
| | Average | 0 | - | 23,239 | 25,866 | 11.3 |

[a]ICMBio brigade members.

**Table 9 Name, average number of brigade members (2014–2023), area (ha) per brigade members, number of active fires (2003–2012 and 2014–2023), and difference in the number of active fires between the two time periods in the ILs of the Amazon biome covered by BRIFs.**

| N° | Indigenous land | Brigade members/ year | Area (ha)/brigade members | Active fires 2003–2012 | Active fires 2014–2023 | Active fires difference |
|---|---|---|---|---|---|---|
| 1 | Uaçá I e II | 15.2 | 30,931.8 | 1871 | 1589 | −15.1 |
| 2 | Araribóia | 36.9 | 11,200.2 | 2695 | 2408 | −10.6 |
| 3 | Caru | 11.8 | 14,632.8 | 251 | 75 | −70.1 |
| 4 | Sororó | 9.0 | 2917.5 | 21 | 11 | −47.6 |
| 5 | Mekragnoti | 14.6 | 336,592.8 | 381 | 308 | −19.2 |
| 6 | Baú | 12.0 | 118,533.1 | 69 | 101 | +46.4 |
| 7 | PI Xingu | 47.3 | 55,856.3 | 3696 | 4323 | +17.0 |
| | Average | 21.0 | 81,523.5 | 8984 | 8815 | −1.9 |

**Table 10 Name, average number of brigade members (2014–2023), area (ha) per brigade members, number of active fires (2003–2012 and 2014–2023), and difference in the number of active fires between the two time periods in the ILs of the Amazon biome covered by BRIFs Program.**

| N° | Indigenous land | Brigade members/ year | Area (ha)/brigade members | Active fires 2003–2012 | Active fires 2014–2023 | Active fires difference |
|---|---|---|---|---|---|---|
| 1 | Alto Rio Guamá | 0 | - | 1775 | 3335 | +87.9 |
| 2 | Waiãpi | 0 | - | 122 | 167 | +36.9 |
| 3 | Awá | 0 | - | 1290 | 314 | −75.7 |
| 4 | Alto Turiaçú | 0 | - | 577 | 431 | −25.3 |
| 5 | Mãe Maria | 0 | - | 55 | 33 | −40.0 |
| 6 | Kayapó | 0 | - | 2796 | 2707 | −3.2 |
| 7 | Munduruku | 0 | - | 1357 | 1465 | +8.0 |
| 8 | Trincheira/Bacajá | 0 | - | 832 | 1085 | +30.4 |
| 9 | Panará | 0 | - | 223 | 390 | +74.9 |
| 10 | Capoto/Jarina | 0 | - | 72 | 652 | +805.6 |
| | Average | 0 | - | 9025 | 10,368 | +14.9 |

**Table 11 Values of chi-square adherence test (5%).**

| Biome | *P* value (BRIFs × No BRIFs) | | *P* value (2003-2012 × 2014–2023) | |
|---|---|---|---|---|
| | 2003-2012 | 2014–2023 | BRIFs | No BRIFs |
| Amazônia | 0.7600 | 0.0000 | 0.2052 | 0.0000 |
| Cerrado | 0.5974 | 0.0000 | 0.0000 | 0.0000 |
| Total | 0.7739 | 0.0000 | 0.0000 | 0.0000 |

**Table 12 Estimated costs of the BRIFs Program in 2023 (100 BRIFs and 2093 brigade members).**

| Type of costs | Value USD[a] | Observations |
|---|---|---|
| Temporary hiring of brigade members (6 months/year) | 6,760,182.78 | Data provided by DPA/Prevfogo/Ibama[b]. Includes all brigade members (firefighters, chiefs, and supervisors). |
| Domestic travel allowance | 3,086,833.23 | Data provided by DPA/Prevfogo/Ibama includes other diverse Prevfogo activities. |
| National air tickets | 256,387.96 | Data provided by DPA/Prevfogo/Ibama includes other diverse Prevfogo activities. |
| Other miscellaneous expenses | 120,064.28 | Data provided by DPA/Prevfogo/Ibama for the maintenance and supply of various equipment. |
| Personal Protective Equipment | 2,688,702.05 | USD 1,284.60/brigade member, estimated by DPA/Prevfogo/Ibama. |
| Fire management and suppression equipment | 1,088,740.91 | USD 10,837,41 /BRIF, estimated by DPA/Prevfogo/Ibama. |
| 100 4×4 trucks rented/year | 1,745,454.54 | Estimated 100 trucks X USD 1454.54/month. |
| Helicopter rental | 2,062,361.27 | Estimated at 65% of the total costs of Level III combat operations and fire management in 2023 (mainly transporting brigades). |
| Total | 17,803,726.96 | Does not include Funai expenses, mainly fuel and base renovation. |

[a]Considering, USD 1.0 = R$ 5.5.
[b]DPA: Prevfogo Planning and Administration Division, and the expenses, reported through an Excel spreadsheet, were higher than in the table. However, adjustments were made to exclude expenses not related to the brigades, as well as expenses incurred in previous years or covered by other sectors of Ibama.

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## Author contributions

RMF all phases of implementing the evaluated program, research, and writing the article. GCZ and FVR: data collection and revising the article. GCO: data collection. RC: guidance, drafting, and revising the article. IBS: guidance, drafting, and revising the article and methodology. LS: revising the article.

## Competing interests

The authors declare no competing interests.

## Ethical statements

This article does not contain any studies with human participants performed by any of the authors.

## Informed consent

The study used publicly available satellite hotspot data as described in the methodology section. The study did not involve human participants or their data. Therefore, the consent statement is not applicable.

## Additional information

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