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Emergency policies are not enough to resolve Amazonia's fire crises

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The fire crises in the Amazon continues to increase the risk of large-scale forest dieback, threatening regional biodiversity and global climate. This issue gained international attention in 2019 when fires in the Brazilian Amazon led to a fire ban imposition. Despite the uncertainty of its impact, the fire ban was reenacted in subsequent years. Here we assess the effectiveness of each fire ban by comparing observed fire counts with climate-driven predictions of fire for 2019–2021. While the 2019 ban likely reduced the number of fires to expected levels, it was largely ineffective in the years that followed. Four years later in 2023 under a different political dynamic, the Brazilian Amazon faced another fire crisis. Resolving this recurrent issue requires interventions that target the underlying causes of fire and extend beyond emergency measures, including long-term strategies focused on landscape management, public awareness and education, and engagement with local communities and stakeholders.

Altered fire regimes impacting forest ecosystems is a global phenomenon that has negative consequences for biodiversity and human health, and contributes to climate change[1,2]. In recent years, extensive and devastating fires in fire-adapted regions as diverse as Australia, California and the Mediterranean have caught the attention of both the public and policy makers[3,4]. Of even greater concern, fires have been increasing in regions with little to no history of fire, i.e., fire-sensitive regions that have not evolved with fire, including the Amazon Forest biome, where fire is now increasing the risk of large-scale forest dieback[5,6].

Fires in the Brazilian Amazon gained global recognition in 2019. Following a decade of progress in greatly reducing deforestation rates, a surge in both deforestation and fire across the Amazon marked a disappointing regression. Amidst intense media attention and both domestic and international pressure, contrasting narratives emerged about whether the fires were impacting only newly deforested areas or infiltrating intact forests, and what role dry season conditions played in increasing fire occurrence. Facing an intense backlash, the Brazilian government responded with an emergency fire moratorium in 2019, which was repeated in 2020 and 2021. While emergency measures can be conceptually and politically appealing, their impact may be short-lived if not accompanied by a broader set of interventions to address the socio-economic factors driving fire use in the Amazon.

Here, we examine the effectiveness of the three consecutive fire moratoria (2019, 2020, 2021) in reducing fire numbers during the burning seasons, including the extent to which policy effectiveness varied by fire type across the region. Fire prevention policies can be hampered by an inability to differentiate fire types given that they require distinct intervention strategies[7]. Here we examine the three main fire types in the region: deforestation fires associated with the process of land clearing (i.e., when felled trees are dried and burned); pasture fires commonly used for pasture maintenance; and wildfires, which have escaped from adjacent land clearing or pasture maintenance activities to invade intact forest. Subsistence fires, used by traditional and Indigenous populations as part of subsistence agricultural practices, were not analysed as they were exempt from the bans. In our analysis, we combine remote sensing products to categorise the different fire types and gather precipitation data for each of the 68 geographical regions of the Brazilian Amazon. These regions represent a politically meaningful spatial division for a policy assessment. Specifically, we investigate how the fire moratoria influenced fire numbers of different fire types across the regions while accounting for climatic variability. By comparing predictions of expected fire (i.e. in the absence of a ban) with observed fire activity during the ban periods, we quantify fire anomalies while disentangling the relative contributions of climate (precipitation) and policy (moratoria).

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The 2019 fire ban was likely effective in reducing fire counts to expected levels, but similar bans in 2020 and 2021 were largely ineffective, with fire activity exceeding climate-driven predictions. Our findings suggest that emergency fire bans alone are insufficient to address the root causes of fires in the Amazon. Instead, a combination of targeted interventions for different fire types and comprehensive strategies involving landscape management, public awareness, education and community engagement is necessary to address the fire crises effectively.

Results

Fire anomalies and the effectiveness of 2019–2021 fire moratoria

In the 8 weeks preceding the 2019 fire ban (initiated 29 August), the combined incidence of the three main fire types – deforestation, pasture and forest fires – exceeded more than twice the number expected based on our predictions for that period (124%, 95% CI [96 to 152%]; Fig. 1a). The fire ban was effective in reducing excess fire: over the 60-day moratorium, fire occurrence decreased, approaching expected levels (+14%, 95% CI [−13 to 41%]). Following the ban, fire counts remained at expected levels until the end of 2019 (+2%, 95% CI [−23 to 27%]). In 2020, fire activity increased again, surpassing expectations by 81% during the period of the ban (95% CI [53.5 to 108%]; 15 July to 11 November; Fig. 1a), suggesting that the 2020 intervention was much less effective than the previous year.

Despite the relative ineffectiveness of the 2020 ban, the policy was repeated in 2021. Imposed almost 2 months in advance of the anticipated burning season, which typically spans the months of August–October, this ban also appeared to be largely ineffective in reducing fire numbers: observed fires were 50% higher than expected levels for the 120 days covered by the ban (95% CI [23 to 78%]; Fig. 1a). Overall, the cumulative fire count in each of the three years (2019, 2020, 2021) exceeded the level predicted for that year (Fig. 1b). Notably, 2020 recorded the highest fire count, marking a 14.2% increase over 2019 and 38.5% higher than 2021.

Spatial patterns of each fire type

In the pre fire ban period of 2019, no anomalies were registered in the northern portions of the Brazilian Amazon, meaning that fire counts matched expected levels based on our predictions. The central and southern portions of the Amazon recorded predominantly high fire anomalies (fire count > expected) (Fig. 2a, e, i), with the highest numbers recorded for pasture fires in Rondônia state (Fig. 2e).

With the imposition of the 2019 fire ban, all three fire types showed a strong reduction in fire count compared to the pre-ban period, with fire occurrence returning to expected levels across most of the region (Fig. 2b, f, j). Eastern Amazonia even registered low fire anomalies (fire count < expected), indicating a good response to the fire ban in these specific regions, especially for pasture fires (Fig. 2f). Still, high fire counts continued to be observed in some areas. Deforestation fires would remain high in the north of Mato Grosso and parts of Rondônia and Acre. Similarly, the number of pasture fires was above expected levels in some regions of Rondônia and Acre as were, forest fires also in Acre and the north of Mato Grosso.

During the 2020 fire ban, fire counts remained above expected levels across most of the Brazilian Amazon for all types of fire (Fig. 2c, g, k) with the exception of the northern portion where no anomalies were detected. During the 2021 ban, high fire anomalies were observed for the three fire types in the central and south-western portions of the Amazon, with the highest numbers associated with forest fires (Fig. 2d, h, l). The eastern part, however, registered low fire anomalies, potentially indicative of the effectiveness of the fire ban in that region, especially for pasture fires (Fig. 2h).

Discussion

Our analyses suggest that the 2019 fire ban likely reduced fire activity from markedly elevated values prior to the ban, but not enough to reach below-average numbers. In contrast, the 2020 and 2021 fire bans were largely ineffective. While our analyses provide insights into the effectiveness of the fire bans between years, they do not explain why the bans were generally effective in 2019 and not in subsequent years. However, there are a number of explanations for the observed outcomes, and these are not mutually exclusive.

First, the impacts caused by command-and-control interventions tend to be short-lived because their long-term effectiveness depends on a transition plan to address the underlying causes for the crisis among other strategies aiming to increase ecosystem resilience[8]. Second, the 2019 ban could have simply delayed the burning of felled trees (i.e. deforestation fires)

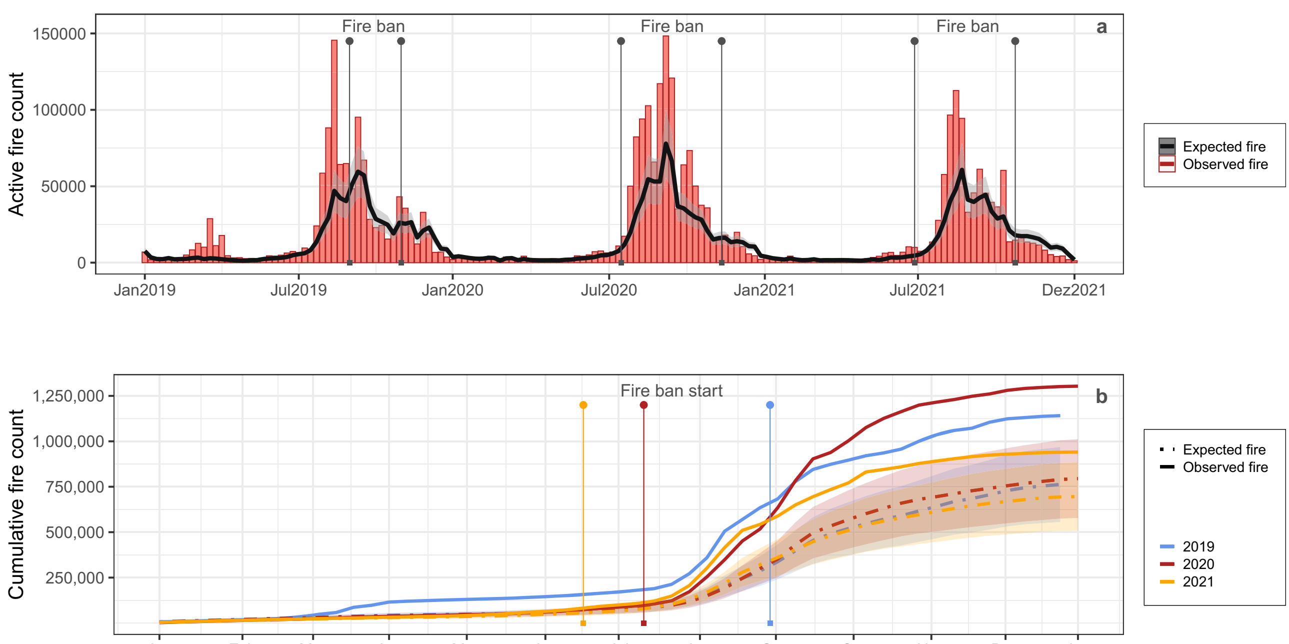

Fig. 1 | Fire count in the Brazilian Amazon in 2019–2021. **a** Weekly sum of expected fire (black line) with confidence intervals (shaded grey) and observed fire count (red bars) in 2019, 2020 and 2021 across the Brazilian Amazon. Fire ban periods are shown within vertical grey lines. **b** Cumulative expected fire count (dashed line) with confidence intervals (shaded) and observed fire count (solid line) for 2019 (blue), 2020 (red) and 2021 (yellow). The start date of fire ban periods is shown with vertical lines, blue for 2019, red for 2020 and yellow for 2021.

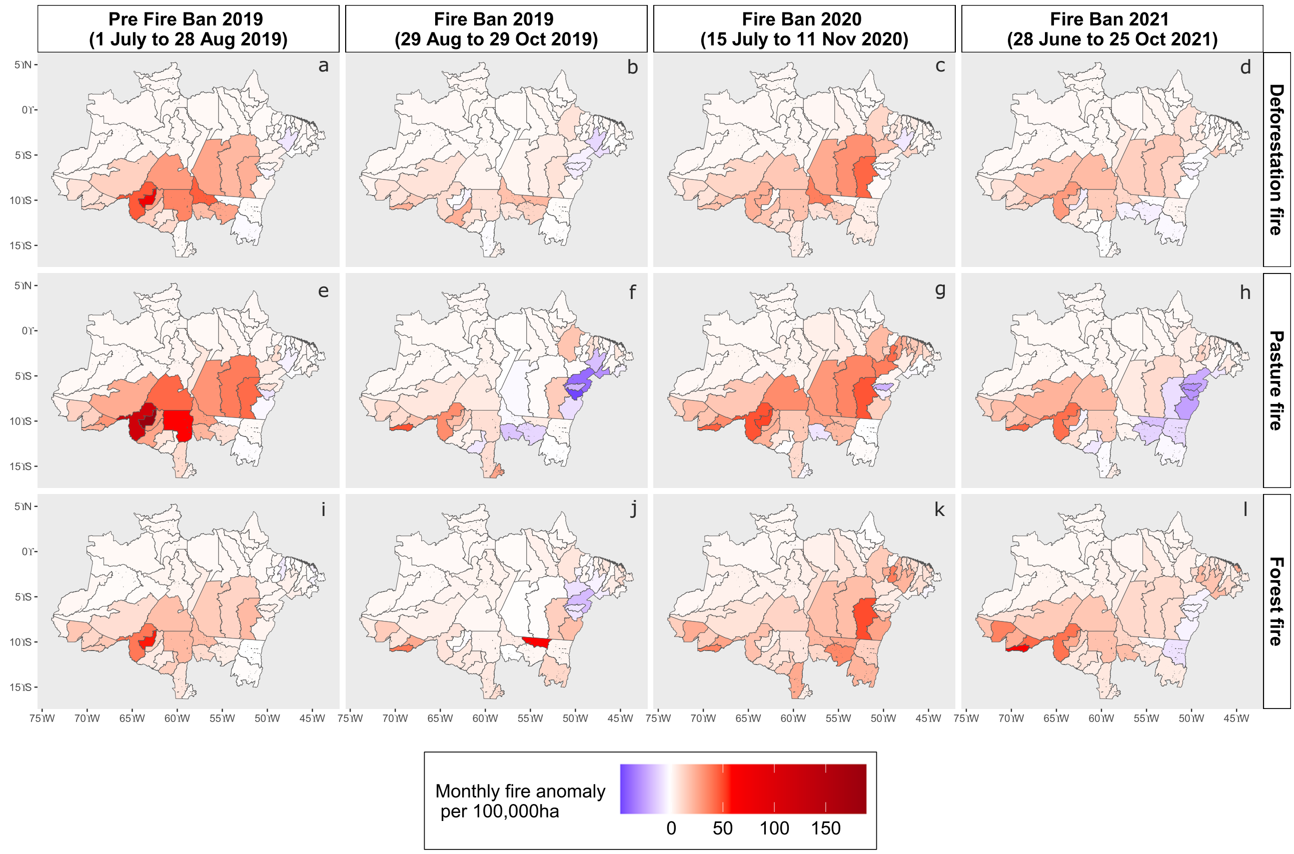

Fig. 2 | Spatial distribution of fire anomalies in the Brazilian Amazon. Monthly fire count deviation from expected (sum of difference between observed and expected fire) for deforestation (**a**, **b**, **c**, **d**), pasture (**e**, **f**, **g**, **h**) and forest fires (**i**, **j**, **k**, **l**) during the 8 weeks preceding 2019 fire ban (**a**, **e**, **i**), during the 2019 fire ban (**b**, **f**, **j**), during the 2020 fire ban (**c**, **g**, **k**) and during the 2021 fire ban (**d**, **h**, **l**), adjusted according to each period's length and per 100,000 ha. The geographic boundaries represent 'immediate regions' determined by the Brazilian Institute of Geography and Statistics.

and pasture maintenance (i.e., pasture fires), which then occurred in 2020 and/or 2021[9]. Third, the COVID-19 pandemic may have limited the command-and-control operations in 2020 and 2021, with the lack of enforcement acting as an incentive for burning[10]. Fourth, the media attention around the ban was much greater in 2019 than in 2020 or 2021, which may have heightened awareness and encouraged compliance. Fifth, 2021 was a moderate La Niña year, which produced somewhat wetter conditions in the region, likely decreasing fuel flammability. While climate alone is not responsible for creating fires, dry conditions are needed to enable fire spread, and severe droughts can greatly exacerbate fire occurrence[11,12], which is likely the underlying cause behind the elevated fire numbers observed in the burning season of 2023 with the beginning of an El Niño event. Crucially, blanket bans on fire fail to capture the different motivations for burning, meaning they are unable to address the root causes of the different fire types. Fire in the Brazilian Amazon must be understood as a complex problem involving a diverse group of actors[13,14]. Thus, one-size-fits-all solutions are very unlikely to succeed long term.

Considering that command-and-control interventions, such as fire bans, demand substantial resources and are generally unpopular yet may fail to produce the desired outcomes, it is crucial that decision makers develop forward looking strategies that extend beyond the moment of emergency. A range of alternatives have already been identified and tested in the Amazon. In the case of deforestation fires, reducing deforestation rates is an imperative[14]. This urgency extends beyond the immediate context of direct deforestation fires as deforestation is arguably the primary cause of the fire crises. Fires initially ignited for land clearance can become wildfires when they encroach into adjacent forest. Furthermore, deforestation is the precursor to the creation of pastures, which demand maintenance burning. Additionally, other indirect consequences, including the creation of edges and the exacerbation of climate change leading to extreme events like droughts, are all factors that can set the stage for more fires[15].

Between 2004 and 2012, Brazil achieved an 80% reduction in deforestation by employing a multifaceted approach that included collaborative efforts across various societal sectors, establishment of new protected areas, imposition of stricter requirements for rural credit eligibility among farmers situated in the most threatened Amazonian municipalities[16,17] and command-and-control operations supported by real-time satellite monitoring. Despite the success of these initiatives, the decline in deforestation lasted only a few years, succumbing to a change in government in 2019, which had markedly different socio-economic priorities. After several years of high deforestation rates, another change in government resulted in a 22.3% reduction in deforestation in 2022–2023[18]. This reduction, however significant, was not sufficient to prevent widespread wildfires that were likely fuelled by 2023's severe El Niño driven drought. Looking to a future marked by hotter and drier conditions, and the associated increased flammability of Amazon forests, reducing sources of ignition will be critical to the prevention of wildfires[19].

Where pasture fires are concerned, there is a need to promote the transition towards fire-free land management, including the sustainable intensification of cattle production, which has proven more productive and negates the need for fire-based pasture maintenance[20]. These measures must be accompanied by financial incentives and co-developed technical support to avoid exacerbating the vulnerability of marginalised groups who lack alternatives to fire use[21].

Reducing deforestation and improving farming practices will help reduce forest fires, but achieving this goal will nevertheless require greater engagement with local actors, improved fire prediction and detection, and long-term investments in community firefighting units[22]. Although fire bans appear to be largely ineffective when implemented frequently and recurrently, it is possible that some emergency measures – such as additional support for rapid fire detection and combat – could be valuable in dry years when risks of forest fires are greatest.

Whatever the approach taken, resolving the Brazilian Amazon's fire crises will require moving beyond reactionary bans. Hastily implemented emergency measures cannot replace thoughtful, sustainable, multisector approaches that address the underlying causes of fire while taking into consideration climatic events and compound effects.

Methods

We modelled time series data of active fires from 2012 to 2018 to predict daily fire activity for 2019, 2020 and 2021 using precipitation as a co-variable (active fires from VIIRS-375 m[23] and precipitation from CHIRPS-Climate Hazards Group InfraRed Precipitation with Station data – Rainfall Estimates from Rain Gauge and Satellite Observations[24]). Among the climatic variables we considered using to model fire activity, we chose precipitation as the most suitable because only rainfall is capable of effecting an immediate change in fire pattern that is readily distinguishable from the effect of fire management policy. We calculated the daily average precipitation for each geographic 'immediate region' delineated by the Brazilian Institute of Geography and Statistics[25]. This specific geographic division offers a spatial resolution that is fine enough to capture local climatic variation and coarse enough to encompass fire activity even in regions of low fire occurrence. Moreover, opting for a geo-political spatial division is more appropriate in a policy assessment compared to an artificial grid. To account for fire typology, we combined annual land-cover maps[26] with deforestation data (annual Global Forest Change[27] data from 2012 to 2020; and DETER[28] alerts for 2021) and the active fire dataset so that the land cover class could be assigned to each active fire with the goal of labelling each active fire (2012–2021) in the Brazilian Amazon as either a deforestation, pasture or forest fire.

For the analysis, we modelled the response variable (daily fire count) against time – each day across 1 year (i.e., 'day–month') and daily precipitation using data from 2012 to 2018 as repetition, and year as a random factor. We trained the model using Generalised Additive Mixed Modelling[29] with a Poisson distribution for count data in each of the 68 'immediate regions' and for each of the three fire types, which totalled 204 models. Once we established the relationship between fire and precipitation across time, we used the model to predict daily fire activity for 2019–2020–2021 using observed precipitation data of these three years.

For the purposes of results interpretation, we focused on four main periods: 'before 2019 fire ban' – 1 July to 28 August 2019 to investigate potential anomalies in fire activity that may have driven media attention during this period; '2019 fire ban' – 29 August to 29 October 2019; '2020 fire ban' – 15 July to 11 November 2020; and '2021 fire ban' – 28 June to 25 October 2021. We defined a fire anomaly as the difference in fire number between observed and predicted fires. To evaluate the effectiveness of the bans, we first considered all three fire types across the whole of Brazilian Amazon region, then looked into each 'immediate region' separately for the spatial assessment of differences among fire types. The anomalies accounted for each period's duration and each region's area, and were then displayed for 100,000 ha in Fig. 2. We multiplied the daily average of anomaly by 30 to produce a monthly estimate so as to simplify the interpretation of results.

Data availability

The raw data that support the findings of this study are publicly available and their links are shared below.

Land cover: https://brasil.mapbiomas.org/en/ and https://glad.umd.edu/projects/global-forest-watch

Active fire: https://www.earthdata.nasa.gov/learn/find-data/near-real-time/firms/active-fire-data

Precipitation: https://www.chc.ucsb.edu/data/chirps

Deforestation: http://terrabrasilis.dpi.inpe.br/downloads/

Geopolitical divisions: https://www.ibge.gov.br/geociencias/cartas-e-mapas/redes-geograficas/15778-divisoes-regionais-do-brasil.html

The datasets created in this study are deposited here: https://doi.org/10.5287/ora-orkay0dem.

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Author contributions
M.S.M., E.B., I.O.M. and Y.M. conceived and designed the study. M.S.M. gathered the data and performed the analysis with important contribution from P.M.B. M.S.M. wrote the manuscript with important contribution from E.B., P.M.B., A.A., J.B., I.O.M. and Y.M. All authors reviewed and approved the manuscript.

Competing interests
The authors declare no competing interests.

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