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Policy Forums

Intensification of drought-associated wildfires challenges actions for Amazonia's sustainable development

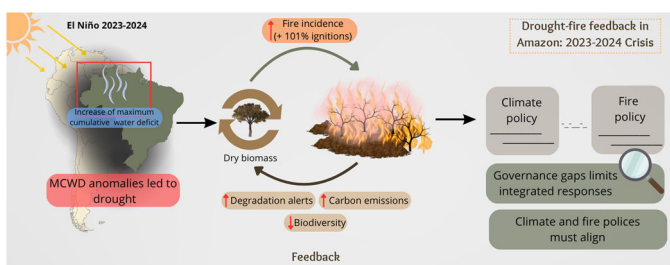
Débora Joana Dutra [a,b,*], Igor José Malfetoni Ferreira [a,b], Érick Teixeira Rodrigues [a], Daniel Braga [a,b], Breno Izidoro [a,b], Guilherme Mataveli [b,c,d], Luiz Eduardo Oliveira e Cruz de Aragão [a,b,d], Liana Oighenstein Anderson [a,b,d,e]

[a] Remote Sensing Postgraduate Program (PGSER), Coordination for Education, Research and Outreach (COEPE), Brazil's National Institute for Space Research (INPE), Brazil
[b] TRopical Ecosystems and Environmental Sciences lab (TREESlab), Brazil's National Institute for Space Research (INPE), Brazil
[c] Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia (UEA), United Kingdom
[d] Earth Observation and Geoinformatics Division (DIOTG), Earth Sciences General Coordination (CGCT), Brazil's National Institute for Space Research (INPE), Brazil
[e] Center for Monitoring and Early Warning of Natural Disasters (CEMADEN), Brazil

HIGHLIGHTS

- Drought–fire feedback is accelerating the collapse of the Amazon ecosystem.
- Fires are increasingly linked to forest degradation rather than deforestation.
- MCWD anomalies reveal a persistent and intensifying drying trend in the Amazon.
- Governance gaps hinder Brazil's capacity to manage drought–fire interactions.
- Fragmented climate and fire policies weaken coordinated responses to degradation.

GRAPHICAL ABSTRACT



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ABSTRACT

Between 2023 and 2024, Brazil experienced one of the most severe droughts in the century, with temperatures in the Amazon reaching 2–4 °C above average. Amplified by El Niño and North Atlantic warming, the drought disrupted the hydrological cycle and essential ecosystem services, affecting agriculture, transportation, and the livelihoods of urban, rural, and Indigenous communities. This event revealed substantial shortcomings in Brazil's fire governance framework. Moreover, it demonstrated that drought conditions exacerbate Brazil's susceptibility to wildfires, underscoring the urgent need for coordinated and immediate policy action. This study maps and quantifies hydrological stress, forest degradation, and fire dynamics associated with the drought, identifying critical implications for environmental management. Our analysis reveals the intensification of a drought–fire–degradation feedback loop. Wildfire-affected areas increased by 9%, and degradation alerts rose by 19% in relation to long-term average levels (2016-2024). At the drought's peak (in 2024), 4.2 Mha of fire-affected areas were detected. Maximum Cumulative Water Deficit anomalies exceeded historical thresholds, signaling a continuous dry increase in Brazil. These results highlight the urgent need for integrated fire governance. This includes comprehensive environmental education, enhanced early warning systems, targeted investments in ecosystem restoration, and stronger coordination between federal and state policies. By linking

* Corresponding author.
E-mail addresses: debora.joana@inpe.br, ddutra.ambiental@gmail.com (D.J. Dutra).

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scientific evidence to actionable policy recommendations, this work guides decision-makers seeking to reduce socio-environmental risks and strengthen climate adaptation in the Amazon.

Background

Between 2023 and 2024, Brazil experienced a severe drought, characterized by record-high temperatures of approximately +2 to +4 °C above average in the Amazon region (Marengo et al., 2024). This drought event was linked to El Niño and warming in the tropical North Atlantic Ocean, which delayed the onset of the rainy season and reduced evapotranspiration (NOAA, 2024). The impacts of this event extended beyond localized environmental degradation, affecting wider regions and significantly disrupting agriculture, river transport, energy supply, and the livelihoods of urban, rural, and Indigenous communities (Marengo et al., 2024). Entire Amazonian towns and communities became isolated, facing shortages of fuel and food, as well as collapses in fishing and hunting activities, and outbreaks of vector-borne diseases such as malaria and dengue fever (Lenton et al., 2023).

These regional extremes unfolded against a backdrop of unprecedented global warming (Hansen et al., 2025). Findings from the most recent Climate Bulletin of the Copernicus Climate Change Service (C3S), based on ERA5 reanalysis data, identify November 2025 as the third-warmest November globally, with mean surface air temperatures 1.54 °C above estimated pre-industrial levels (1850–1900) (Copernicus Programme, 2025). With one month remaining in the calendar year, 2025 is virtually certain to rank as the second or third warmest year on record, following the record-breaking year of 2024 and potentially tying with 2023 (Copernicus Programme, 2025). Importantly, the three-year global mean temperature for 2023–2025 is projected to exceed 1.5 °C above pre-industrial levels for the first time in the instrumental record, highlighting the rapid acceleration of climate change and the narrowing window for effective mitigation (Copernicus Programme, 2025; Reisinger et al., 2025).

In recent decades, recurrent droughts have become a key challenge for forest and climate governance in the Amazon. The rising frequency, intensity, and spatial extent of extreme dry events undermine both ecosystem resilience and the effectiveness of conservation policies (NOAA, 2024). Previous droughts (2005, 2010, and 2015/16) have demonstrated the biome's sensitivity to water deficits, with cascading impacts on forest structure, carbon dynamics, and biodiversity (Allen et al., 2015; Anderson et al., 2018; Aragão et al., 2018). Although 2020 did not exhibit a strong basin-wide drought, localized water deficits and widespread fires occurred in the absence of major climate modes such as ENSO or AMO, highlighting that significant disturbance events can occur even in the absence of pronounced large-scale anomalies (Silveira et al., 2022).

Although drought is not a direct ignition source, it strongly influences the biophysical conditions that enable wildfires to develop and spread (Allen et al., 2015). Fire occurrence requires three factors: fuel, an ignition source, and conducive weather conditions, such as low humidity, high temperatures, and wind (Batista, 2007). These climatic conditions, exacerbated during drought events, interact by reducing fuel moisture, increasing the flammability and combustibility of vegetation, and increasing fire spread rates through stronger and more variable wind flows, thereby creating an environment in which ignition events are more likely to evolve into large wildfires.

In the Amazon, drought intensifies fire risk by drying leaf litter and dead biomass, increasing fuel flammability (Faith and Walker, 2002). Ignitions, however, are primarily anthropogenic, stemming from land-use practices that involve burning to clean or manage fields (Anderson et al., 2018; Mataveli et al., 2025). The interaction between fuel dryness, human-induced ignitions, and favorable weather conditions creates a highly flammable environment, particularly in transitional zones between intact forests and areas undergoing degradation or recent agricultural expansion (Ribeiro et al., 2024).

Thus, the cycle of drought, fire, and forest degradation in the Amazon constitutes a dangerous feedback loop. Forests exposed to repeated fires have a lower regeneration capacity, with changes in species composition, and reduced ability to retain water and sequester carbon (Hoffmann et al., 2003; Ripple et al., 2023). These processes heighten socio-environmental vulnerability by directly compromising the provision of essential ecosystem services that support both the local and global population, including carbon storage, water regulation, climate regulation, and biodiversity maintenance (Cordeiro Ramalho et al., 2024). Strengthening governance mechanisms that integrate climate risk, fire prevention, and forest conservation is essential for reducing the exposure of ecosystems and communities to the consequences of future extreme events. In this context, we aim to examine the 2023/2024 Amazon drought as a coupled environmental and governance challenge by mapping its spatial extent and severity, and evaluating how the resulting hydrological stress influenced fire activity and forest degradation.

The 2023/24 drought and forest degradation

The 2023/24 Amazon drought produced an exceptional expansion of wildfire-affected areas. Using the full PRODES year (August to July), a total of 2.705 Mha of wildfire-affected areas were mapped in 2023/24 by the DETER dataset (Fig. 1a). This corresponds to +1.327 Mha above the historical mean (2016–2024) burned area of 1.378 Mha, an increase of approximately 96% confirming that fire activity during the 2023/24 drought far exceeded typical annual conditions. The subsequent fire year (2024/2025) is shown only partially in Fig. 1a, since data were available only up to January 2025, which represents the peak of the drought but not the full annual cycle.

Forest disturbance alerts from DETER intensified throughout the year. Between 2023 and 2024, the number of recorded events increased by approximately 19%. (Fig. 1a). To quantify actual burned areas, we relied on DETER fire-scar polygons, which delineate perimeters with clear satellite evidence of burned vegetation. During the peak of the 2023/24 drought, between August 2024 and January 2025, burned areas expanded rapidly. During this period, mapped wildfire-affected areas exceeded the historical mean by 1.537 Mha, representing an increase of approximately 101% relative to typical conditions for the same months. This concentrated expansion of burned area is consistent with the severity of the 2023/24 drought and explains most of the fire-driven degradation observed in Fig. 1a.

The MCWD anomaly further demonstrates the intensification of hydrological stress during recent drought years. Recurring droughts in 2005, 2010, 2015, and 2020 frequently exceeded two standard deviations from the climatological mean, placing them beyond the 90% confidence interval. Values above 1.65 standard deviations exceed the 90 % confidence interval. In 2023 and 2024, large portions of the basin exceeded the 90 % anomaly threshold (Fig. 1b and c). The area with MCWD anomalies above the 90 % interval reached ~50 Mha, highlighting the broad spatial extent of extreme water stress during the drought.

These trends indicate a shift toward more severe negative water anomalies over the past decade, consistent with increased atmospheric aridity, reduced moisture recycling, and intensifying water deficits (Van Der Werf et al., 2006). These results indicate that the Amazon has become drier over the last decade, associated with a shift toward more frequent and spatially extensive negative MCWD anomalies and increasingly recurrent climate extremes (e.g., 2015/16, 2023/24). This shift not only undermines forest health but also has immediate

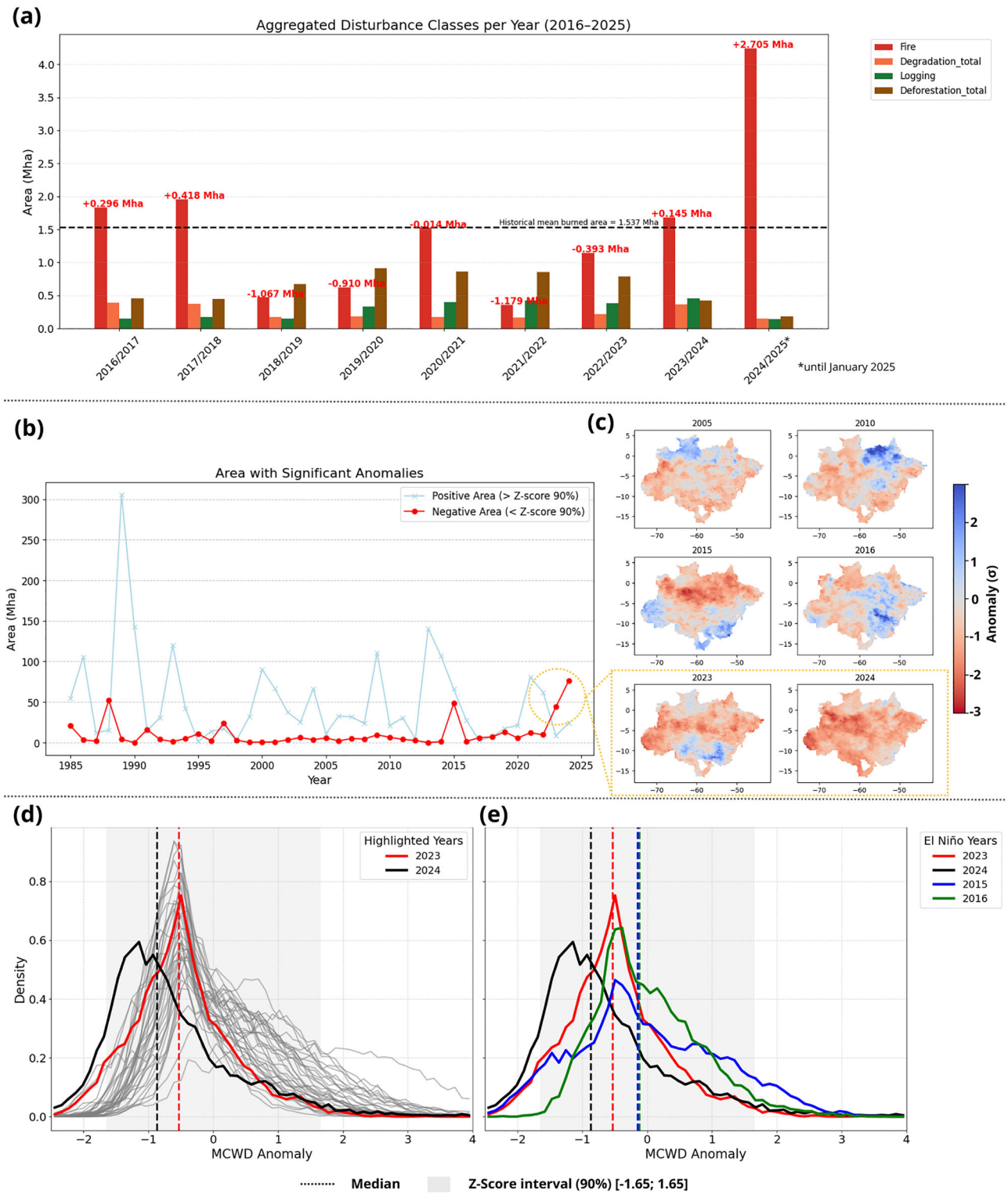

Fig. 1. Spatiotemporal dynamics of forest disturbances and climatic anomalies in the Brazilian Amazon. (a) Annual aggregated disturbance classes (fire, degradation, logging, deforestation) from 2016 to 2025, highlighting the exceptional burned area in 2024/2025 relative to the historical mean (1.27 Mha), (https://terrabrasilis.dpi.inpe.br/app/dashboard/alerts/biomes/amazonia-nb/aggregated/); (b) Time series of spatial extent with significant climatic anomalies (Z-score > |1.65|) from 1985 to 2025, distinguishing positive and negative extremes and highlighting the sharp increase after 2023 (https://zenodo.org/uploads/14635469; (c) Spatial patterns of MCWD anomalies for selected years (2005, 2010, 2015, 2016, 2023, 2024), showing the intensification and spatial expansion of drought conditions during major El Niño events and in 2023–2024; (d) Distribution of MCWD anomalies for 2023 and 2024 compared with the long-term climatology, showing a shift toward stronger water deficits; and (e) Comparison of MCWD anomaly distributions for major El Niño years (2005, 2010, 2015, 2016) with 2023 and 2024, indicating that recent drought severity approaches or exceeds historical extremes.

consequences, including elevated carbon emissions, water insecurity, and health crises, particularly during 2023/24 (Marengo et al., 2024; Mataveli et al., 2024).

Although deforestation declined across much of the Amazon, wildfire activity rose sharply in old-growth forests (Mataveli et al., 2024). In 2023, the burned area increased by approximately 152% relative to 2022, coinciding with stronger drought conditions. Recurrent fire events reduce forest resistance, delay post-fire recovery, and cause persistent structural and functional changes even when forests remain standing (Brando et al., 2025). As degradation intensifies, the probability of the Amazon approaching critical ecological tipping points increases (Banerjee et al., 2022; Brando et al., 2025; Nobre and Borma, 2009).

Policy implications: governance challenges in managing drought, degradation, and fire

The 2023/2024 Amazon drought exposed structural weaknesses in Brazil's capacity to govern drought–fire dynamics. These weaknesses have direct implications for climate mitigation, biodiversity conservation, and regional resilience. Joint evidence from MCWD anomalies, Deter-B fire-affected areas, degradation indicators, and the Fogo em Foco assessment reveals that current institutional arrangements are not sufficient to anticipate hydrological stress, suppress fire spread, or manage the resulting ecological degradation (Rede Brasa de Pesquisa, 2025; Terrabrasilis, 2022). These findings highlight the need to strengthen early warning systems, institutional coordination, financing mechanisms, and restoration strategies, such as:

1 **Early warning system limitations:** Burned areas increased sharply during the 2023/24 drought, while MCWD metrics indicated months of accumulated water deficit, and Deter-B data confirmed the expansion of fire-affected areas in old-growth forests. These trends demonstrate the need to integrate drought–fire indicators more effectively into national early warning systems and contingency planning. Although the National Fire Management Policy (PNMIF) (Brazil, 2024) was established to support integrated fire management, its early warning component remains limited and is not consistently linked to climate-risk metrics such as MCWD, fire weather indices, and socioenvironmental vulnerability mapping. The Fogo em Foco report indicates that state Military Fire Brigades (CBM) largely rely on heat-detection systems, seasonal operations, and field patrols, but do not employ systematic integration of hydrological indicators or predictive modelling tools (Rede Brasa de Pesquisa, 2025). Improving early warning capacity, therefore, requires stable investment in real-time monitoring platforms, strengthening local rapid-response units, and enhancing interoperability among environmental, climate, disaster-risk, and fire management institutions (Alencar et al., 2024; Barbosa et al., 2025).

2 **Rising degradation despite declining deforestation:** Even with declining deforestation rates, fire-related degradation in mature forests has increased significantly (Mataveli et al., 2024). Deter-B data show a growing extent of fire scars in standing forests, a process not consistently included in climate mitigation or fire management strategies (Assis et al., 2019). The Fogo em Foco assessment indicates that CBM operations primarily focus on fire suppression and residual fire control. Post-fire ecological assessment, carbon accounting, and restoration remain outside their core mandate (Rede Brasa de Pesquisa, 2025). This institutional gap limits the capacity to manage the long-term consequences of repeated burning. Policy frameworks should therefore incorporate forest degradation into fire management and climate policy, including mechanisms to finance restoration, expand fire-free land-use practices, and support ecological recovery. Recognizing degradation-related emissions in greenhouse gas accounting and national climate commitments can mobilize resources for restoration and promote preventive actions across different Amazonian regions (Alencar et al., 2024; Barbosa et al., 2025).

3 **Fragmented and under-implemented policy response:** Brazil's Nationally Determined Contributions (NDC) and the PNMIF share overlapping objectives but remain weakly coordinated in practice (Brasil, 2024; Brazil, 2024). The PNMIF, while robust in design, suffers from implementation gaps, including insufficient funding, limited local capacity, and weak institutional articulation across ministries, states, and agencies. Moreover, the absence of a centralized governance mechanism inhibits its effective implementation, particularly in frontier regions where fire is used as an agricultural tool under growing climate stress (Oliveras Menor et al., 2025). Although the PNMIF has a comprehensive structure, it faces persistent implementation barriers, including insufficient funding, limited operational capacity in frontier regions, and institutional fragmentation across federal and state agencies. The Fogo em Foco report identifies additional constraints: heterogeneous capacity among state CBM units, limited integration with environmental agencies, and frequent reliance on emergency decrees to mobilize personnel and equipment (Rede Brasa de Pesquisa, 2025). While states such as Mato Grosso do Sul have advanced with Integrated Fire Management Plans (PEMIF/MS), most states still lack stable financing, permanent prevention programs, or routine application of prescribed burning protocols (Rede Brasa de Pesquisa, 2025). Strengthening implementation requires establishing a dedicated financing architecture that supports fire prevention, ecological restoration, and community-level adaptation programs through public, private, and international funding sources (Dutra et al., 2024).

4 **Toward integrated, climate-informed fire governance**: Addressing these challenges requires a transition from parallel sectoral approaches to integrated, climate-informed governance. Key actions include:
- Operationalizing the PNMIF through decentralized planning, technical support to local actors, and systematic incorporation of drought–fire indicators into early action protocols and CBM operational planning.
- Aligning NDC implementation with fire management by recognizing degradation-related emissions, funding restoration in fire-affected areas, and prioritizing fire-free alternatives in land-use planning.
- Expanding ecological restoration in degraded and drought-sensitive regions and providing financial incentives for landholders and communities to adopt sustainable and fire-resilient practices (Dutra et al., 2024).
- Strengthening state-level Integrated Fire Management Plans, such as PEMIF/MS, through stable financing, improved interagency coordination, and integration of CBM, environmental agencies, and Civil Defense into unified response strategies (Rede Brasa de Pesquisa, 2025).

Effective drought–fire governance relies on coordinated institutions, stable investment, and long-term commitment to prevention, monitoring, and restoration. Strengthening early warning systems, financial mechanisms, and restoration programs will enhance governance capacity and help reduce the accumulated risks posed by drought and fire in Amazonian forests.

Conclusion

The analysis of the 2023/24 drought and associated fire events provides clear evidence for actionable interventions. Decision-makers should prioritize integrating drought and fire risk indicators into national early warning systems, expanding monitoring coverage, and developing response protocols. Policies must address forest degradation directly, including financing restoration initiatives, promoting fire-free land management, and encouraging community-based prevention

programs. Strengthening institutional coordination across federal, state, and municipal levels is critical. Equally critical is aligning climate mitigation targets with biodiversity and land-use policies. Investments in local capacity building, technical support, and governance mechanisms will enhance resilience against future drought–fire events. By implementing these evidence-based actions, Brazil can reduce the likelihood of cascading forest degradation, including drought-related wildfires, safeguard carbon stocks, and maintain ecosystem services critical for both regional and global communities. The policy choices made in the coming years will directly shape Amazon's trajectory toward sustainable management and long-term resilience.

Declaration of competing interest

The authors declare that there are no financial, personal, or professional conflicts of interest that could be perceived as influencing the content or conclusions of this correspondence.

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References

Alencar, A., Arruda, V., Martenexen, F., Rosa, E.R., Vélez-Martin, E., Pinto, Luis Fernando Guedes, Duverger, S.G., Monteiro, N., Silva, W., 2024. Fogo no Brasil em 2024: O Retrato Fundiário da Área Queimada nos Biomas (nota técnica). IPAM, Brasília.

Allen, C.D., Breshears, D.D., McDowell, N.G., 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere 6, 1–55. https://doi.org/10.1890/ES15-00203.1.

Anderson, L.O., Ribeiro Neto, G., Cunha, A.P., Fonseca, M.G., Mendes De Moura, Y., Dalagnol, R., Wagner, F.H., De Aragão, L.E.O.E.C., 2018. Vulnerability of Amazonian forests to repeated droughts. Phil. Trans. R. Soc. B 373, 20170411. https://doi.org/10.1098/rstb.2017.0411.

Aragão, L.E.O.C., Anderson, L.O., Fonseca, M.G., Rosan, T.M., Vedovato, L.B., Wagner, F. H., Silva, C.V.J., Silva Junior, C.H.L., Arai, E., Aguiar, A.P., Barlow, J., Berenguer, E., Deeter, M.N., Domingues, L.G., Gatti, L., Gloor, M., Malhi, Y., Marengo, J.A., Miller, J.B., Phillips, O.L., Saatchi, S., 2018. 21st Century drought-related fires counteract the decline of Amazon deforestation carbon emissions. Nat. Commun. 9, 536. https://doi.org/10.1038/s41467-017-02771-y.

Assis, L.F.F.G., Ferreira, K.R., Vinhas, L., Maurano, L., Almeida, C., Carvalho, A., Rodrigues, J., Maciel, A., Camargo, C., 2019. TerraBrasilis: A Spatial Data Analytics Infrastructure for Large-Scale Thematic Mapping. ISPRS Int. J. Geo-Inf. 8, 513. https://doi.org/10.3390/ijgi8110513.

Banerjee, O., Cicowiez, M., Macedo, M.N., Malek, Ž., Verburg, P.H., Goodwin, S., Vargas, R., Rattis, L., Bagstad, K.J., Brando, P.M., Coe, M.T., Neill, C., Marti, O.D., Murillo, J.Á., 2022. Can we avert an Amazon tipping point? The economic and environmental costs. Environ. Res. Lett. 17, 125005. https://doi.org/10.1088/1748-9326/aca3b8.

Barbosa, H.A., Buriti, C.O., Kumar, T.V.L., 2025. Assessment of fire dynamics in the Amazon Basin through satellite data. Atmosphere 16, 228. https://doi.org/10.3390/atmos16020228.

Batista, A.C., 2007. Incêndios Florestais: Controle. Efeitos E Uso Do Fogo, Não definido.

Brando, P.M., Barlow, J., Macedo, M.N., Silvério, D.V., Ferreira, J.N., Maracahipes, L., Anderson, L., Morton, D.C., Alencar, A., Paolucci, L.N., Jacobs, S., Stouter, H., Randerson, J., Flores, B.M., Starinchak, B., Coe, M., Pires, M.M., Rattis, L., Armenteras, D., Artaxo, P., Ordway, E.M., Trumbore, S., Staver, C., Berenguer, E., Menor, I.O., Maracahipes-Santos, L., Potter, N., Spracklen, D.V., Uribe, M., 2025. Tipping points of Amazonian forests: beyond myths and toward solutions. Annu. Rev. Environ. Resour. 50, 97–131. https://doi.org/10.1146/annurev-environ-111522-112804.

Brasil, 2024. LEI nº 14.944, DE 31 DE JULHO DE 2024. URL https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2024/lei/L14944.htm.

Brazil, 2024. BRAZIL'S NDC National Determination to Contribute and Transform. URL. https://www.gov.br/mma/pt-br/assuntos/noticias/brasil-entrega-a-onu-nova-ndc-alinhada-ao-acordo-de-paris/brazils-ndc.pdf/.

Copernicus Programme, 2025. 2025 is on Track to be Joint-Second Warmest Year. Climate Change Service (Accessed 15 December 2025). URL. https://climate.copernicus.eu/2025-track-be-joint-second-warmest-year.

Cordeiro Ramalho, A.H., Fiedler, N.C., Machado Dias, H., Machado De Oliveira Peluzio, T., Rosa Dos Santos, A., Moura Fonseca Lucas, F., 2024. Compreendendo a ação do fogo nos ecossistemas brasileiros. Biodivers. Bras. 14, 8–25. https://doi.org/10.37002/biodiversidadebrasileira.v14i1.2180.

Dutra, D.J., Silveira, M.V.F., Mataveli, G., Ferro, P.D., Magalhães, D.S., De Medeiros, T. P., Anderson, L.O., Aragão, L.E.O.C., 2024. Challenges for reducing carbon emissions from land-use and land cover change in Brazil. Perspect. Ecol. Conserv. 22, 213–218. https://doi.org/10.1016/j.pecon.2024.04.004.

Faith, D.P., Walker, P.A., 2002. The role of trade-offs in biodiversity conservation planning: linking local management, regional planning and global conservation efforts. J Biosci 27, 393–407. https://doi.org/10.1007/BF02704968.

Hansen, J.E., Kharecha, P., Sato, M., Tselioudis, G., Kelly, J., Bauer, S.E., Ruedy, R., Jeong, E., Jin, Q., Rignot, E., Velicogna, I., Schoeberl, M.R., Von Schuckmann, K., Amponsem, J., Cao, J., Keskinen, A., Li, J., Pokela, A., 2025. Global warming has accelerated: are the United Nations and the public well-informed? Environ. Sci. Policy Sustain. Dev. 67, 6–44. https://doi.org/10.1080/00139157.2025.2434494.

Hoffmann, W.A., Schroeder, W., Jackson, R.B., 2003. Regional feedbacks among fire, climate, and tropical deforestation. J. Geophys. Res. 108, 2003JD003494. https://doi.org/10.1029/2003JD003494.

Lenton, T.M., Xu, C., Abrams, J.F., Ghadiali, A., Loriani, S., Sakschewski, B., Zimm, C., Ebi, K.L., Dunn, R.R., Svenning, J.-C., Scheffer, M., 2023. Quantifying the human cost of global warming. Nat. Sustain. 6, 1237–1247. https://doi.org/10.1038/s41893-023-01132-6.

Marengo, J.A., Cunha, A.P., Espinoza, J.-C., Fu, R., Schöngart, J., Jimenez, J.C., Costa, M. C., Ribeiro, J.M., Wongchuig, S., Zhao, S., 2024. The drought of Amazonia in 2023-2024. AJCC 13, 567–597. https://doi.org/10.4236/ajcc.2024.133026.

Mataveli, G., Jones, M.W., Carmenta, R., Sanchez, A., Dutra, D.J., Chaves, M., de Oliveira, G., Anderson, L.O., Aragão, L.E.O.C., 2024. Deforestation falls but rise of wildfires continues degrading Brazilian Amazon forests. Glob. Change Biol. 30, e17202. https://doi.org/10.1111/gcb.17202.

Mataveli, G., Maure, L.A., Sanchez, A., Dutra, D.J., De Oliveira, G., Jones, M.W., Amaral, C., Artaxo, P., Aragão, L.E.O.C., 2025. Forest degradation is undermining progress on deforestation in the Amazon. Glob. Change Biol. 31, e70209. https://doi.org/10.1111/gcb.70209.

NOAA, 2024. Cold & Warm Episodes by Season. Historical El Niño / La Niña Episodes (1950 - present). National Weather Service (NWS). Climate Prediction Center (Accessed 8 June 2024). URL. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.

Nobre, C.A., Borma, L.D.S., 2009. 'Tipping points' for the Amazon forest. Curr. Opin. Environ. Sustain. 1, 28–36. https://doi.org/10.1016/j.cosust.2009.07.003.

Oliveras Menor, I., Prat-Guitart, N., Spadoni, G.L., Hsu, A., Fernandes, P.M., Puig-Gironès, R., Ascoli, D., Bilbao, B.A., Bacciu, V., Brotons, L., Carmenta, R., de-Miguel, S., Gonçalves, L.G., Humphrey, G., Ibarnegaray, V., Jones, M.W., Machado, M.S., Millán, A., De Morais Falleiro, R., Mouillot, F., Pinto, C., Pons, P., Regos, A., Senra De Oliveira, M., Harrison, S.P., Armenteras Pascual, D., 2025. Integrated fire management as an adaptation and mitigation strategy to altered fire regimes. Commun. Earth Environ. 6, 202. https://doi.org/10.1038/s43247-025-02165-9.

Rede Brasa de Pesquisa, 2025. Fogo em foco: diagnóstico dos incêndios no Brasil em 2024/2025 (Monitoramento no. 2024–2025), Fogo em foco. INPE, São José dos Campos.

Reisinger, A., Fuglestvedt, J.S., Pirani, A., Geden, O., Jones, C.D., Maharaj, S., Poloczanska, E.S., Morelli, A., Johansen, T.G., Adler, C., Betts, R.A., Seneviratne, S.I., 2025. Overshoot: a conceptual review of exceeding and returning to global warming of 1.5°C. Annu. Rev. Environ. Resour. 50, 185–217. https://doi.org/10.1146/annurev-environ-111523-102029.

Ribeiro, A.F.S., Santos, L., Randerson, J.T., Uribe, M.R., Alencar, A.A.C., Macedo, M.N., Morton, D.C., Zscheischler, J., Silvestrini, R.A., Rattis, L., Seneviratne, S.I., Brando, P.M., 2024. The time since land-use transition drives changes in fire activity in the Amazon-Cerrado region. Commun. Earth Environ. 5, 96. https://doi.org/10.1038/s43247-024-01248-3.

Ripple, W.J., Wolf, C., Lenton, T.M., Gregg, J.W., Natali, S.M., Duffy, P.B., Rockström, J., Schellnhuber, H.J., 2023. Many risky feedback loops amplify the need for climate action. One Earth 6, 86–91. https://doi.org/10.1016/j.oneear.2023.01.004.

Silveira, M.V.F., Silva-Junior, C.H.L., Anderson, L.O., Aragão, L.E.O.C., 2022. Amazon fires in the 21st century: the year of 2020 in evidence. Global Ecol. Biogeogr. 31, 2026–2040. https://doi.org/10.1111/geb.13577.

Terrabrasilis, 2022. Deter (Avisos) (Accessed 27 January 2024). URL http://terrabrasilis.dpi.inpe.br/app/dashboard/alerts/legal/amazon/daily/#.

Van Der Werf, G.R., Randerson, J.T., Giglio, L., Collatz, G.J., Kasibhatla, P.S., Arellano, A.F., 2006. Interannual variability in global biomass burning emissions from 1997 to 2004. Atmos. Chem. Phys. 6, 3423–3441. https://doi.org/10.5194/acp-6-3423-2006.