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LETTER TO THE EDITOR

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Improving the spatial-temporal analysis of Amazonian fires

Amazonian fires have been of great scientific and political concern in recent years, as they indicate changes in environmental governance, altered environmental conditions, and lie at the interface of climate and land-use changes—two of the dominant stressors in tropical environments (Barlow et al., 2018). Research on complex socio-environmental systems, such as the Amazon, is crucial to inform more effective decision making. With this in mind, we were concerned that recent papers—including that of Xu et al. (2020) in this journal—have failed to contemplate critical nuances that underpin Amazonian fires, leading to flawed results. In the interest of supporting science that is more informative, we outline five key features of the Amazon that need to be considered when analyzing spatial-temporal patterns of fires.

1 | AMAZONIAN VEGETATION IS NOT ONLY DETERMINED BY CLIMATE

While climatic conditions do influence Amazonian vegetation, forest structure and stem dynamics are predominantly determined by edaphic conditions (Quesada et al., 2009). As such, it is not possible to accurately characterize vegetation heterogeneity and ecotones according to Köppen-Geiger climate zones, as assumed by Xu et al. (2020). For example, doing so erroneously suggests the entire southern border of the Amazon Basin is formed by savannas (Xu et al., 2020), when in fact it is mostly covered by forest formations (Figure 1a,b).

2 | SPATIAL-TEMPORAL VARIATION IN CLIMATE NEEDS TO BE ADEQUATELY REPRESENTED

There is well-documented variation in precipitation dynamics across Amazonia that is not captured by static spatial descriptions, such as the Köppen-Geiger zones. The Amazon region spans two hemispheres, with the North and the South presenting dry seasons at opposite times of the year, and with distinct duration and intensity (Mendes De Moura et al., 2015). Additionally, there are clear differences between the East and West precipitation regimes (Figure 1c–e). Any temporal analysis of fire occurrence needs to take account of this variation. Xu et al.'s (2020) use of a single dry season period across the whole Amazon means their results do not capture the fire season across large parts of the Amazon Basin.

This is a Letter to the Editor on Xu et al., 26, 5874–5885. See also response to this letter by Xu et al., 27, e2–e4.

3 | NOT ALL AMAZONIAN FIRES ARE FOREST FIRES

Understanding fire–climate interactions requires differentiating between different fire types (cf. Barlow et al., 2020). For example, both agricultural and deforestation fires are deliberately set, and will have stronger spatial associations with human actions than with climate. In contrast, forest fires are the combined outcome of human activities that provide the ignition source and climatic factors, as forests will only burn when the litter layer is dry enough (Ray et al., 2005). Studies such as Xu et al. (2020) that do not differentiate between such distinct fire types need to be clear about this limitation and avoid making unwarranted inferences about forest fire dynamics.

4 | ASSESSMENTS OF FOREST FIRES MUST USE APPROPRIATE MEASURES

When studies claim to focus on forest fires, it is essential they use fire products that are effective at mapping them. However, the course-scale MODIS active fire products used by Xu et al. (2020) and many others are very poor at detecting understory forest fires—the 50 m tall forest canopy acts as a barrier for the detection of the 30 cm flames of understory fires (Anderson et al., 2017). By using an inadequate product to assess forest fires, Xu et al.'s study does not provide any of their purported insights into forest resilience, alternative states or the fire susceptibility of forests.

5 | DEFORESTATION AND DEGRADATION ARE DIFFERENT PROCESSES

Deforestation is the complete removal of the forest cover, while degradation is the reduction of a forest capacity to supply services (Parrotta et al., 2012), which can be caused by forest fires. Within Brazil, these classifications have critically important legal implications. Deforestation forms the basis of property-level legal regulations, such as the Native Vegetation Protection Law (NVPL, i.e., the law that replaced the Forest Code) and determines a key part of its Nationally Determined Contributions (NDC) to the UNFCCC. Conversely, forest degradation is not directly addressed or quantified in the NVPL and not yet included in the NDCs. Despite the clear differences and legal importance, deforestation and forest degradation are often confused by scientists, including in the article of Xu et al. (2020). For example, in their paper, the authors classify

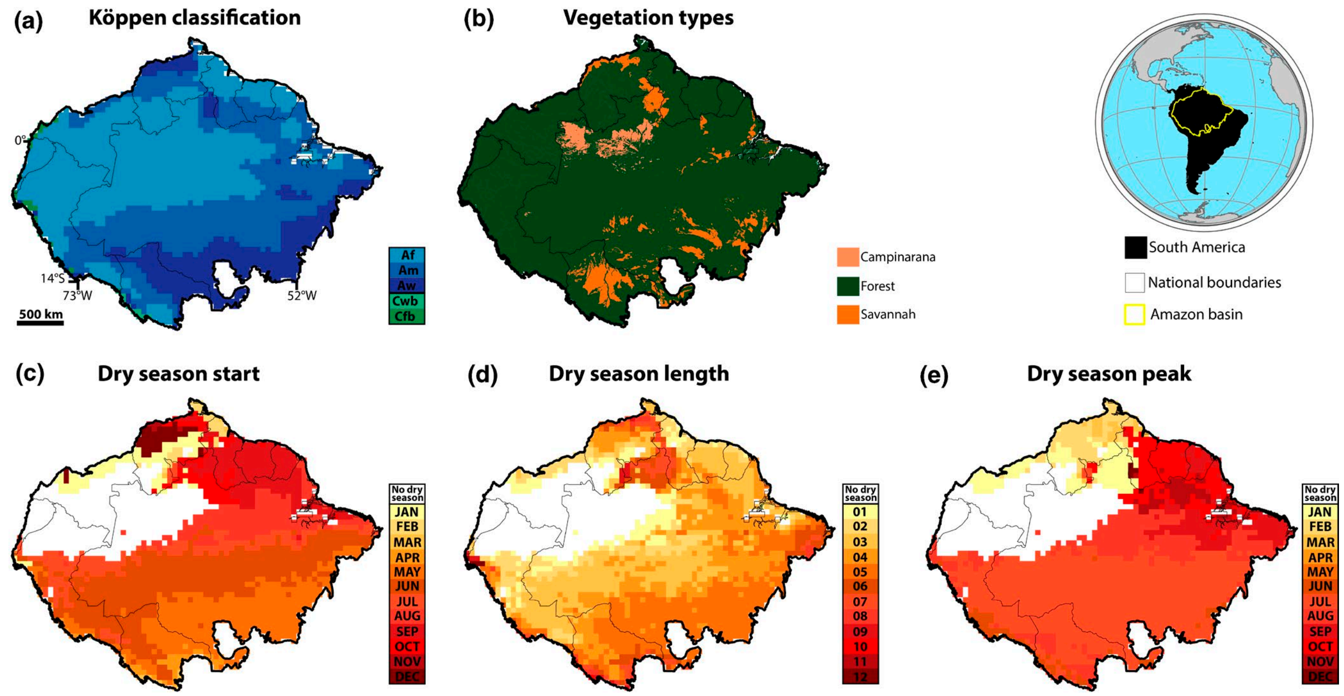

FIGURE 1 Climate and vegetation across the Amazon Basin. (a) The Köppen-Geiger climate classification used by Xu et al. (2020) to determine both climatic and vegetation zones across Amazonia. (b) Amazonia main vegetation types, including forests, campinaranas, and savannas. (c) The starting month, (d) duration, and (e) peak of the dry season where it is present. Vegetation types were defined by combining data of the Terrestrial Ecoregions of the World (Olson et al., 2001) with the regional scale mapping of the Brazilian Amazon (DNPM 1973–1983 Projeto RADAMBRASIL, 1973–1983), meaning non-forest vegetation is likely under-represented in extra-Brazilian regions of the map. Mean month precipitation was calculated using data from CHIRPS between 2010 and 2019 (Funk et al., 2015) at a 0.5° resolution. We considered the dry season to consist of all consecutive months in which precipitation <100 mm, thus below the average evapotranspiration in the region (Aragão et al., 2007). The driest month of the year was considered the peak of the dry season

"disturbed forests" based on deforestation and not disturbance itself, selecting grid cells in which forest cover in 2000 was greater than 70% and the accumulated loss during 2001–2017 was greater than 65%. Confusing the two drivers of change in the Amazon only obfuscates the search for solutions.

CONCLUSION

The Amazon is critically important for the Earth system, people and biodiversity. It is essential that scientists respond to high-profile changes in deforestation and fire occurrence, and we recognize the urgent need for more research on this topic. However, erroneous assumptions and over-simplification are not just unhelpful for research, as they could also jeopardize conservation efforts and decision making. We hope that our analysis of climate variation and our clarification of some common misunderstandings will help to support better climate and fire research in the region.

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DATA AVAILABILITY STATEMENT

All raster files used available at https://doi.org/10.6084/m9.figshare.13070285.

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REFERENCES

Anderson, L. O., Cheek, D., Aragao, L. E. O. C., Andere, L., Duarte, B., Salazar, N., Lima, A., Duarte, V., & Arai, E. (2017). Development of a point-based method for map validation and confidence interval estimation: A case study of burned areas in Amazonia BIOmes of Brasil-resilience, recovery, and diversity: BIO-RED view project. *Journal of Remote Sensing & GIS*, *6*, 1. https://doi.org/10.4172/2469-4134.1000193

Aragão, L. E. O. C., Malhi, Y., Roman-Cuesta, R. M., Saatchi, S., Anderson, L. O., & Shimabukuro, Y. E. (2007). Spatial patterns and fire response of recent Amazonian droughts. *Geophysical Research Letters*, *34*(7), L07701. https://doi.org/10.1029/2006GL028946

Barlow, J., Berenguer, E., Carmenta, R., & França, F. (2020). Clarifying Amazonia's burning crisis. *Global Change Biology*, *26*(2), 319–321. https://doi.org/10.1111/gcb.14872

Barlow, J., França, F., Gardner, T. A., Hicks, C. C., Lennox, G. D., Berenguer, E., Castello, L., Economo, E. P., Ferreira, J., Guénard, B., Gontijo Leal, C., Isaac, V., Lees, A. C., Parr, C. L., Wilson, S. K., Young, P. J., & Graham, N. A. J. (2018). The future of hyperdiverse tropical ecosystems. *Nature*, *559*(7715), 517–526. https://doi.org/10.1038/s41586-018-0301-1

DNPM 1973–1983 Projeto RADAMBRASIL. (1973–1983). *Levantamento de recursos naturais* (Vol. *1–23*). Ministério das Minas e Energia Departamento Nacional de Produção Mineral.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations – A new environmental record for monitoring extremes. *Scientific Data*, *2*, 150066. https://doi.org/10.1038/sdata.2015.66

Mendes De Moura, Y. M., Hilker, T., Lyapustin, A. I., Galvão, L. S., dos Santos, J. R., Anderson, L. O., de Sousa, C. H. R., & Arai, E. (2015). Seasonality and drought effects of Amazonian forests observed from multi-angle satellite data. *Remote Sensing of Environment*, *171*, 278–290. https://doi.org/10.1016/j.rse.2015.10.015

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., & Kassem, K. R. (2001). Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience*, *51*, 933–938.

Parrotta, J. A., Wildburger, C., & Mansourian, S. (2012). Understanding Relationships between Biodiversity, Carbon, Forests and People: The Key to Achieving REDD + Objectives. A Global Assessment Report (Vol. *31*). https://doi.org/1016-3263

Quesada, C. A., Lloyd, J., Schwarz, M., Baker, T. R., Phillips, O. L., Patiño, S., Czimczik, C. I., Hodnett, M. G., Herrera, R., Arneth, A., Lloyd, G., Malhi, Y., Dezzeo, N., Luizão, F. J., Santos, A. J. B., Schmerler, J., Arroyo, L., Silveira, M., Priante-Filho, N., … Ramírez Angulo, H. (2009). Regional and large-scale patterns in Amazon forest structure and function are mediated by variations in soil physical and chemical properties. *Biogeosciences Discussions*, *6*(2), 3993–4057. https://doi.org/10.5194/bgd-6-3993-2009

Ray, D., Nepstad, D., & Moutinho, P. (2005). Micrometeorological and canopy controls of fire susceptibility in a forested Amazon landscape. *Ecological Applications*, *15*(5), 1664–1678.

Xu, X., Jia, G., Zhang, X., Riley, W. J., & Xue, Y. (2020). Climate regime shift and forest loss amplify fire in Amazonian forests. *Global Change Biology*, *26*(10), 5874–5885. https://doi.org/10.1111/gcb.15279