B-EPICC PROJECT KICK-OFF WORKSHOP
2022

Changes in forest carbon dynamics due to Environmental Changes in Amazonia

Luiz E. O. C. Aragão
&
TREES Lab members

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www.treeslab.org

Harmonizing the C cycle from regional to global

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The complex tropical forest mosaic

Uncertain sources

Source: Paulo Brando, Mongabay, NASA

Fate of Anthropogenic CO_2 Emissions

Sources

GLOBAL CARBON PROJECT

Sinks

Sources = Sinks

34.8 $GtCO_2$/yr
89%

11%
4.1 $GtCO_2$/yr

18.6 $GtCO_2$/yr
48%

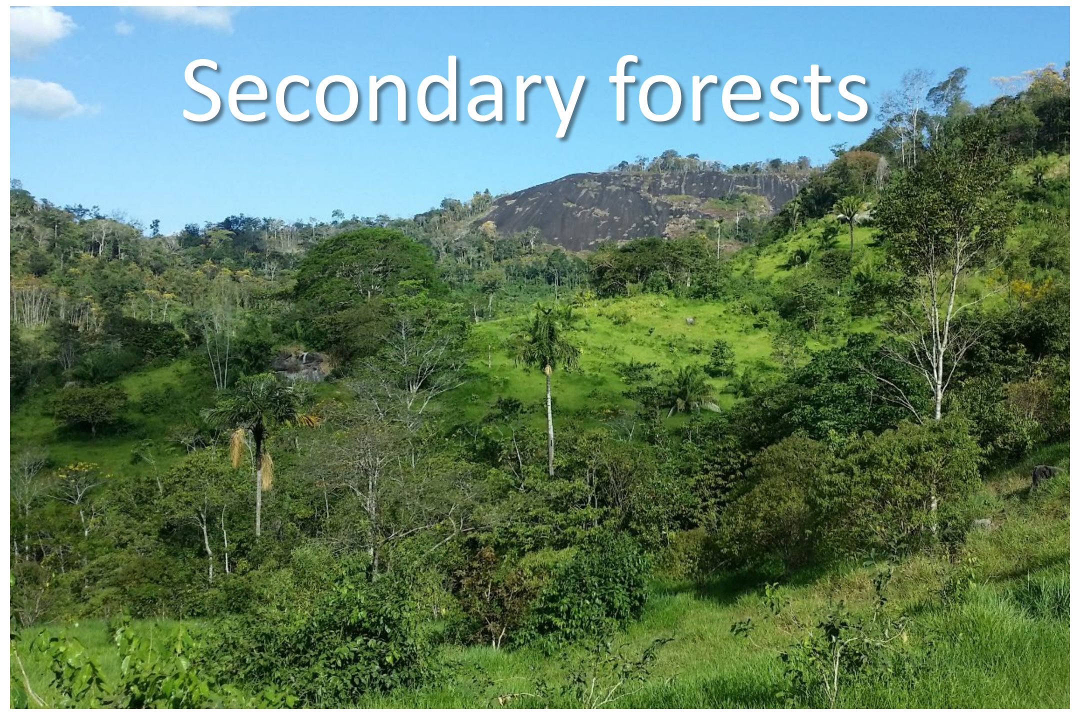
29%
11.2 $GtCO_2$/yr

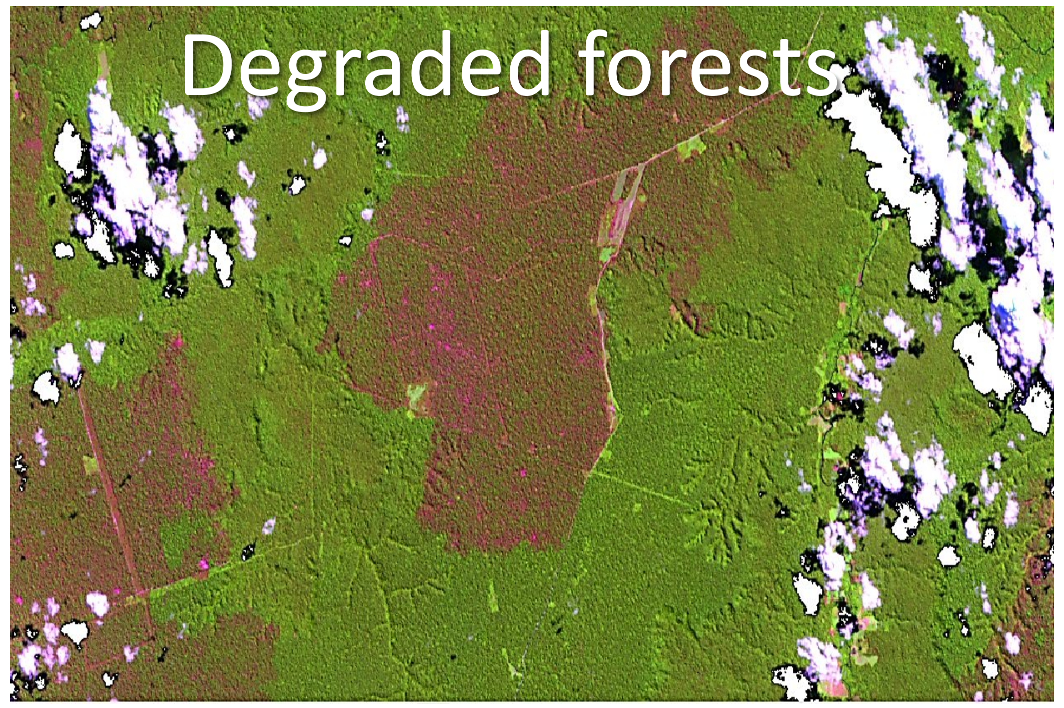
26%
10.2 $GtCO_2$/yr

Budget Imbalance: 3% -1.0 $GtCO_2$/yr
(the difference between estimated sources & sinks)

Friedlingstein et al 2021, Global Carbon Project 2021

Uncertain sinks





First indications of the importance of Amazon forest degradation

By analyzing data on deforestation and satellite fires from the Brazilian Amazon, we show that the occurrence of fires increased by 59% of the area that has suffered a reduction in deforestation rates. Differences in fire frequencies in two land use gradients (extensive and intensive) reveal that fire-free land management can substantially reduce the incidence of fires by up to 69%.

The Incidence of Fire in Amazonian Forests with Implications for REDD

Luiz E. O. C. Aragão[1]*† and Yosio E. Shimabukuro[2]*

Reducing emissions from deforestation and degradation (REDD) may curb carbon emissions, but the consequences for fire hazard are poorly understood. By analyzing satellite-derived deforestation and fire data from the Brazilian Amazon, we show that fire occurrence has increased in 59% of the area that has experienced reduced deforestation rates. Differences in fire frequencies across two land-use gradients reveal that fire-free land-management can substantially reduce fire incidence by as much as 69%. If sustainable fire-free land-management of deforested areas is not adopted in the REDD mechanism, then the carbon savings achieved by avoiding deforestation may be partially negated by increased emissions from fires.

Reducing emissions from deforestation and degradation (REDD) is one of the most cost-effective mitigation mechanisms (*1*) and could contribute to an emission reduction of 13 to 50 billion tons of carbon (Gt C) by 2100 (*2*). REDD is therefore a high-priority mechanism for mitigation of climate change within the United Nations Framework Convention on Climate Change (UNFCCC). The future of REDD implementation relies on forthcoming agreements to tackle the unresolved outcomes from the 15th Convention of the Parties, which took place in December 2009. These negotiations can largely influence the maintenance or replacement of the Kyoto Protocol beyond 2012 and the future of tropical forests. Policy-makers are considering a range of options for developing countries to receive financial incentives to reduce their deforestation rates (*2*). However, the efficacy of REDD as a climate change mitigation strategy depends, in particular, upon the stabilization of deforestation and degradation of the world's largest rainforest, the Amazon.

Deforestation in the Brazilian Amazon (defined as clear cutting and conversion of the original forest cover to other land uses) has resulted in annual forest area loss of 18,918 ± 1,576 km^2 (SEM) from 1998 to 2007, according to the National Institute for Space Research (INPE) in Brazil (*3*). It is estimated that this results in release of 0.28 (0.17 to 0.49) Gt C to the atmosphere annually (*4*), corresponding to 24% of the world's C emissions from land cover change [1.15 (0.58-1.79) Gt C $year^{-1}$] (*5*). In principle, discontinuing ongoing deforestation through mechanisms such as REDD would protect a large fraction of the 86 Gt of the carbon stored in Amazonian forest biomass (*6*), which is equivalent to about a decade of global fossil fuel emissions to the atmosphere. However, there is a pressing need to consider the threat to forests posed by fire.

Fires following drought years are likely to release a similar amount of carbon as emissions from deliberate deforestation (*7*, *8*). The combined effect of deliberate deforestation and forest fires has a similar magnitude to the natural annual carbon sink of 0.45 (0.3 to 0.6) Gt C estimated

models (*10*, *11*), and consequent increasing drought intensity and frequency, may push Amazonia toward an amplified fire-prone system (*12*). Previous studies (*13*, *14*) have shown an increase in fire occurrence following two large-scale Amazonian droughts (1998 and 2005). Changes in fire frequency could jeopardize the benefits achieved through REDD; however, despite its vital importance in this region, fire is currently neglected in the emerging UN framework.

Operational satellite-derived deforestation (*3*) and fire (*15*) data sets produced by INPE, and land cover information from the European Commission's Joint Research Centre (*16*), provide a unique opportunity to quantify the sensitivity of fires to changes in deforestation rates and land use in the Brazilian Amazon. Fire in the Brazilian Amazon is likely to follow three plausible pathways: (i) Fire incidence may decrease with reduced deforestation rates by restraining human activities that are major ignition sources (*8*, *13*, *14*, *17*). (ii) It may increase even with reduced deforestation rates, both through slashing and burning of secondary forests (*18*) in already deforested areas that are not monitored by INPE's Program for Deforestation Assessment in the Brazilian Legal Amazonia (PRODES) (*19*) and through continuous enlargement of forest edges (*20*) and increasing area of secondary forest cover (*21*) that are more susceptible to fire (*22*). (iii) Fire incidence may decrease because of a shift from extensive (unmanaged) to intensive (managed) land-use methods, as the latter is normally not accompanied by deliberate use of fire (*23*).

To distinguish the first two pathways we used all available regionwide data from INPE to perform a pixel-based analysis of temporal trends in deforestation rates and fire incidence (*19*). For each pixel at 0.25° by 0.25° (or 774.35 km^2) spatial resolution, the annual fraction deforested for the period from 2000 to 2007 was derived by aggregating the 60-m spatial resolution pixels from INPE's PRODES annual deforestation maps

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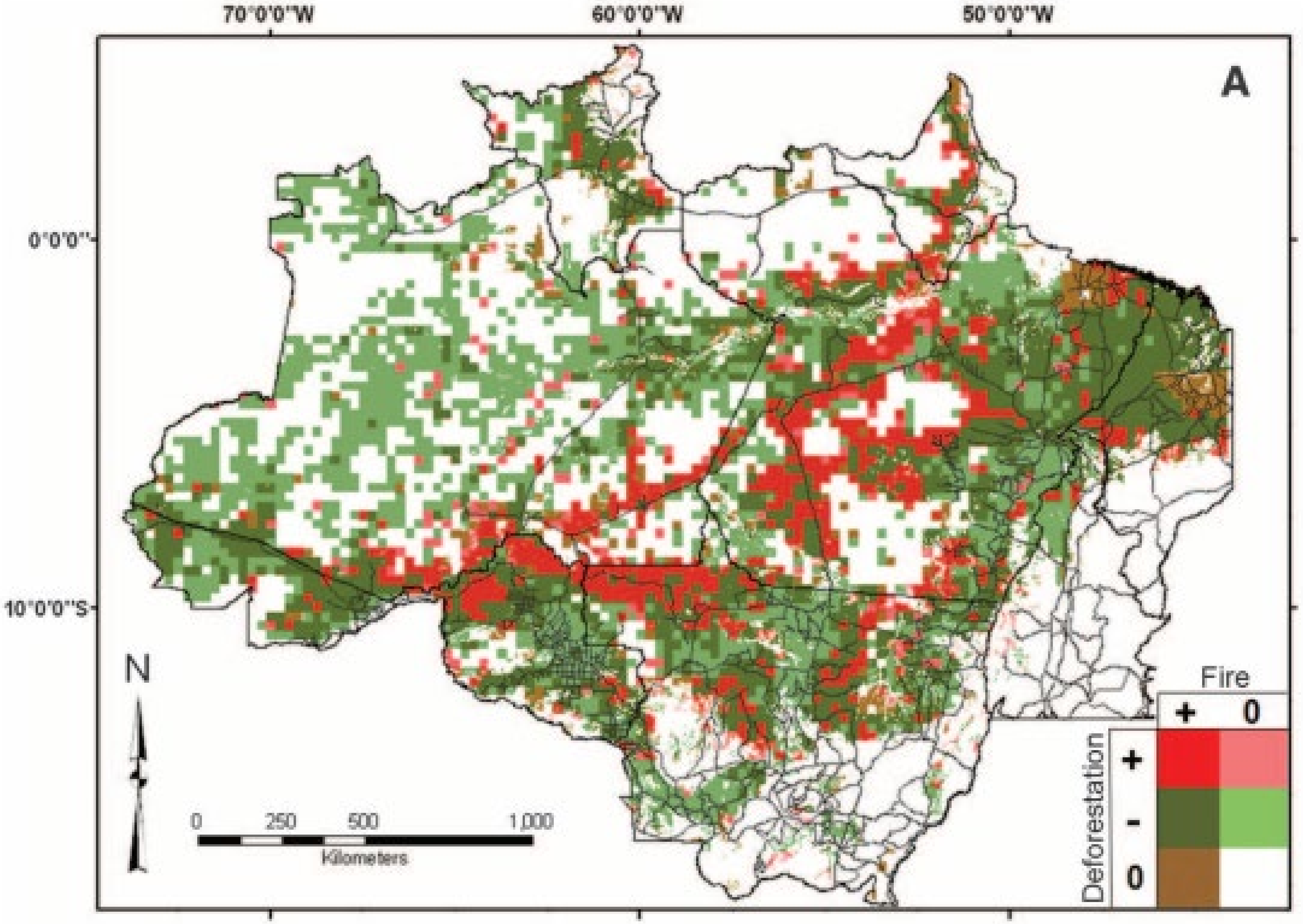
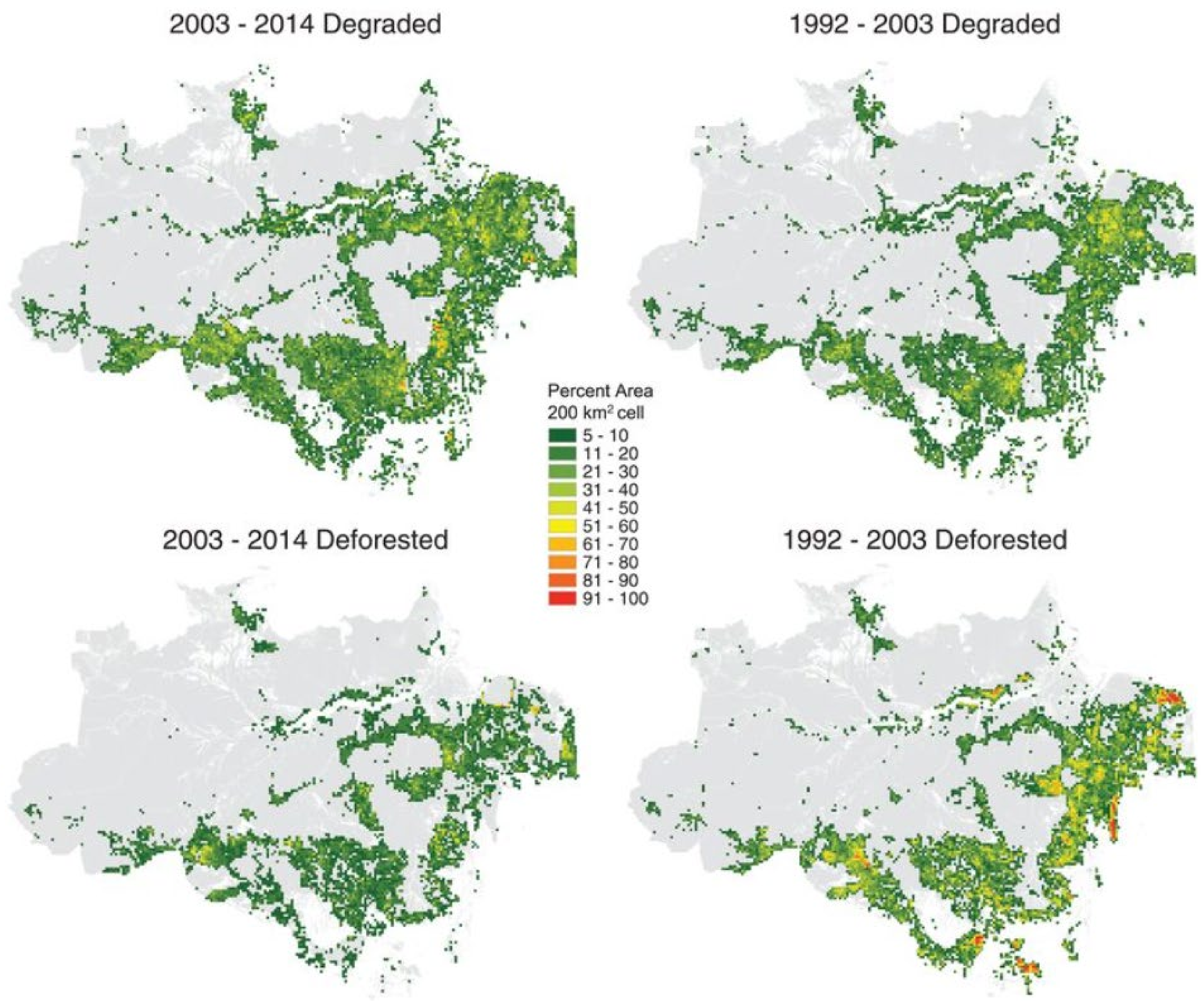
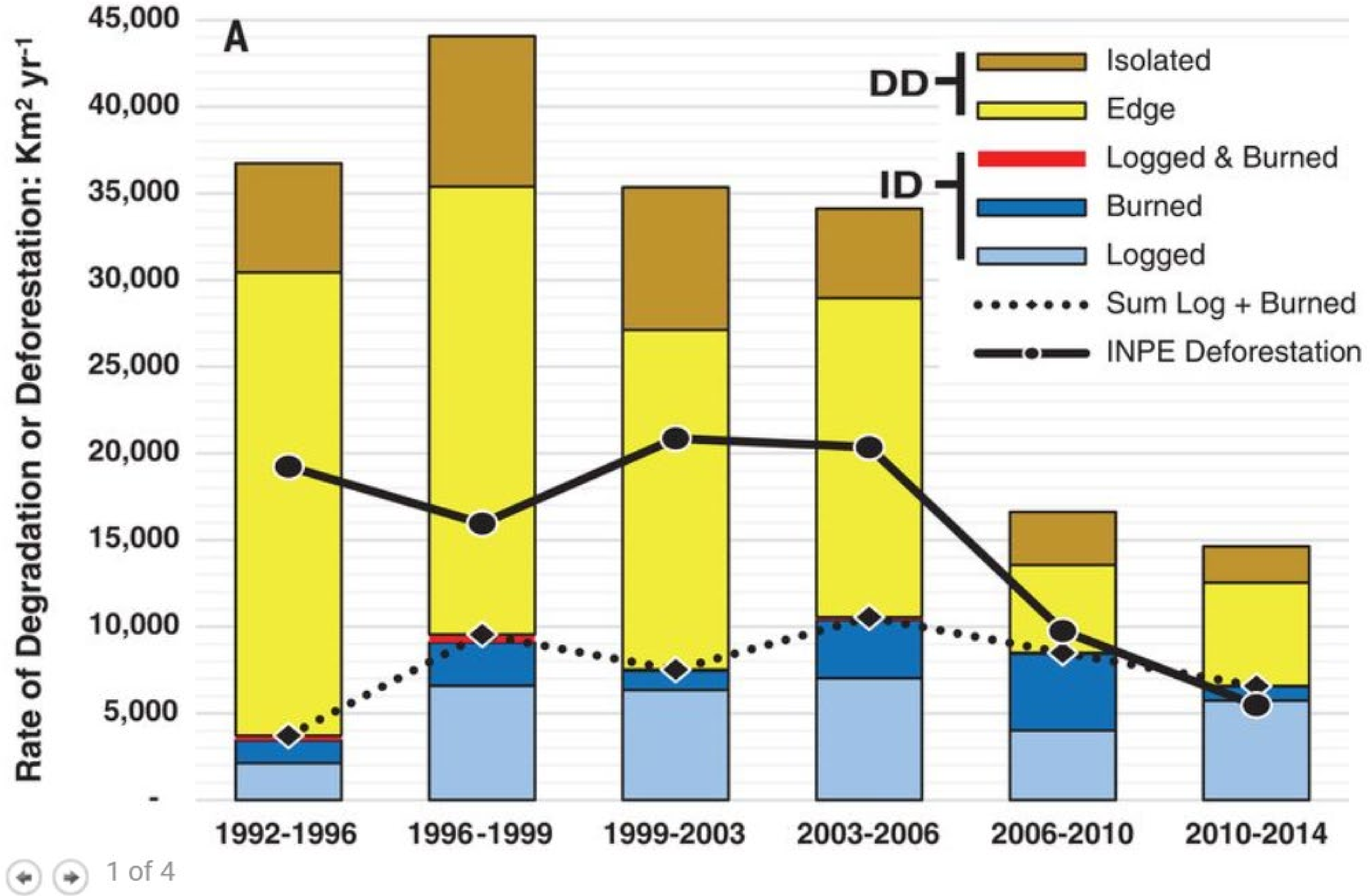


10 years later the progress of forest degradation over the Amazon is confirmed

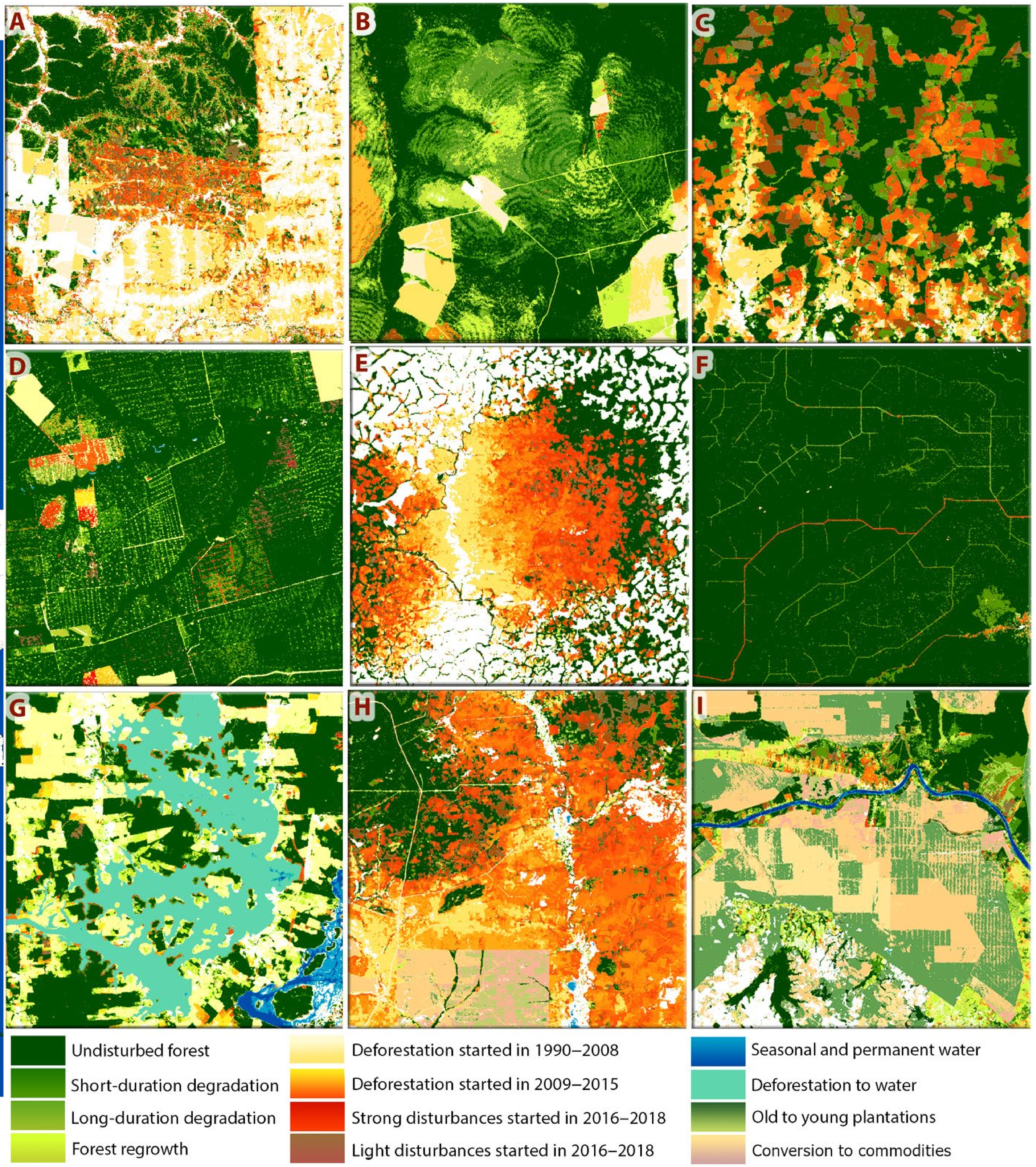




Matricardi et al. 2020. Science

Tropical forest change at 30m spatial resolution

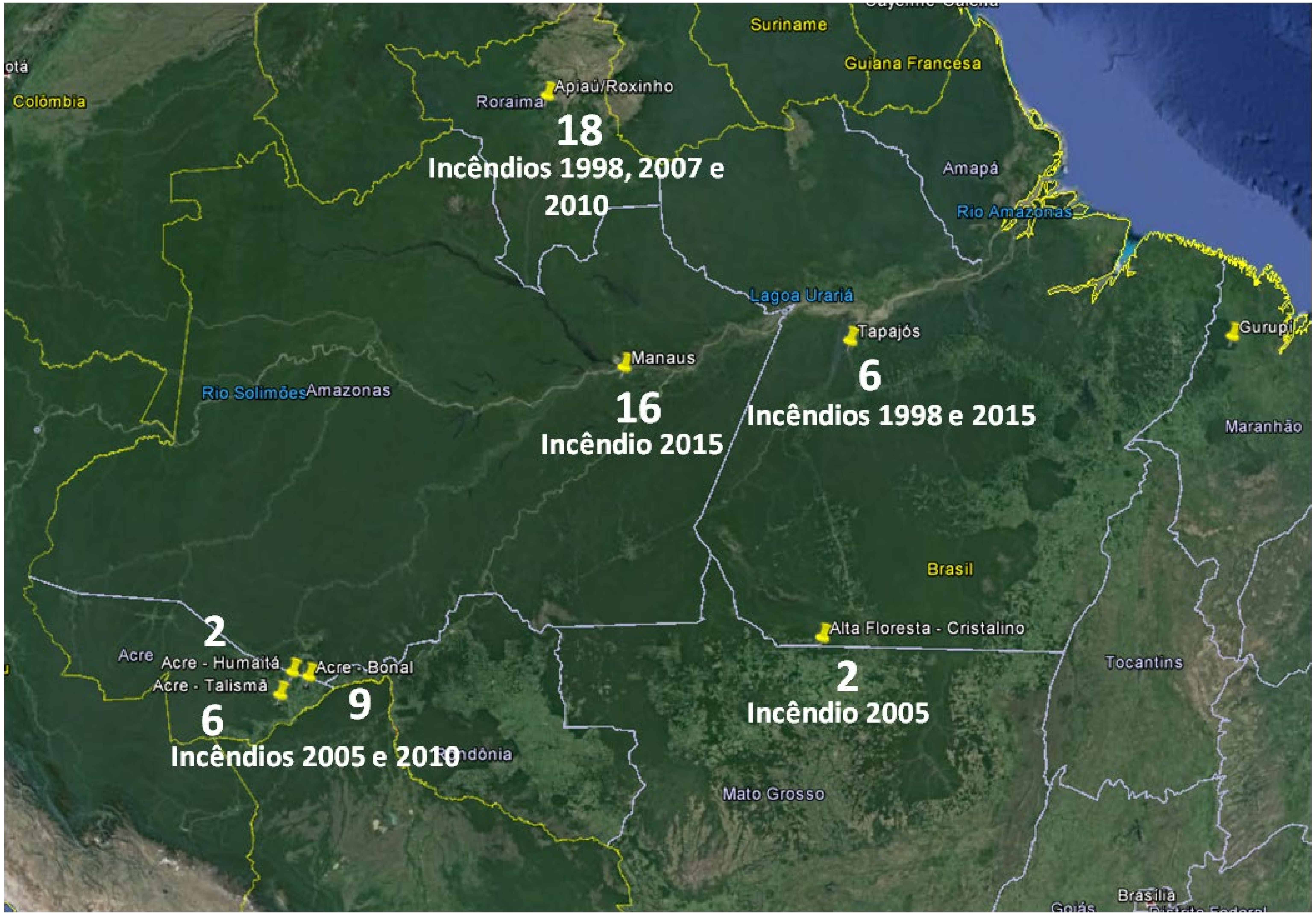
A total of 17% of tropical moist forests have disappeared since 1990 with a remaining area of 1071 million hectares in 2019, from which 10% are degraded



C. Vancutsem,…,Aragão et al. Science Advances 2021

A field perspective of burned forest dynamics

Plot Network - FATE (Fire-Associated Transient Emissions)



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Measuring forest dynamics in fire affected areas

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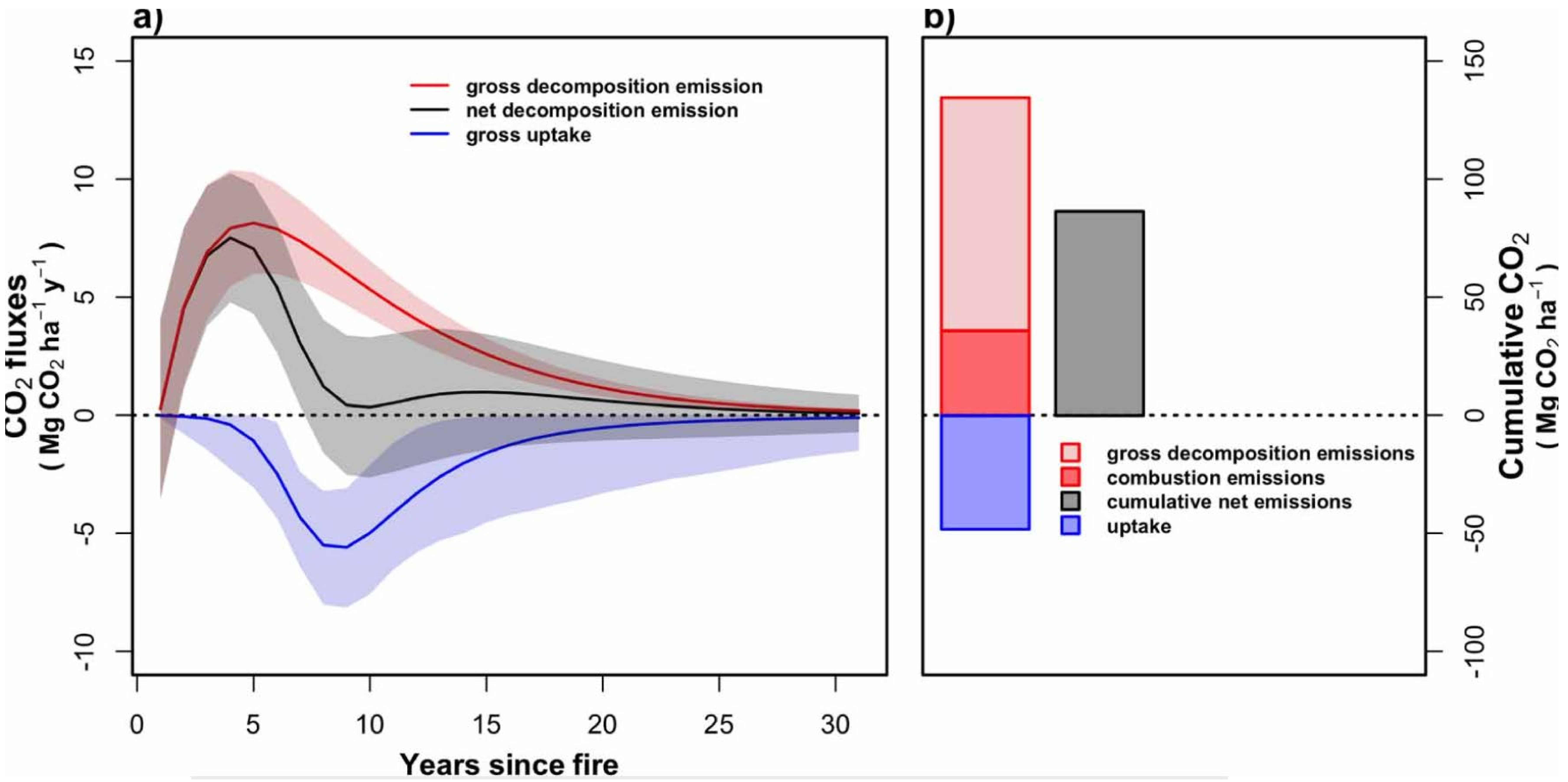
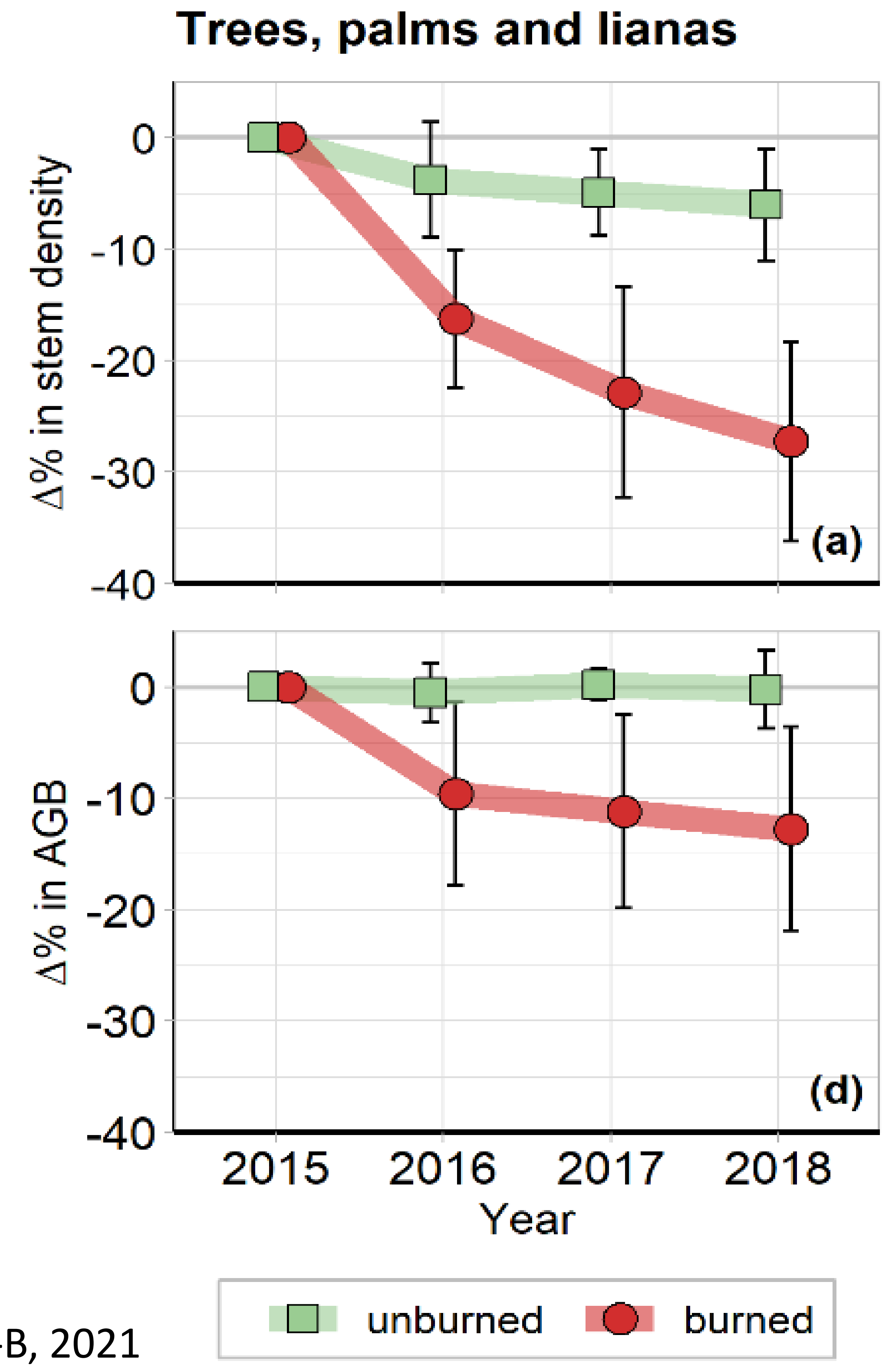
Net carbon balance of burned forests

Recovery of these forests are annulated by tree mortality

Over the 30 yr time period, gross emissions from combustion during the fire and subsequent tree mortality and decomposition were equivalent to 126.1 Mg CO_2 ha^{-1} of which 73% (92.4 Mg CO_2 ha^{-1}) resulted from mortality and decomposition. These emissions were only partially offset by forest growth, with an estimated CO_2 uptake of 45.0 Mg ha^{-1}over the same time period (1.5 Mg ha-1 CO2 year-1).

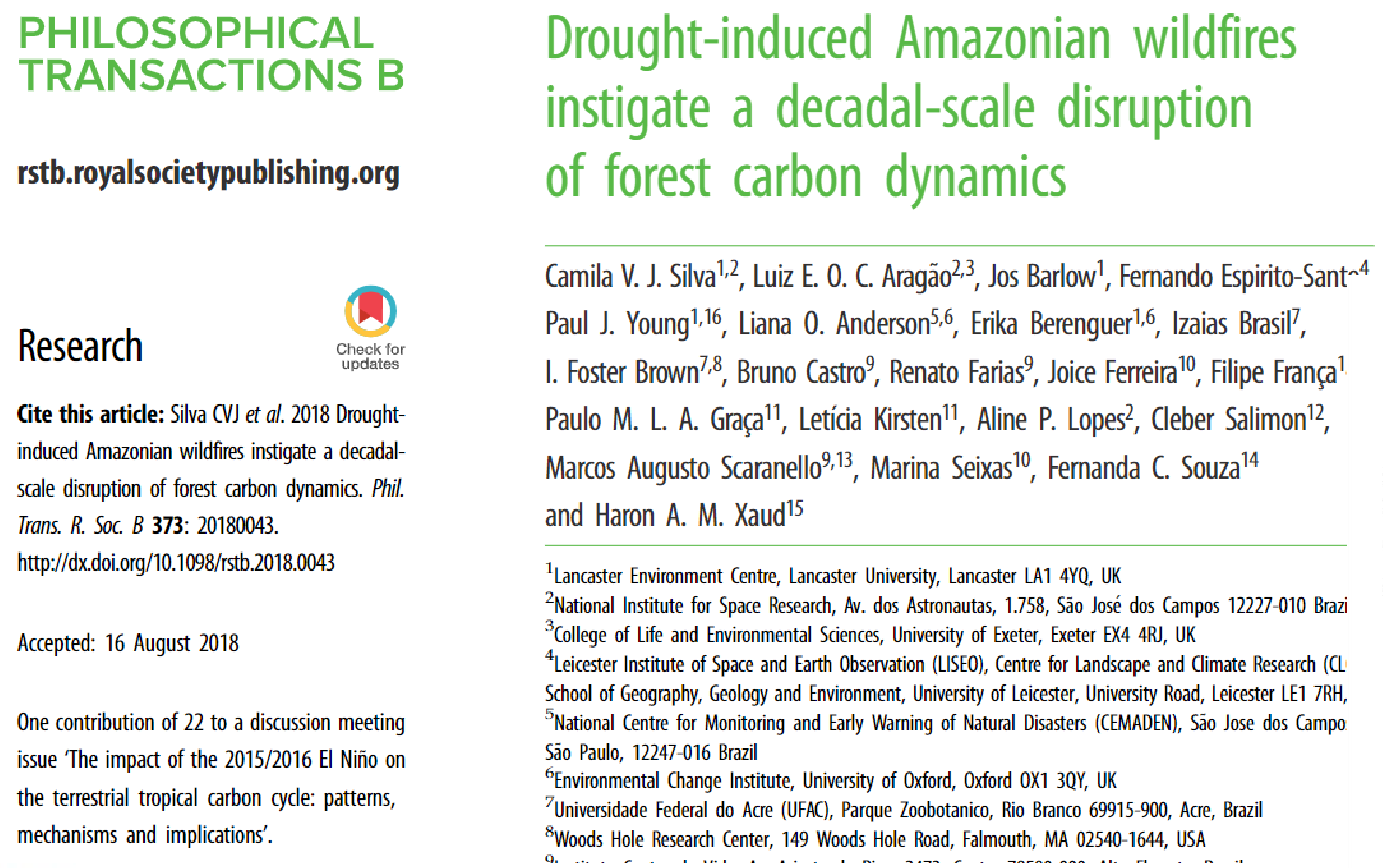




Silva et al. Environmental Research Letters2020

Pontes, PRS-B, 2021

Forest biomass after fire stabilizes at lower biomass levels than undisturbed forests



PHILOSOPHICAL TRANSACTIONS B

rstb.royalsocietypublishing.org

Research

Cite this article: Silva CVJ et al. 2018 Drought-induced Amazonian wildfires instigate a decadal-scale disruption of forest carbon dynamics. Phil. Trans. R. Soc. B 373: 20180043. http://dx.doi.org/10.1098/rstb.2018.0043

Accepted: 16 August 2018

One contribution of 22 to a discussion meeting issue 'The impact of the 2015/2016 El Niño on the terrestrial tropical carbon cycle: patterns, mechanisms and implications'.

Drought-induced Amazonian wildfires instigate a decadal-scale disruption of forest carbon dynamics

Camila V. J. Silva[1,2], Luiz E. O. C. Aragão[2,3], Jos Barlow[1], Fernando Espirito-Sant~[4] Paul J. Young[1,16], Liana O. Anderson[5,6], Erika Berenguer[1,6], Izaias Brasil[7], I. Foster Brown[7,8], Bruno Castro[9], Renato Farias[9], Joice Ferreira[10], Filipe França[1] Paulo M. L. A. Graça[11], Letícia Kirsten[11], Aline P. Lopes[2], Cleber Salimon[12], Marcos Augusto Scaranello[9,13], Marina Seixas[10], Fernanda C. Souza[14] and Haron A. M. Xaud[15]

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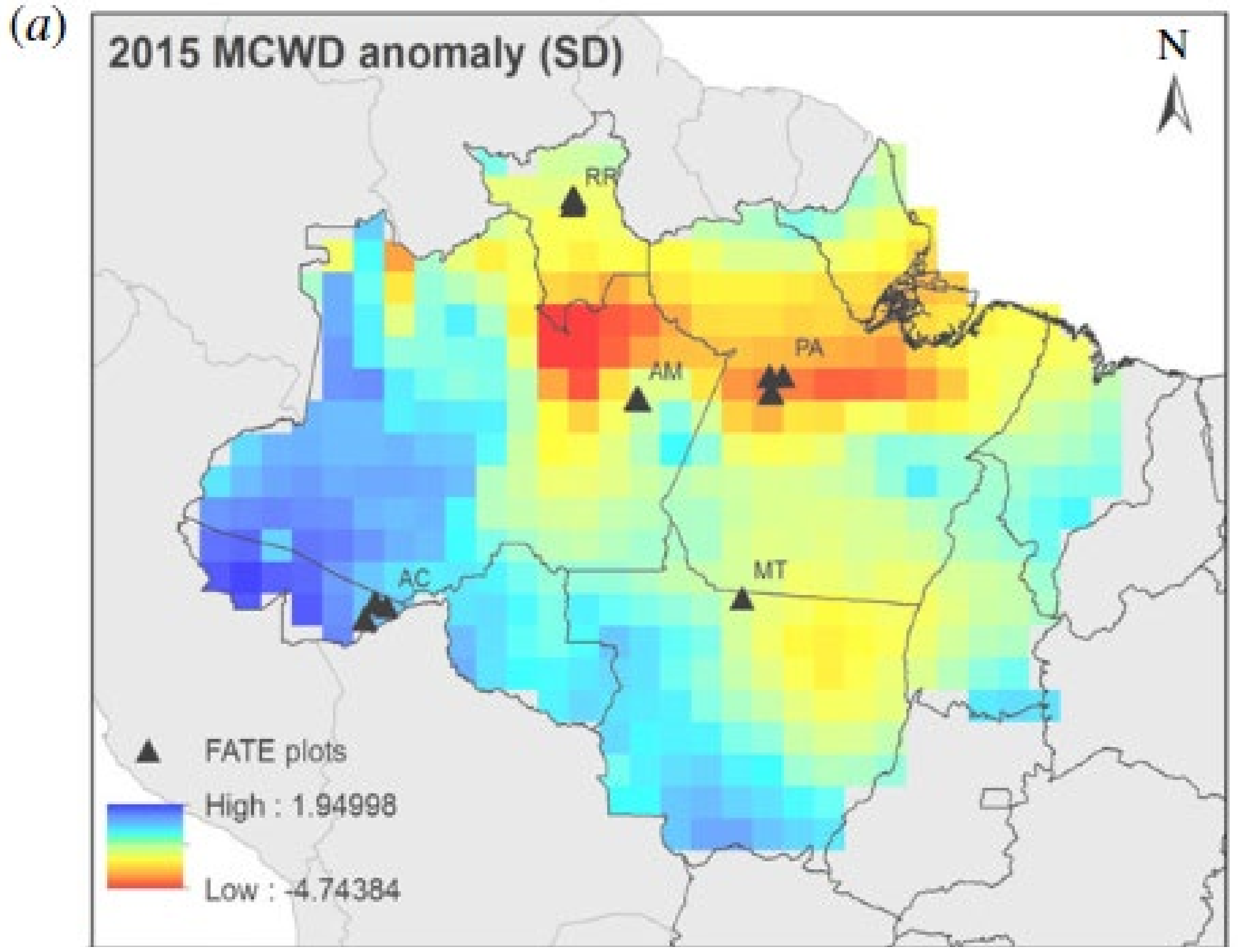
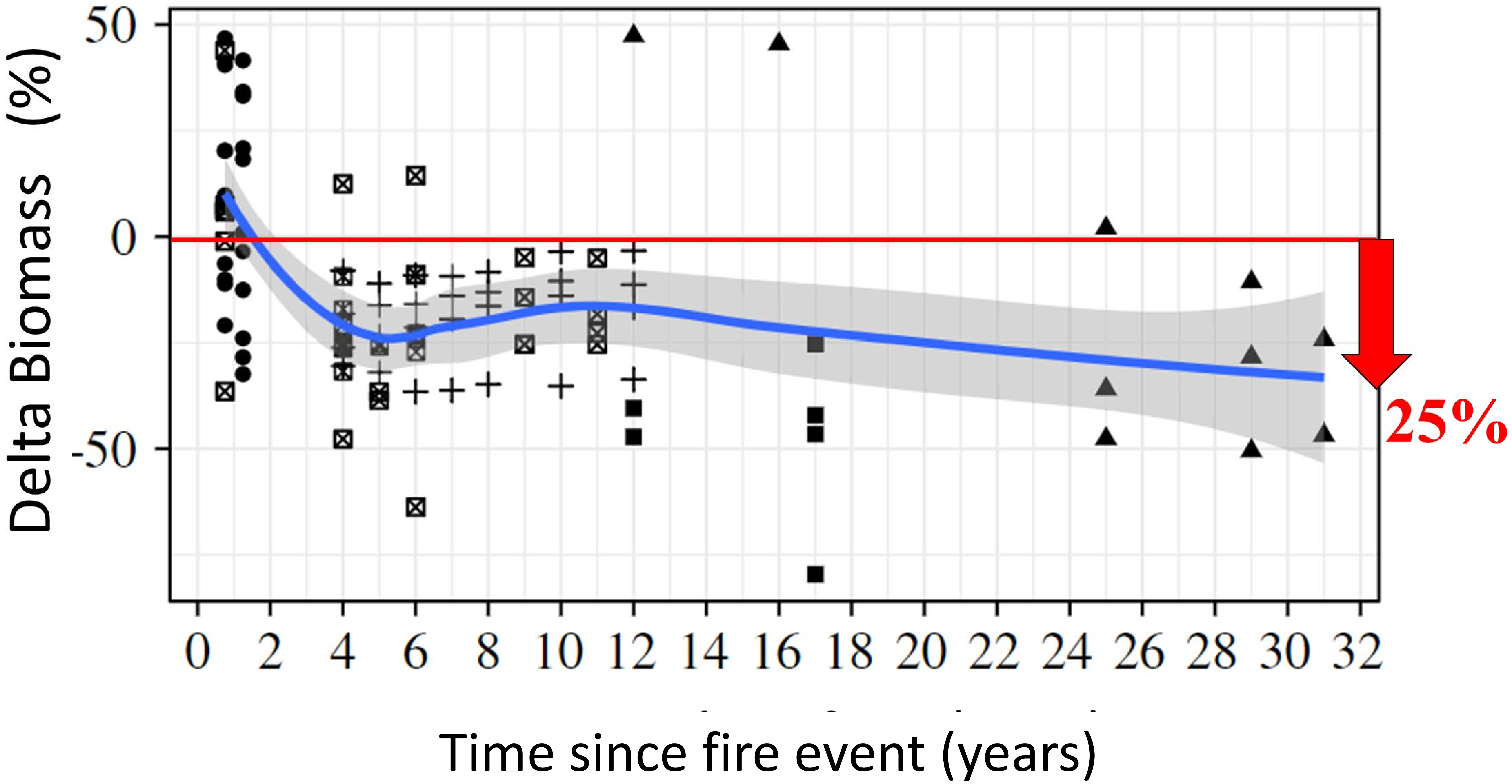
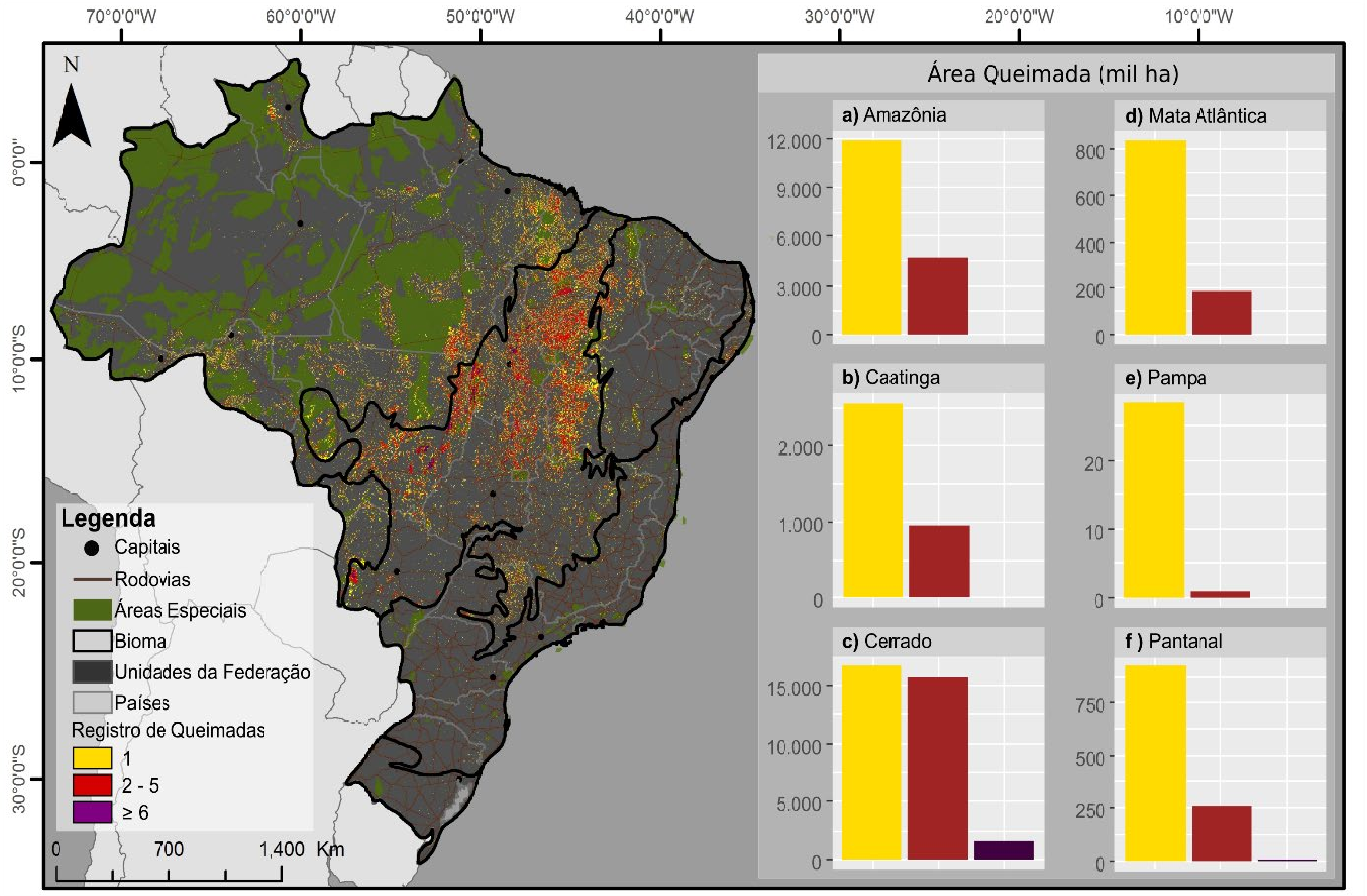
[2]National Institute for Space Research, Av. dos Astronautas, 1.758, São José dos Campos 12227-010 Brazi
[3]College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4RJ, UK
[4]Leicester Institute of Space and Earth Observation (LISEO), Centre for Landscape and Climate Research (CL School of Geography, Geology and Environment, University of Leicester, University Road, Leicester LE1 7RH,
[5]National Centre for Monitoring and Early Warning of Natural Disasters (CEMADEN), São Jose dos Campo São Paulo, 12247-016 Brazil
[6]Environmental Change Institute, University of Oxford, Oxford OX1 3QY, UK
[7]Universidade Federal do Acre (UFAC), Parque Zoobotanico, Rio Branco 69915-900, Acre, Brazil
[8]Woods Hole Research Center, 149 Woods Hole Road, Falmouth, MA 02540-1644, USA



Forests affected by fire have biomass levels 24.8+6.9% below the biomass value of unburned control plots after 31 years.



Accounting for forest fires at large-scale



Queimadas e Incêncios florestais. Campanharo,.., Aragão et al. 2021. Capítulo 8 - Padrões e impactos dos incêndios florestais nos biomas brasileiros

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Defining deforestation and degradation types from the satellite perspective

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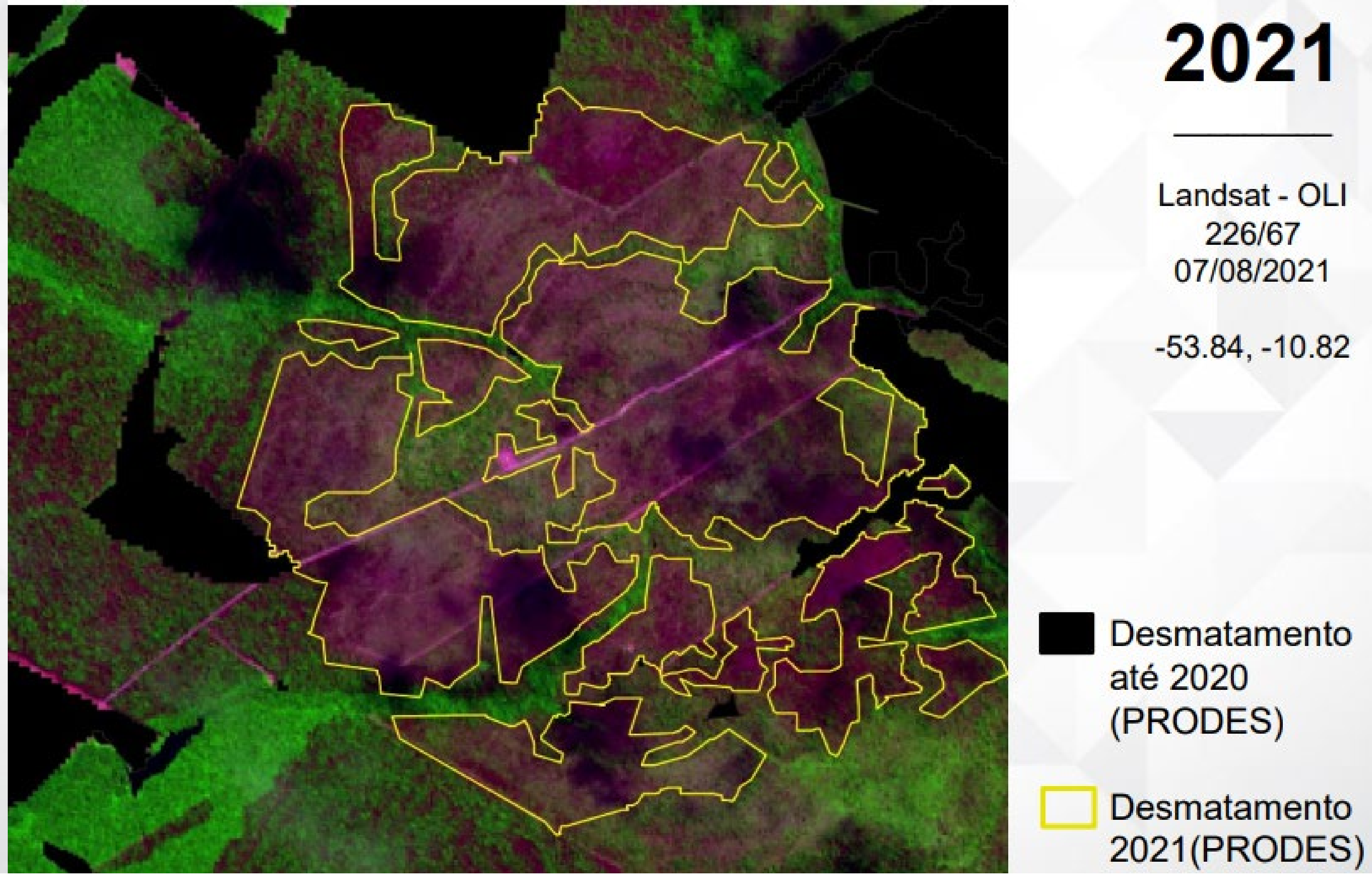
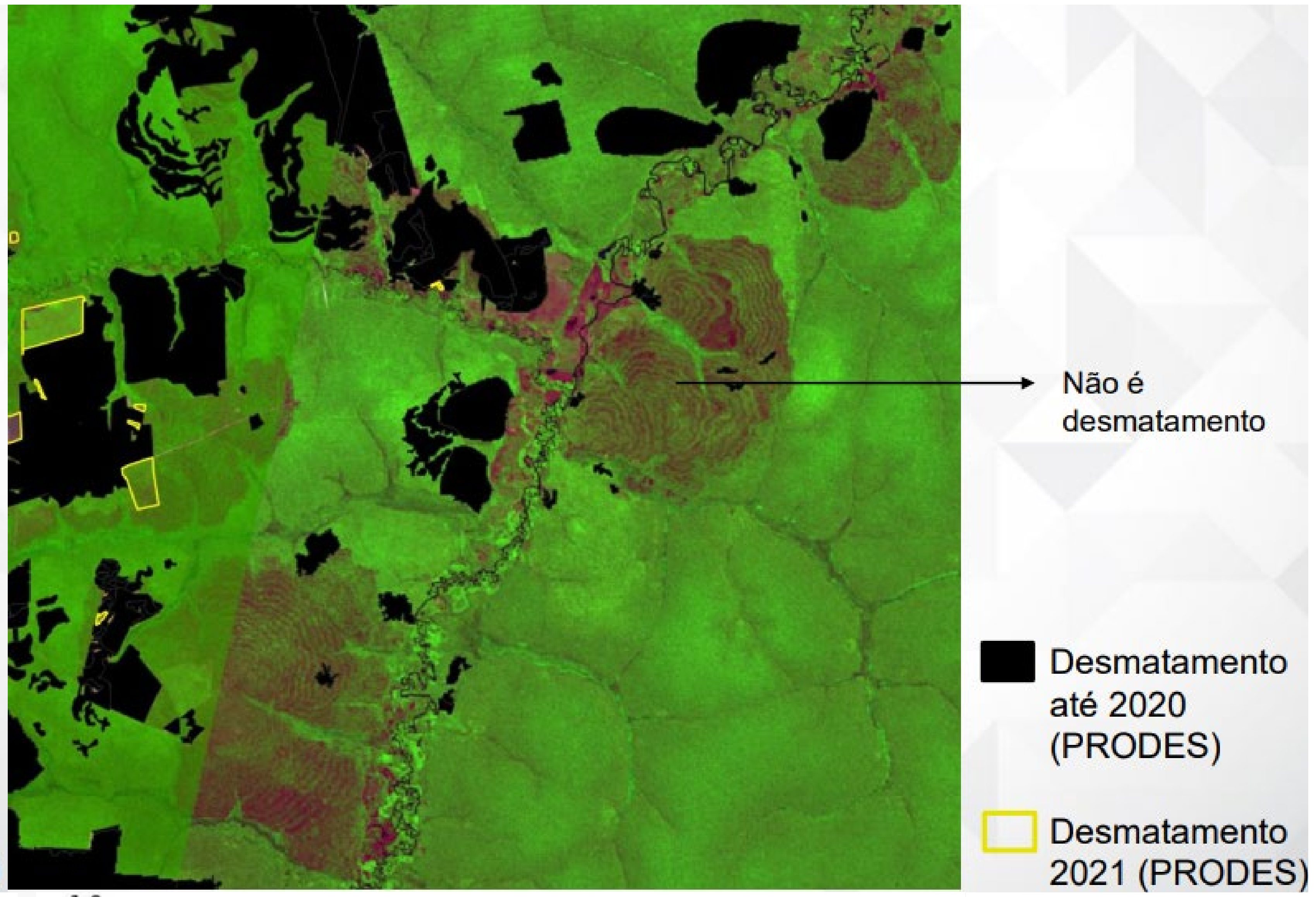
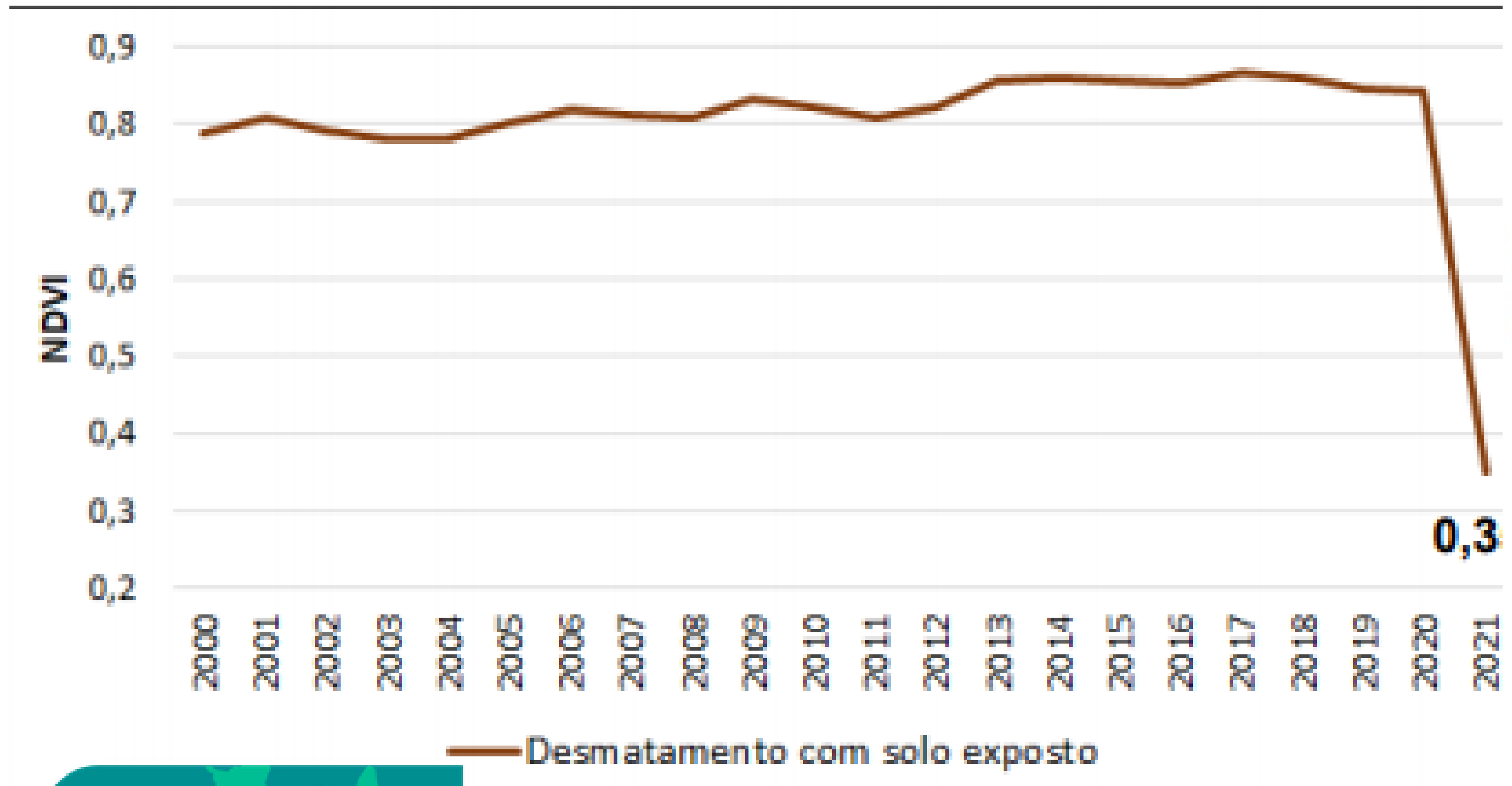
Clear-cut deforestation

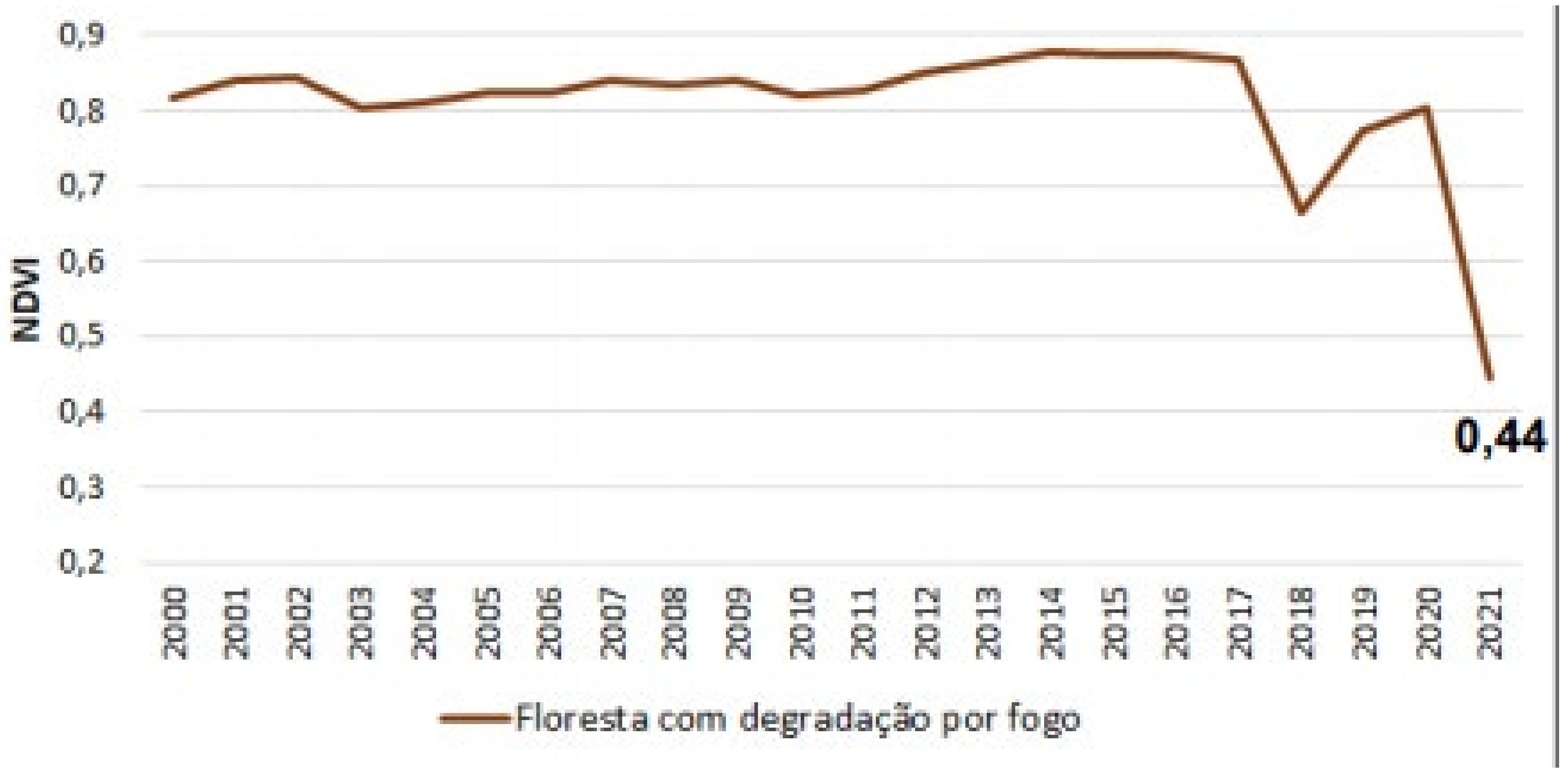
Deforestation by successive degradation

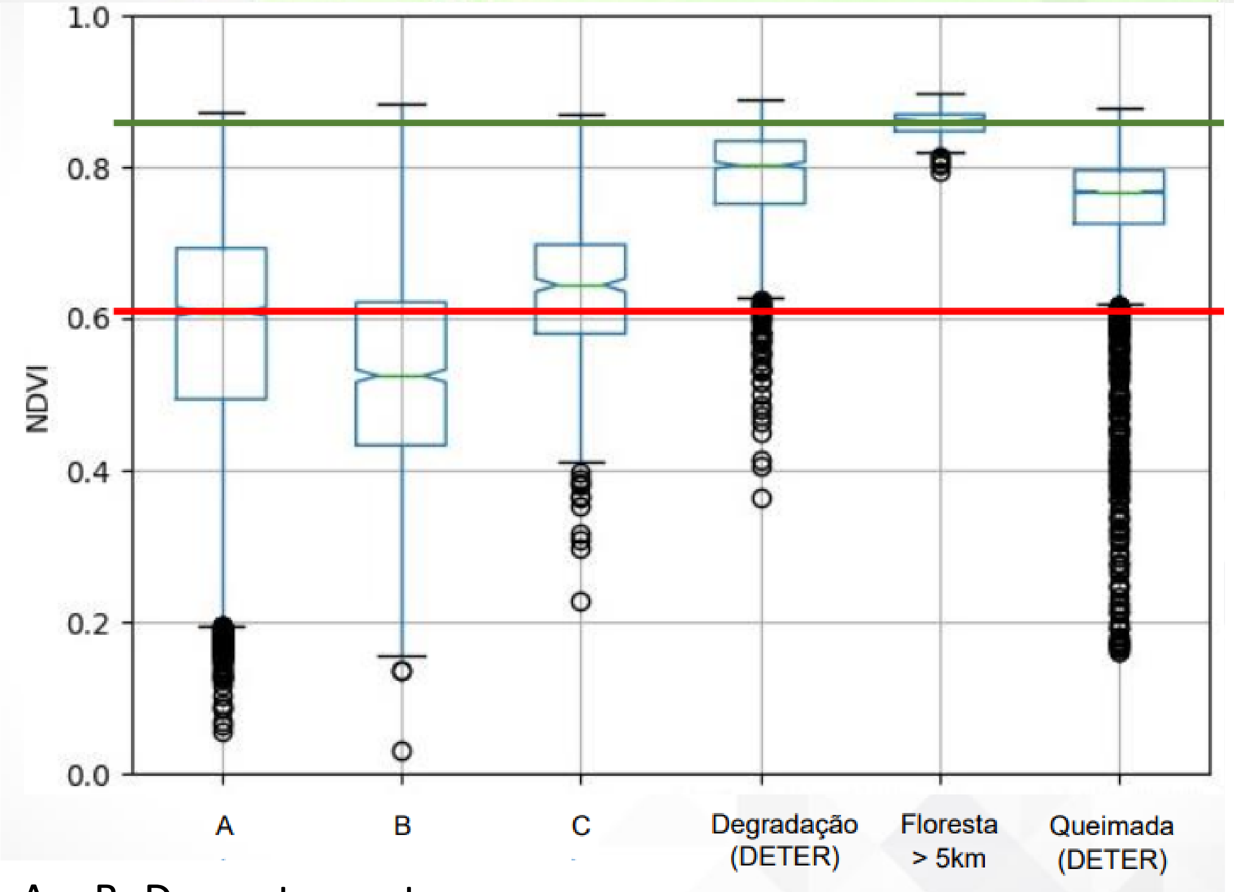


Fire degradation









A e B: Desmatamento

C: Desmatamento por degradação sucessiva não é degradação é desmatamento

PRODES

Forest fires committed carbon emissions increases with drought

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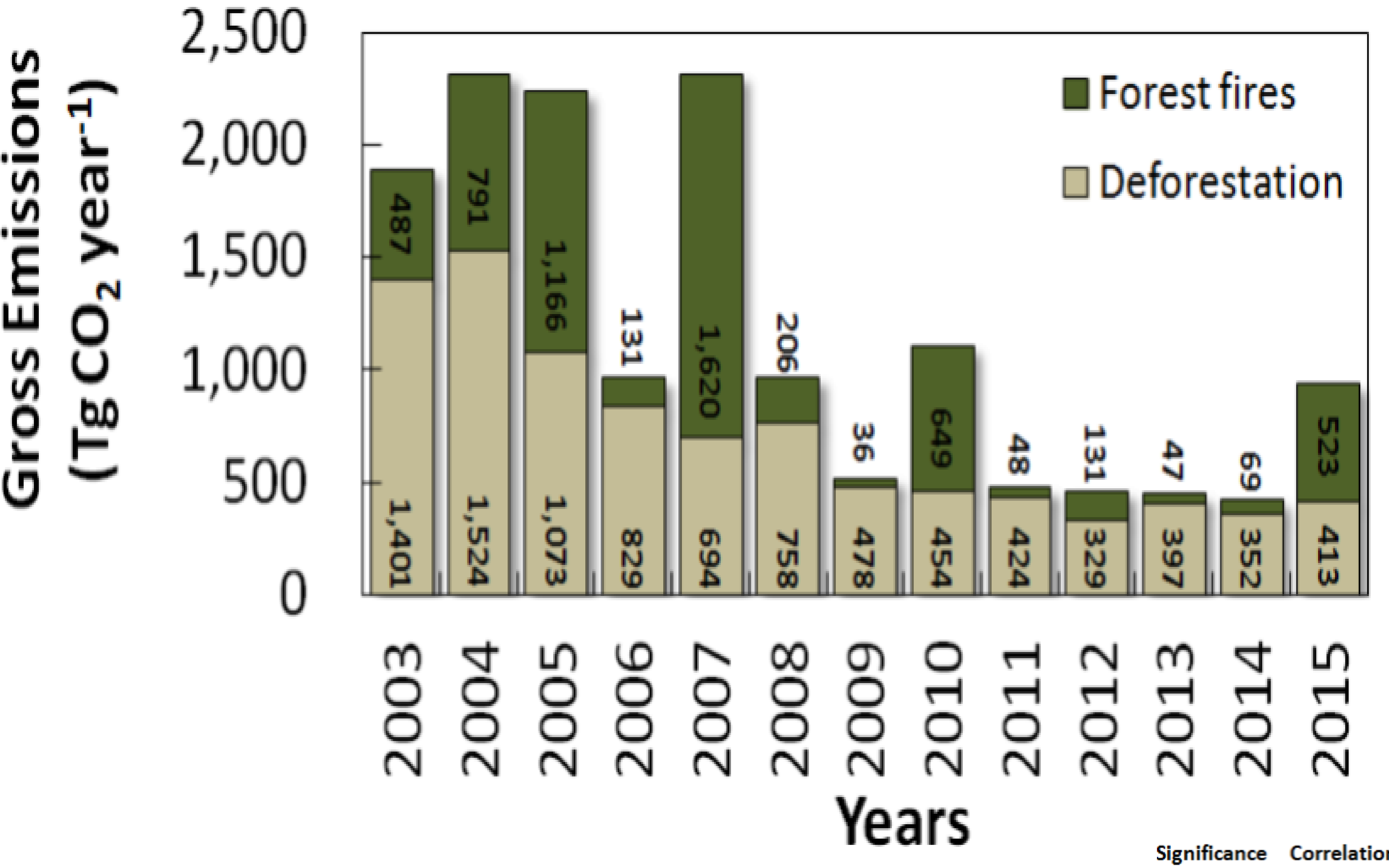
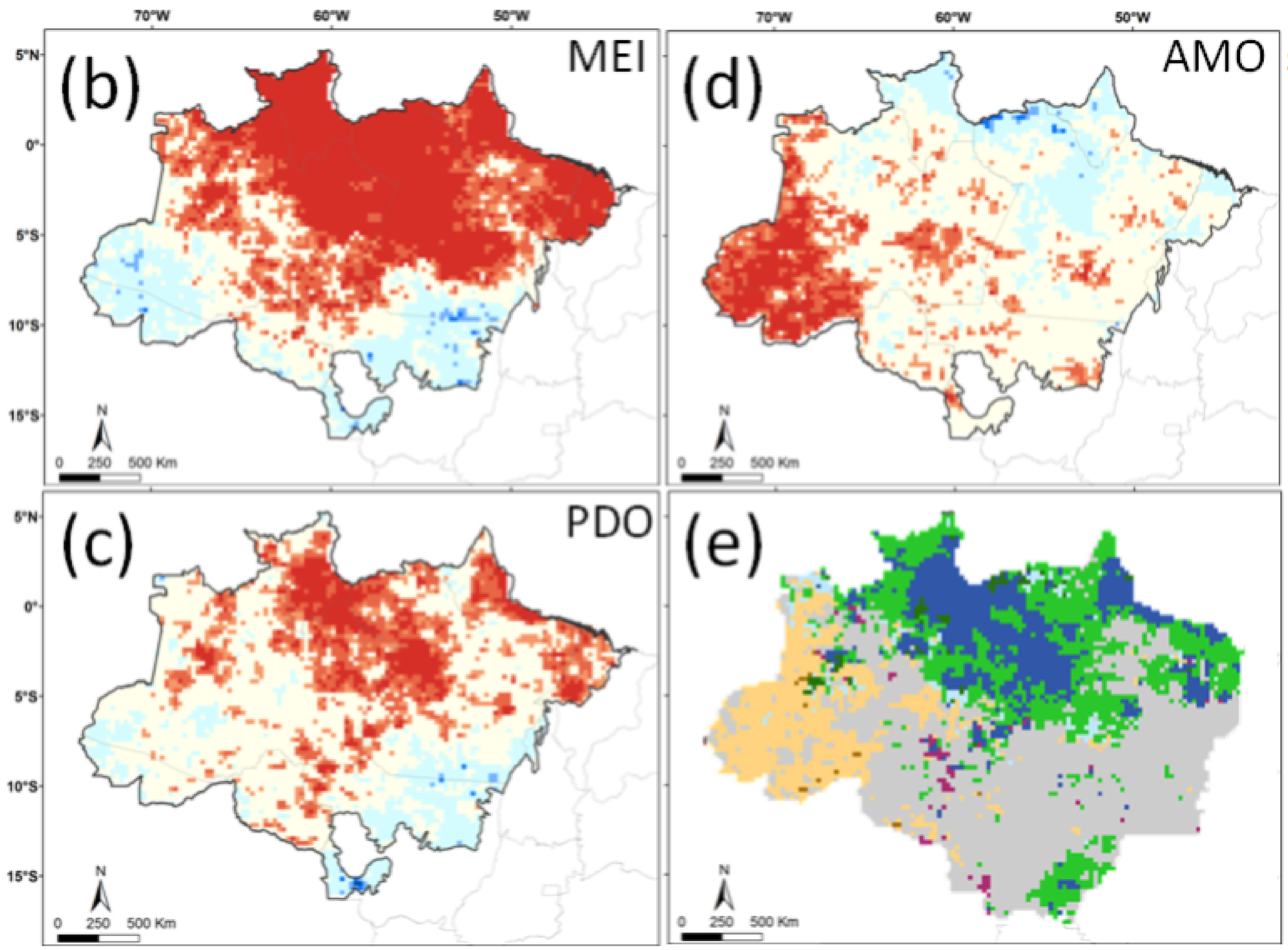
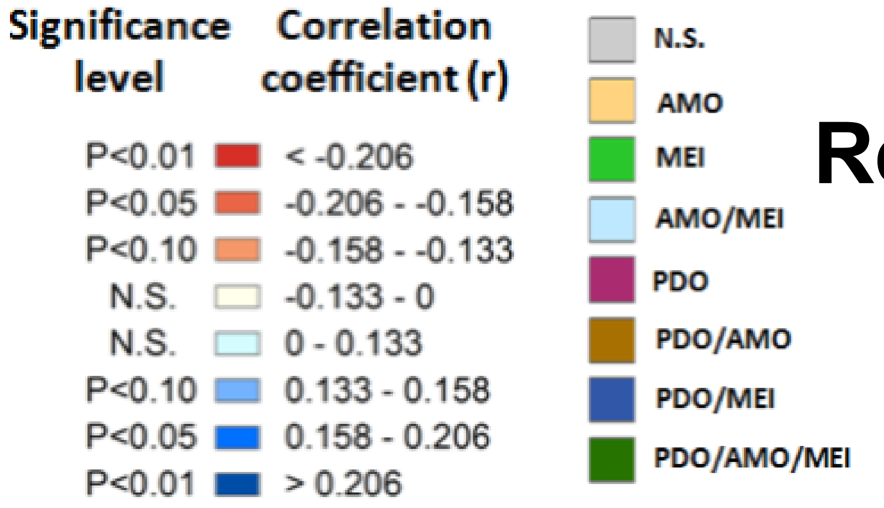
Forest fires contribute, on average, 31±21% of gross emissions from deforestation. These fire emissions exceed 50% during dry years (2005, 2007, 2010 and 2015)



Drought footprint (rainfall anomalies x SST pixel-based correlation)





Passive-microwave rainfall data - IMERG Research-level product (intercalibrated TRMM-GPM data)

Aragão et al. *Nature Communications* (2018)

Human-related drivers of fires in the Amazon

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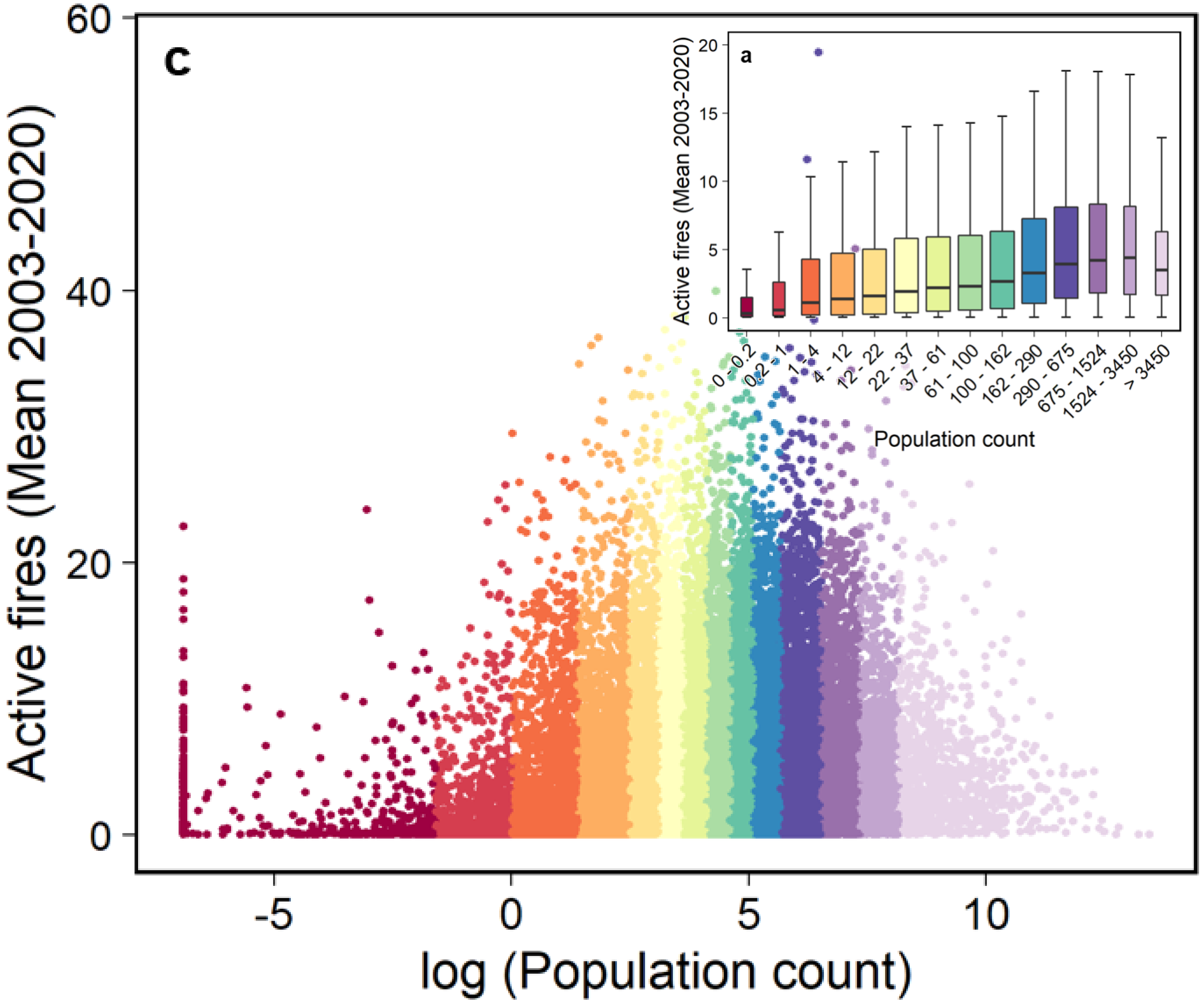
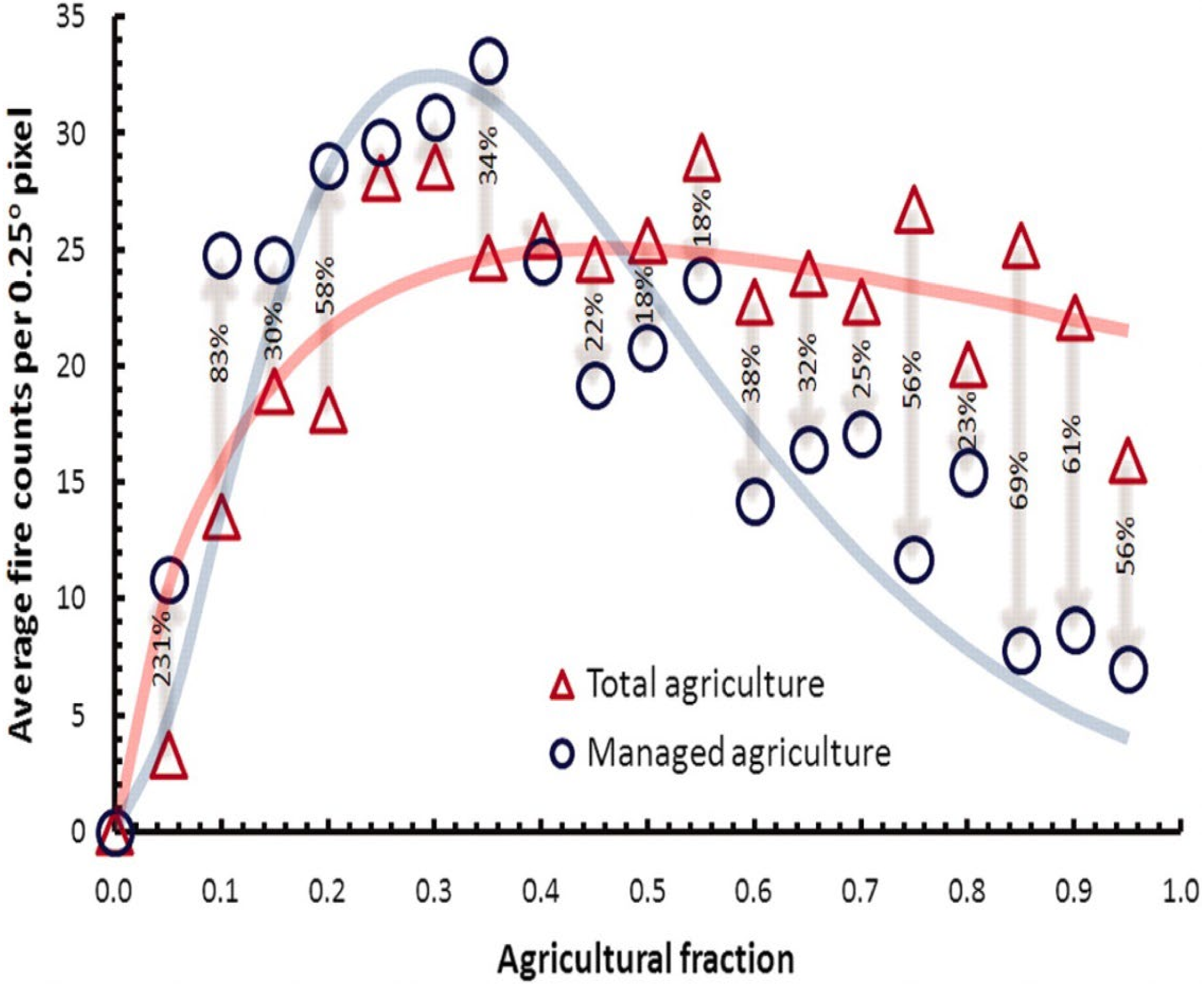
Population density defines maximum fire potential



Pessoa A. C. PhD Thesis (2022)

Agricultural technification reduces the incidence of fire

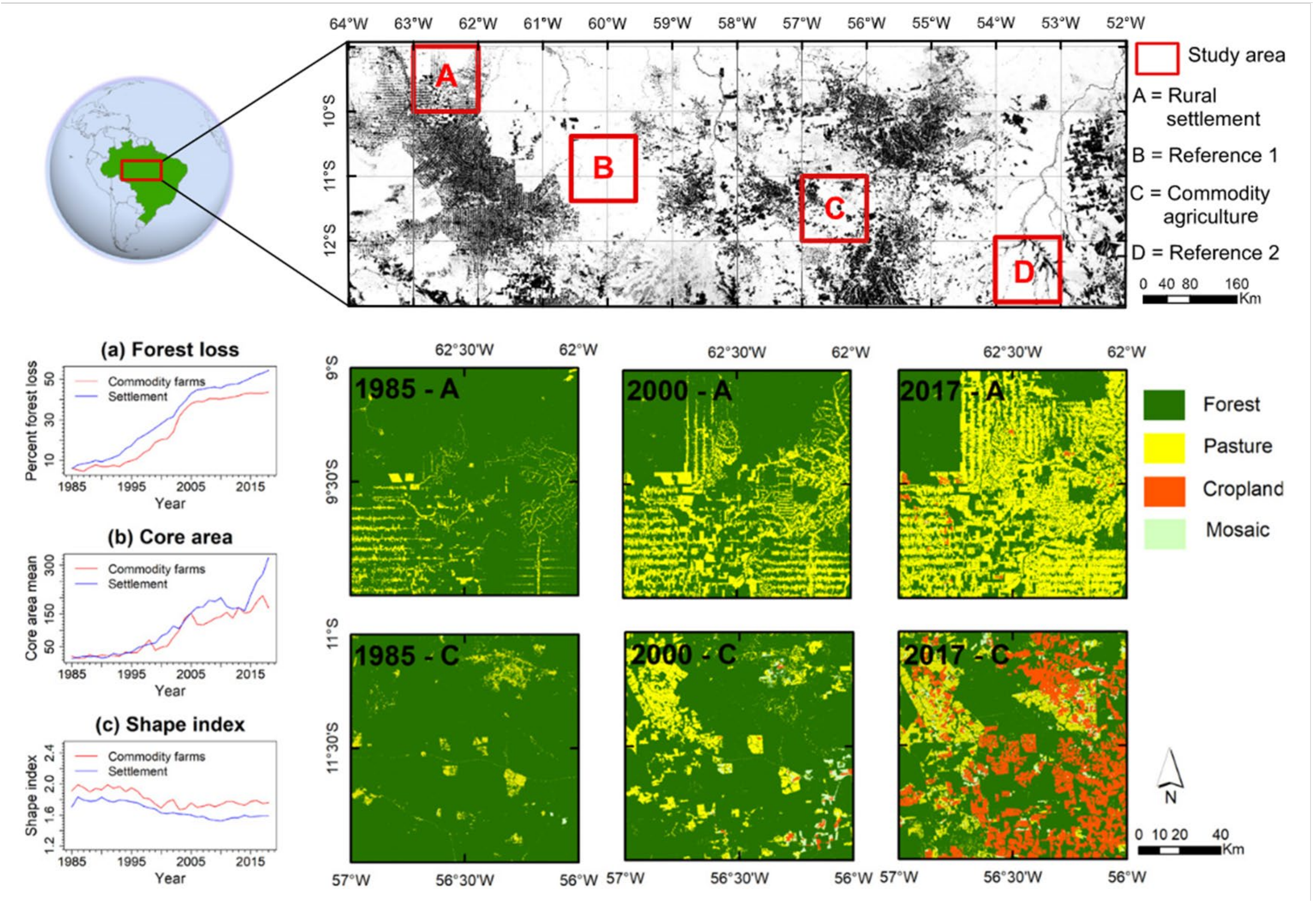


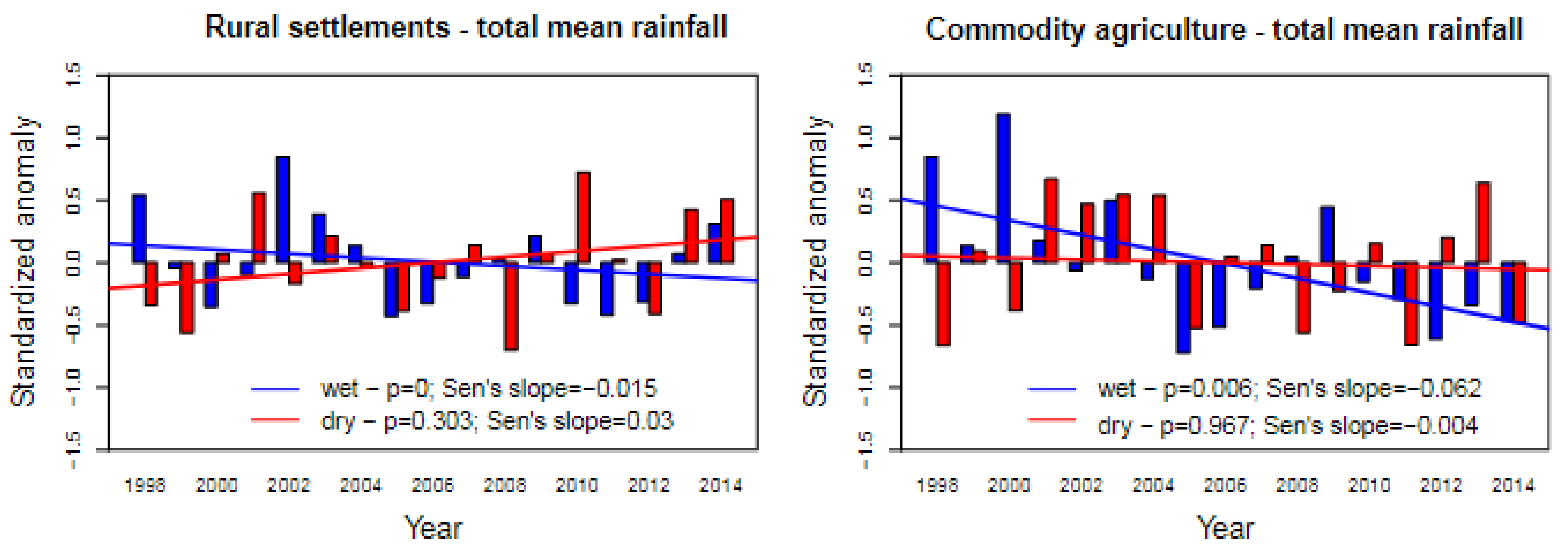
Aragão & Shimabukuro. Science (2010)

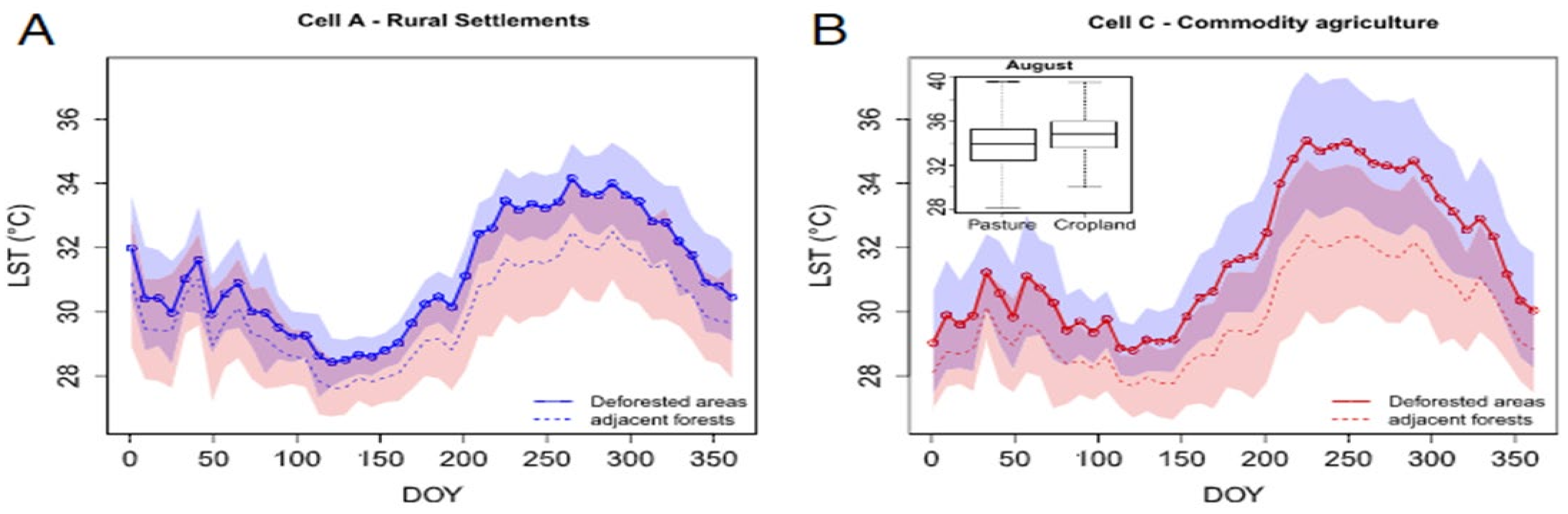
Local climate responds differently to distinct landscape configurations and land uses

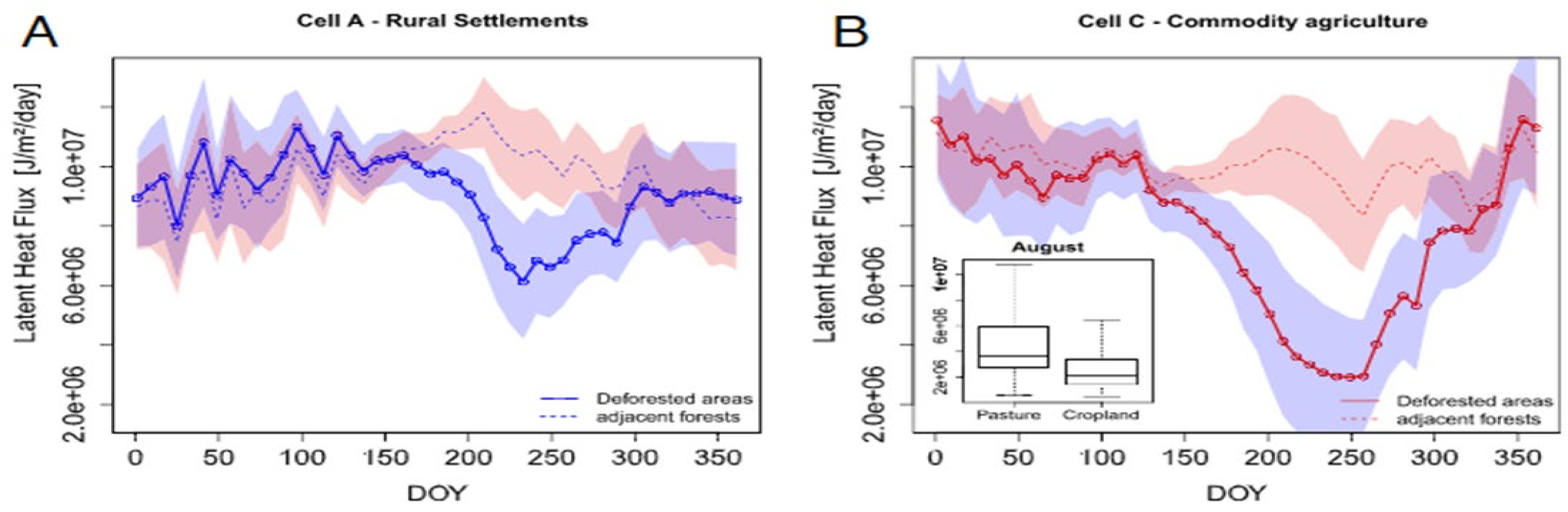
Large-scale commodity agriculture exacerbates the climatic impacts of Amazonian deforestation

Eduardo Eiji Maeda[a,1], Temesgen Alemayehu Abera[a,b], Mika Siljander[a], Luiz E. O. C. Aragão[c,d], Yhasmin Mendes de Moura[e], and Janne Heiskanen[a,b]









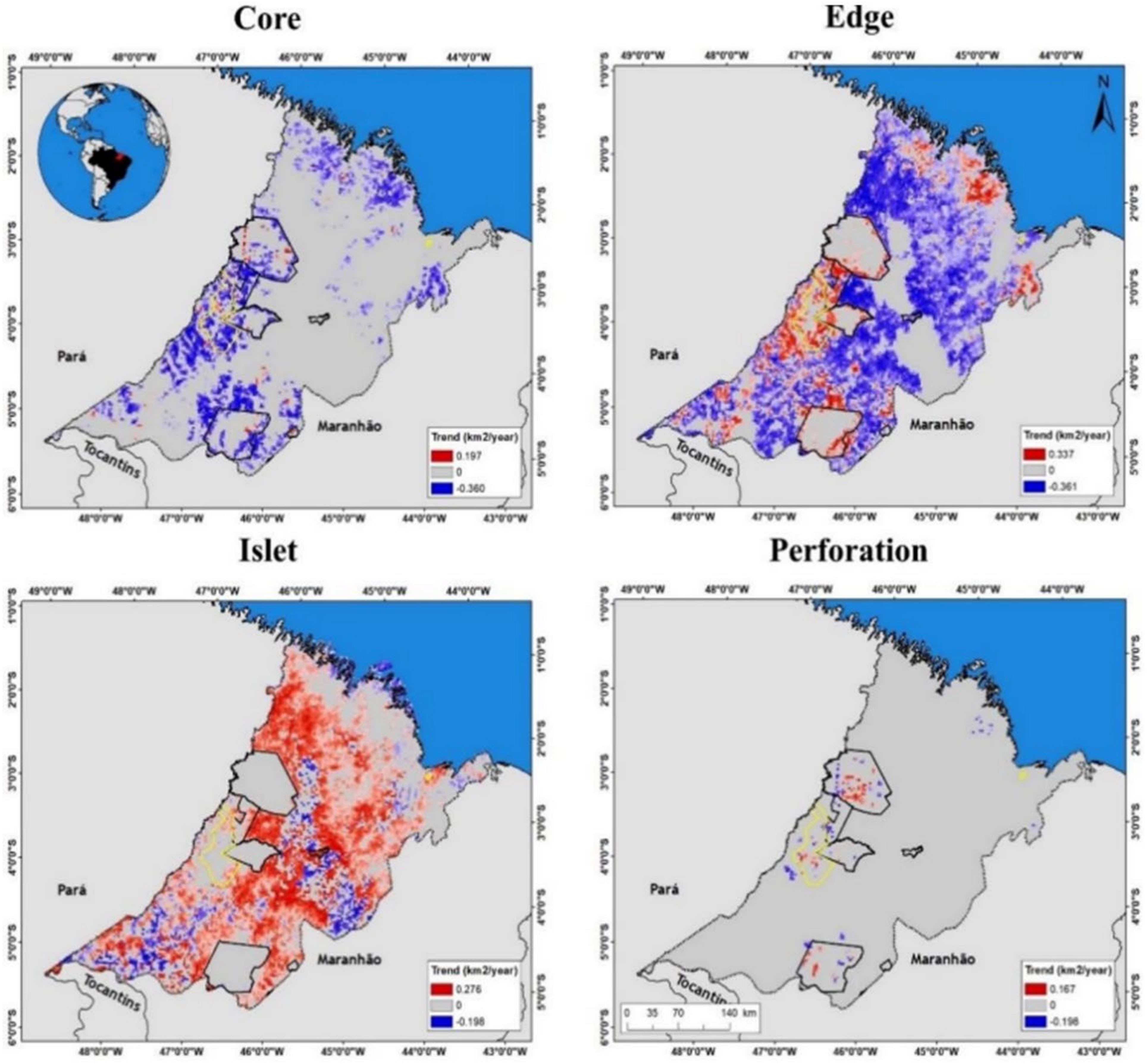
Maeda,..., Aragão et al. (2020) PNAS

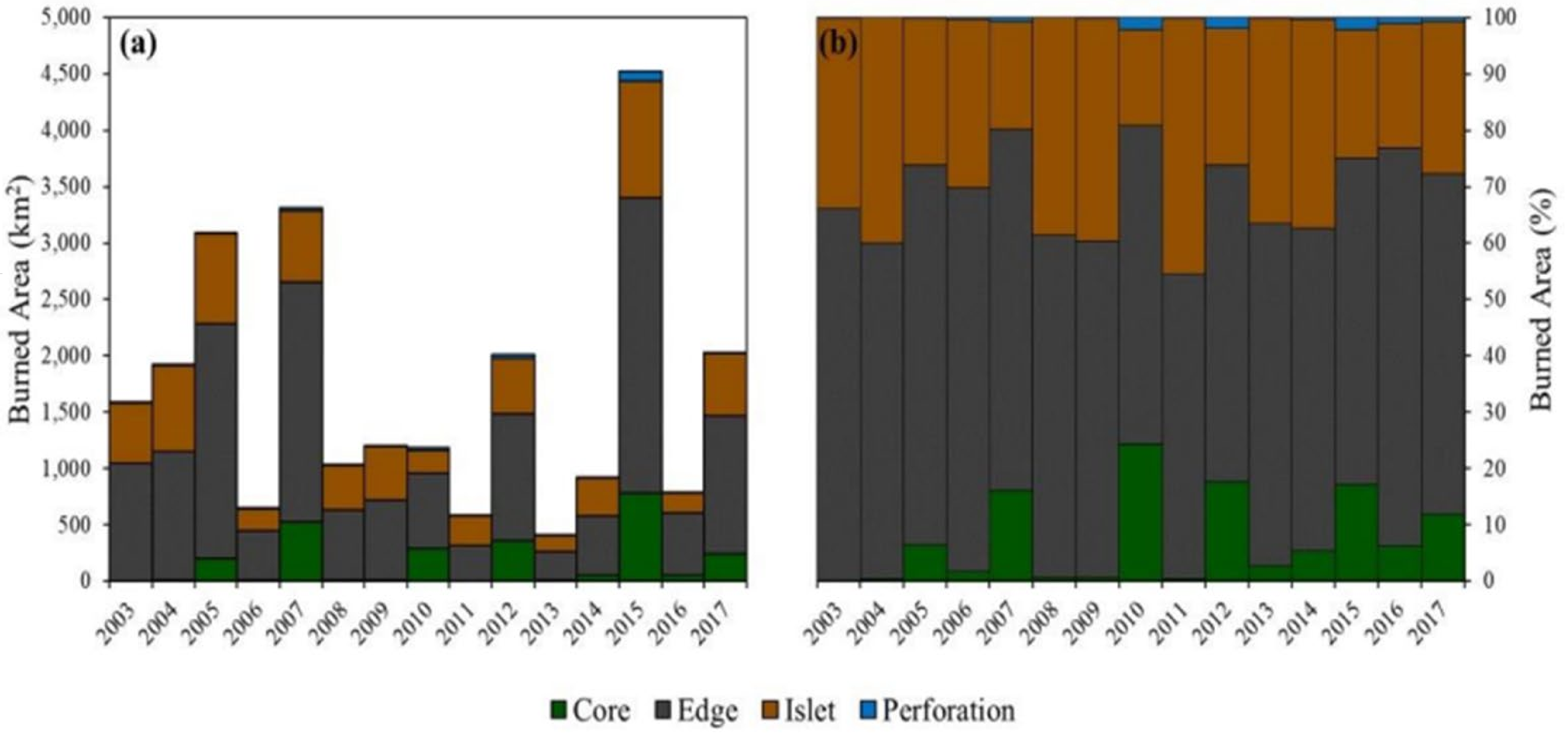
Climate and fragmentation exacerbates fire occurrence in Amazonia

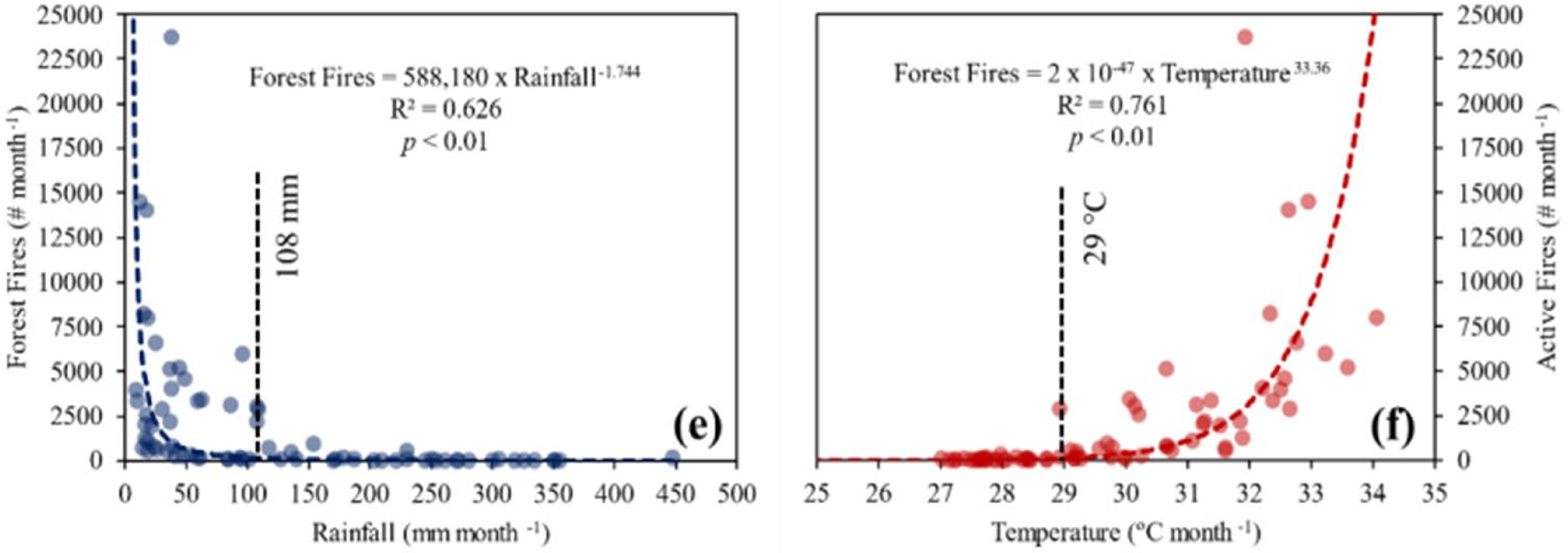
Article

Forest Fragmentation and Fires in the Eastern Brazilian Amazon–Maranhão State, Brazil

Celso H. L. Silva-Junior [1,2,3,*,†], Arisson T. M. Buna [4,†], Denilson S. Bezerra [5,†], Ozeas S. Costa, Jr. [6], Adriano L. Santos [5], Lidielze O. D. Basson [5], André L. S. Santos [7], Swanni T. Alvarado [3], Catherine T. Almeida [8], Ana T. G. Freire [5], Guillaume X. Rousseau [3], Danielle Celentano [3,9], Fabricio B. Silva [4], Maria S. S. Pinheiro [5], Silvana Amaral [10], Milton Kampel [10], Laura B. Vedovato [11], Liana O. Anderson [12] and Luiz E. O. C. Aragão [10,11]







Silva-Junior,..., Aragão et al. (2022) Fire

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Drivers of fires in the Amazon

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Landscape configuration leads to opposite trends in fire impact in Amazonia end Cerrado biomes

frontiers in Forests and Global Change | Tropical Forests

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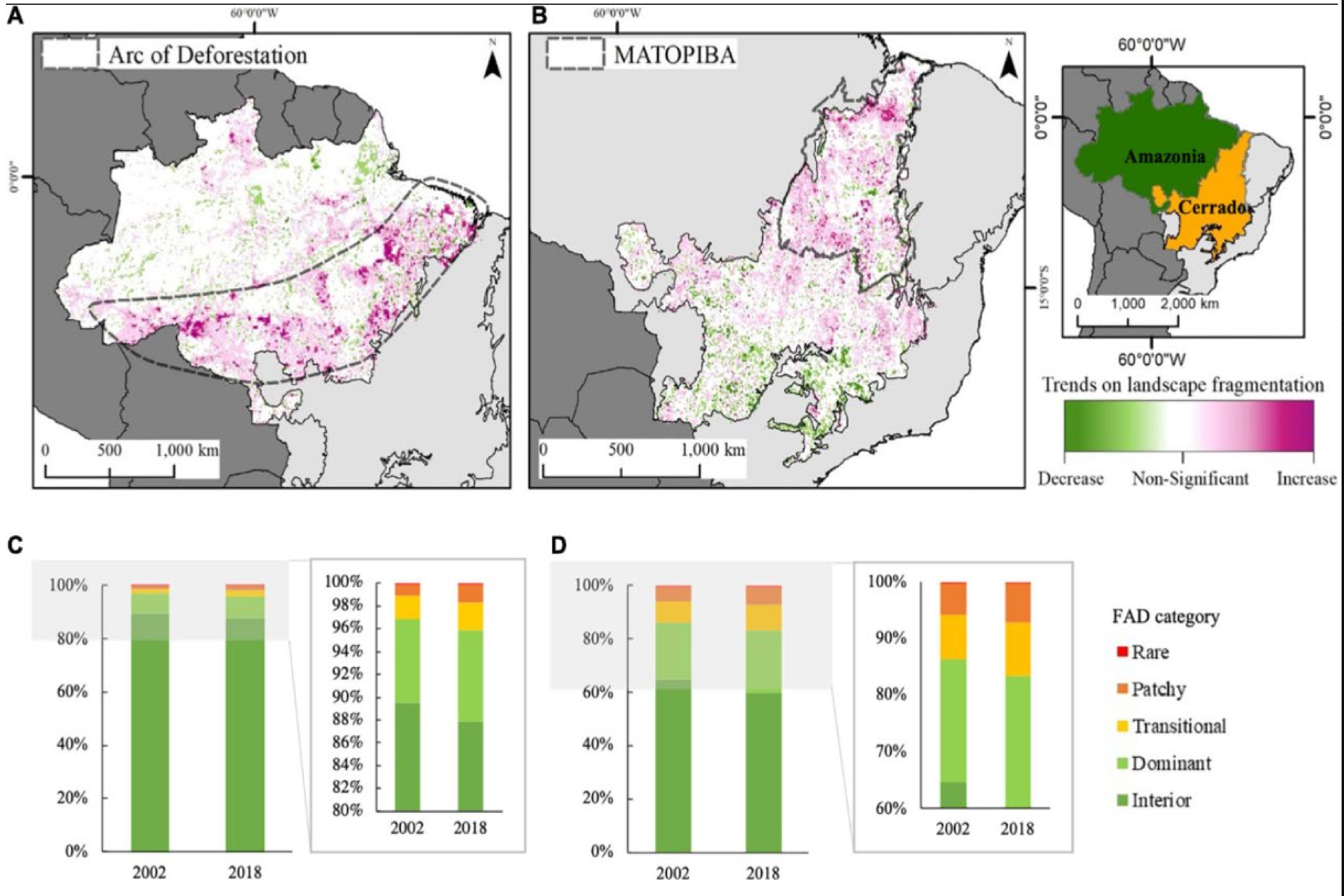
Transformation of Tropical Forests Through Fire View all 5 Articles ›

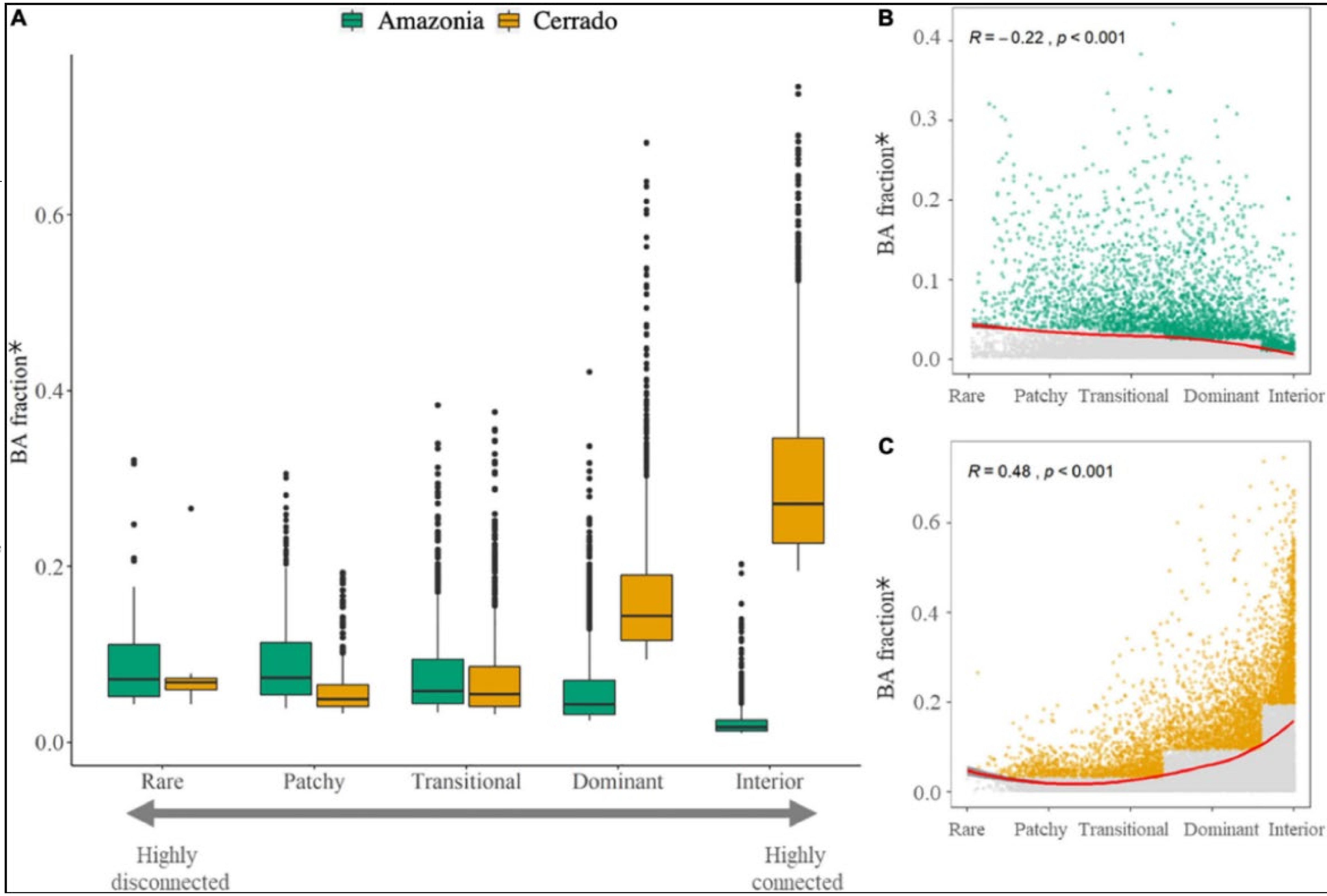
ORIGINAL RESEARCH article
Front. For. Glob. Change, 24 February 2022 | https://doi.org/10.3389/ffgc.2022.801408

Check for updates

Fragmentation-Driven Divergent Trends in Burned Area in Amazonia and Cerrado

Thais M. Rosan[1*], Stephen Sitch[1], Lina M. Mercado[1,2], Viola Heinrich[3], Pierre Friedlingstein[4,5] and Luiz E. O. C. Aragão[1,6]



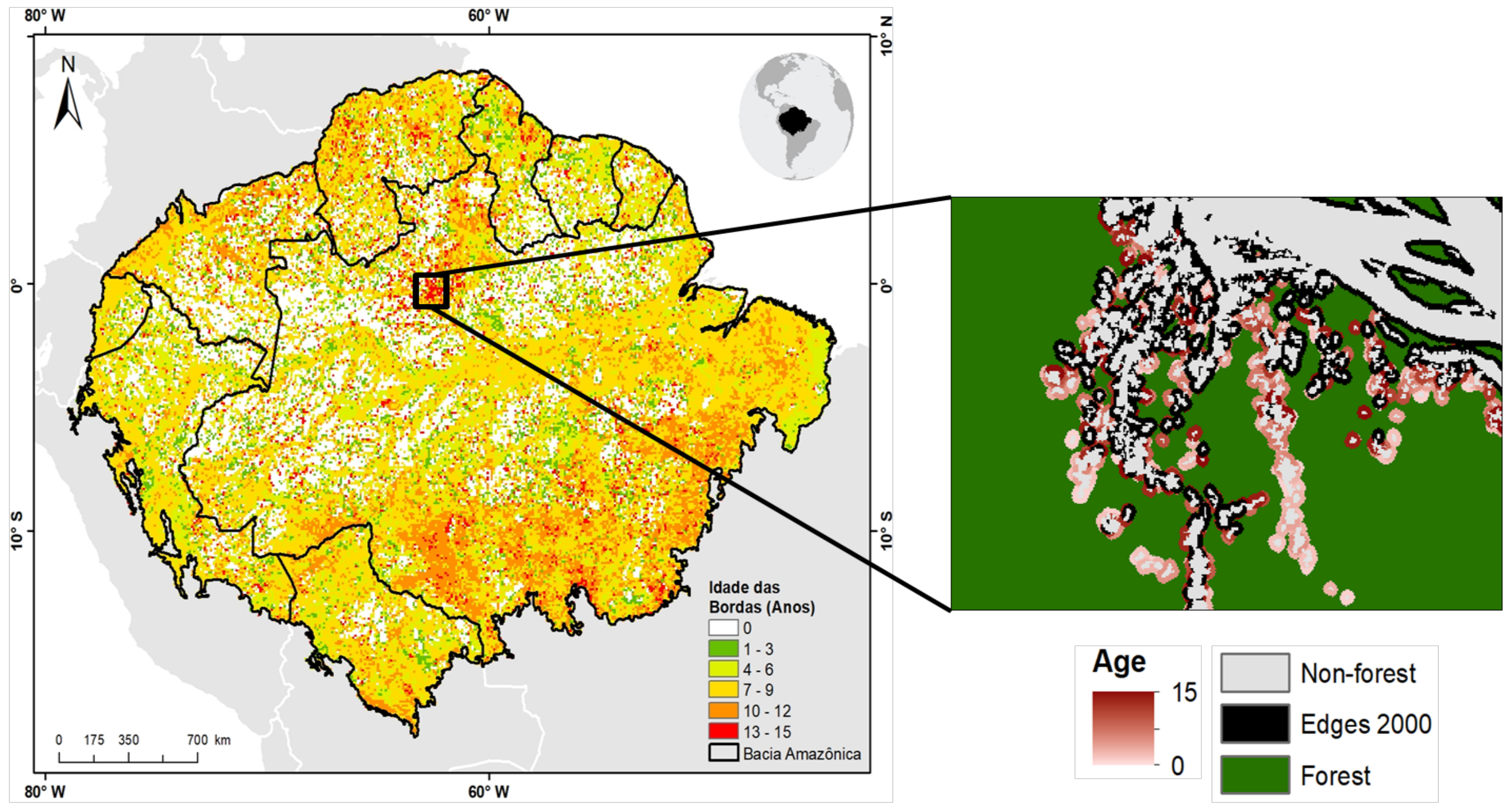


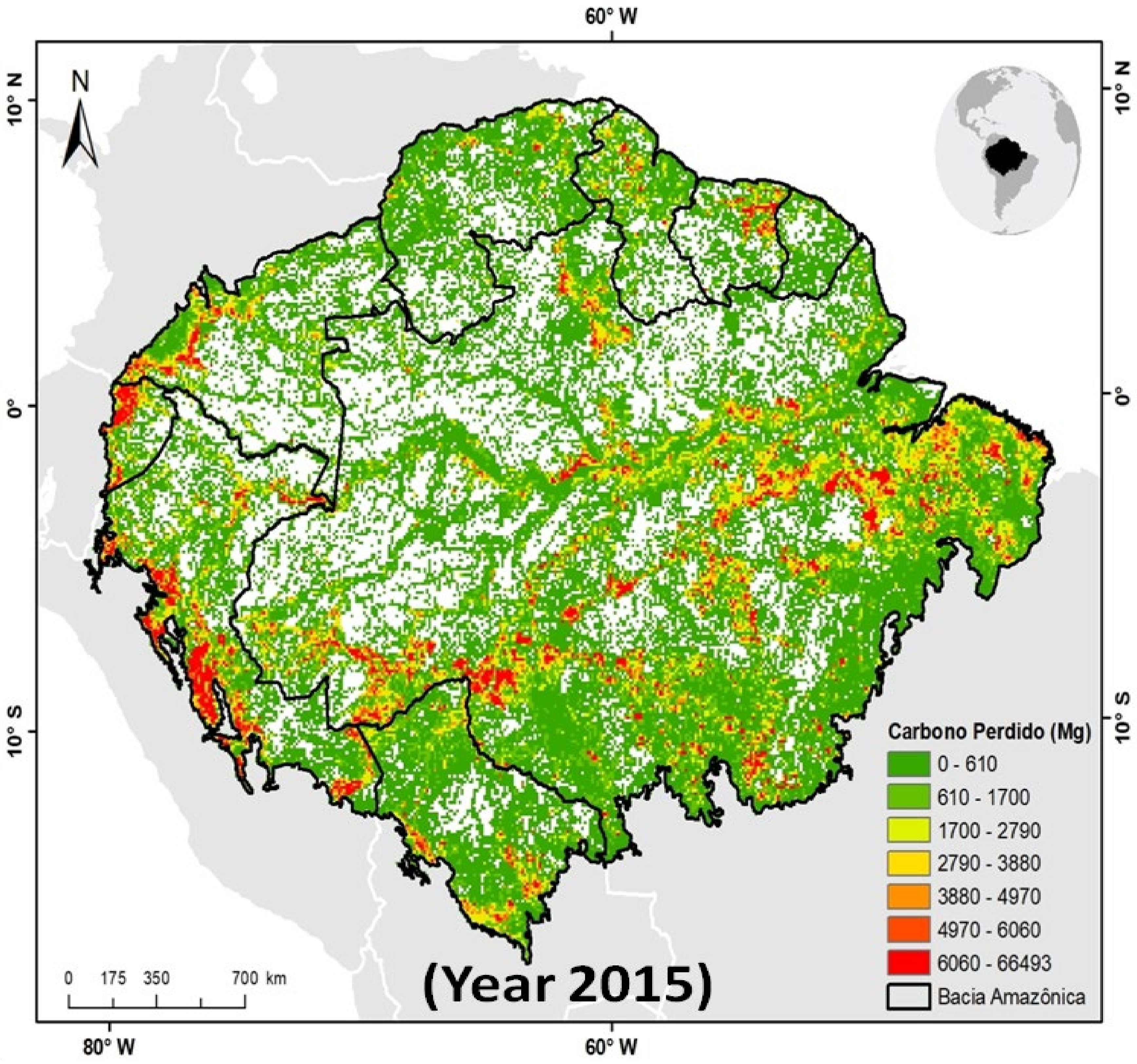
Indirect deforestation effect

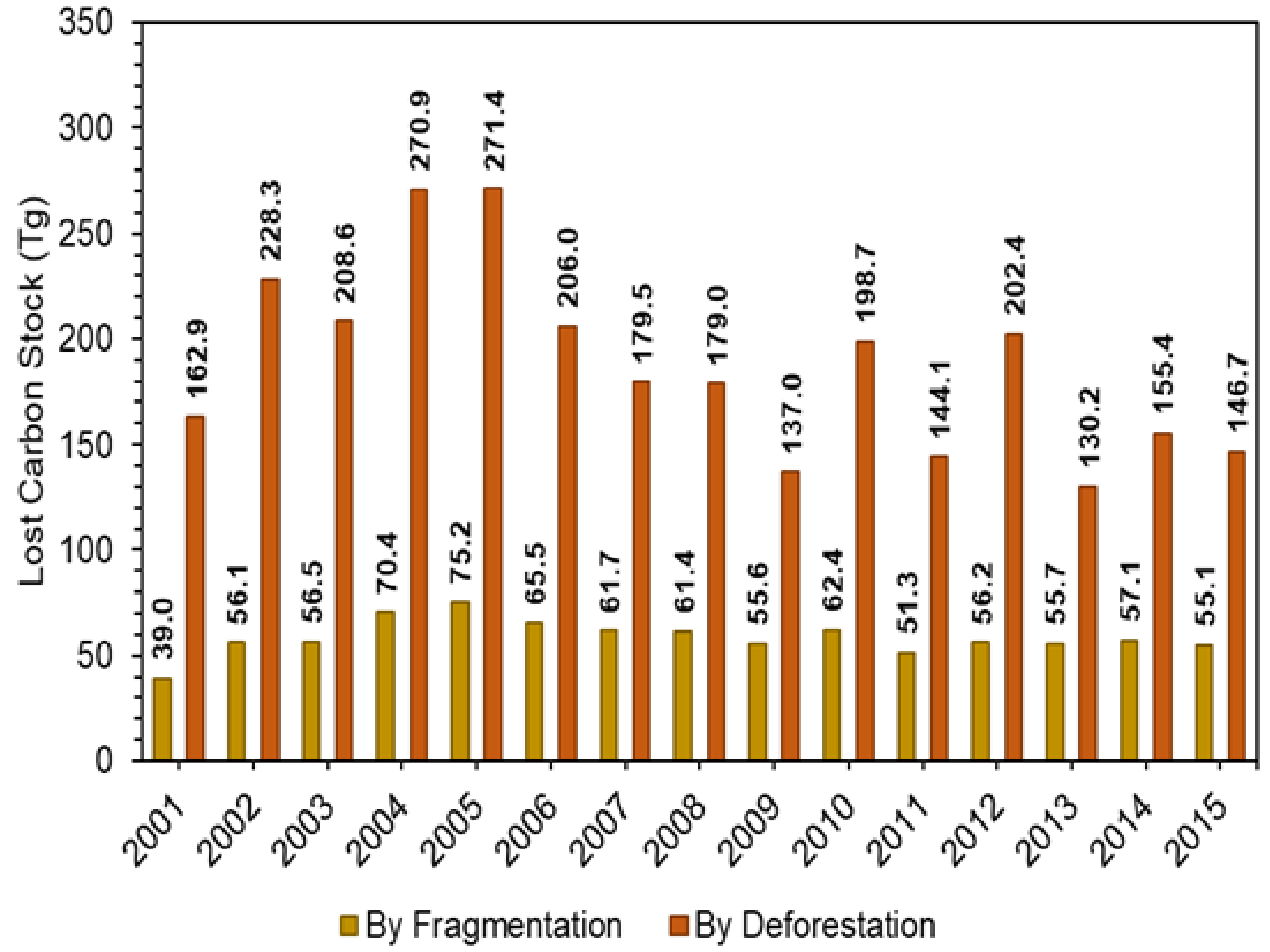
Forest edge degradation

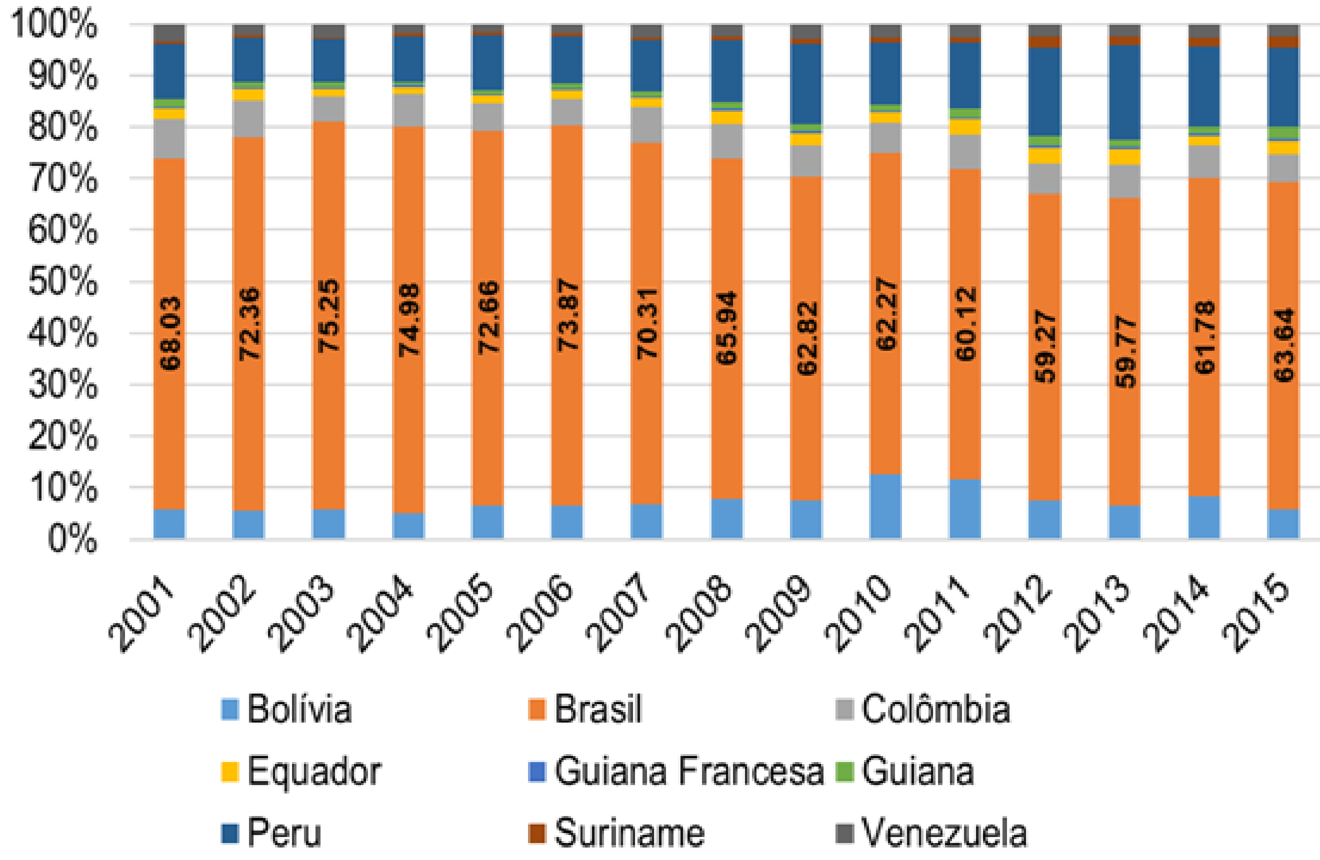
Responsible for about 37% of gross committed emissions from deforestation

(Morphological Spatial Pattern Analysis)



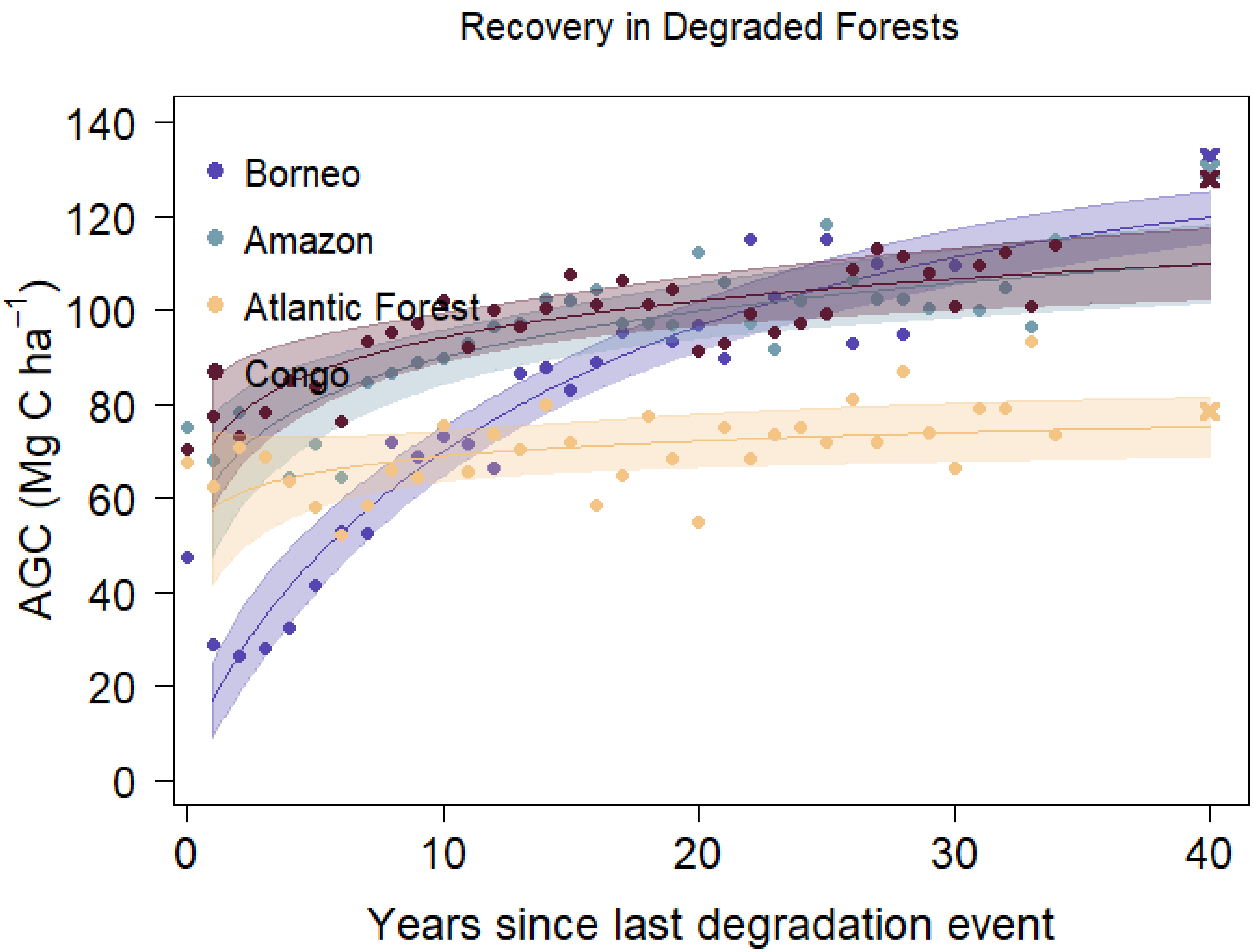






Silva-Junior, Aragão et al. *Science Advances* (2020)

Recovery of degraded forests



Mg C ha^{-1} $year^{-1}$

	Degraded
Borneo	4.3 (91)
Amazon	2.18 (154)
Atlantic	0.86 (59)
Congo	1.79 (149)

Heinrich et al. In preparation

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The secondary forest carbon sink

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SCIENTIFIC DATA

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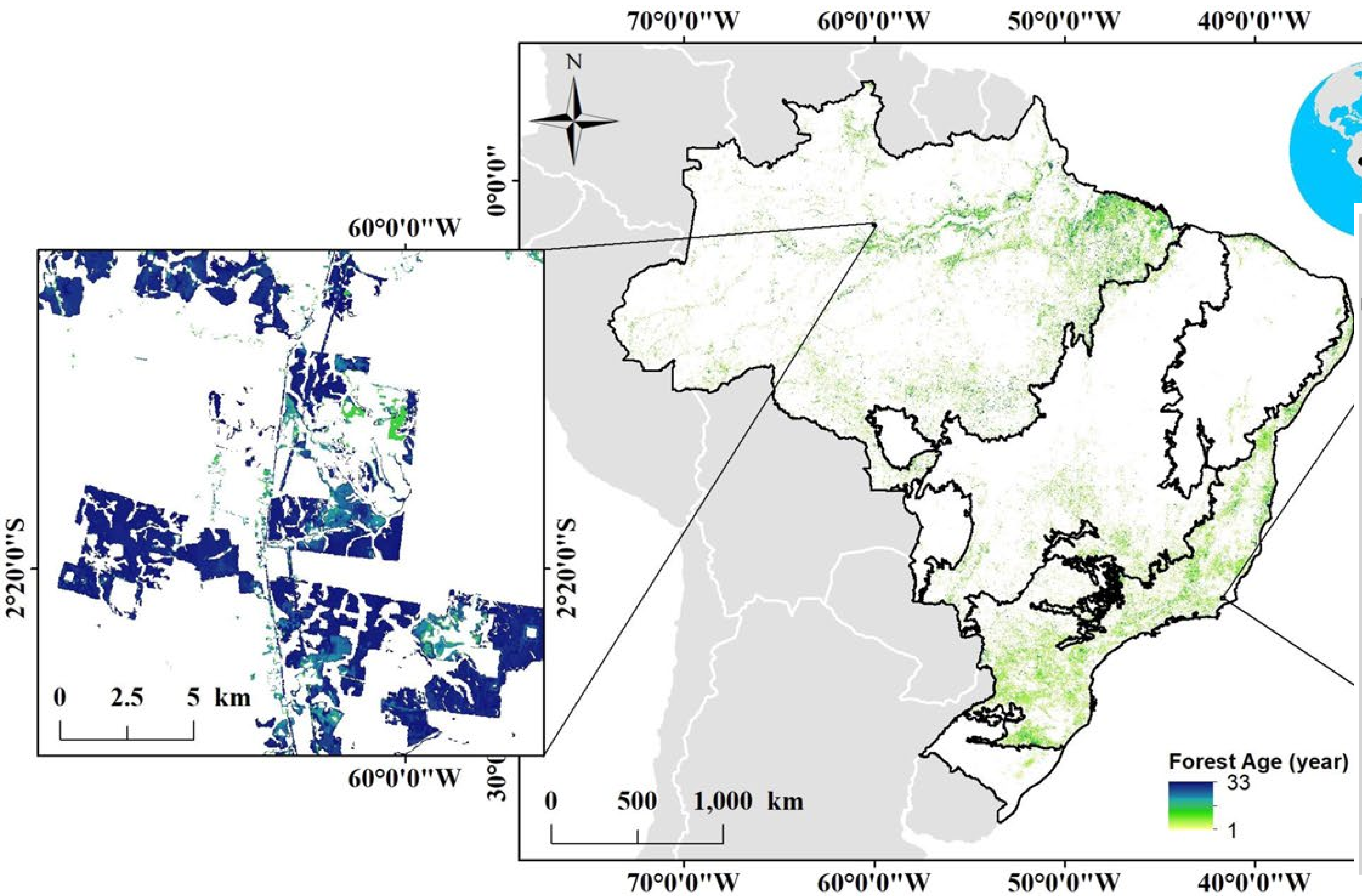
OPEN
DATA DESCRIPTOR

Benchmark maps of 33 years of secondary forest age for Brazil

Celso H. L. Silva Junior[1,2,11], Viola H. A. Heinrich[3,11], Ana T. G. Freire[4], Igor S. Broggio[1,5], Thais M. Rosan[6], Juan Doblas[2], Liana O. Anderson[1,7], Guillaume X. Rousseau[8], Yosio E. Shimabukuro[2], Carlos A. Silva[9,10], Joanna I. House[3] & Luiz E. O. C. Aragão[1,2,6]

- Stand secondary forests in Brazil by 2018 were responsible for an uptake of **835 Tg C** during the 33 years analyze, assuming the neotropical average uptake (3.05Mg C ha^{-1} yr^{-1}), offseting only 12% of carbon emissions from deforestation in the Brazilian Amazon alone (6,740 Tg C).



Biome	Net Uptake (Tg C)	Net Uptake (%)
Amazon	436 ± 26.84	52.21
Atlantic Forest	260 ± 15.98	31.08
Caatinga	17 ± 1.03	2.01
Cerrado	111 ± 6.83	13.29
Pampa	8 ± 0.52	1.00
Pantanal	3 ± 0.21	0.42
Brazil	835 ± 51.40	100

Impact of disturbances on the secondary forest carbon sink

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nature COMMUNICATIONS

ARTICLE

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Large carbon sink potential of secondary forests in the Brazilian Amazon to mitigate climate change

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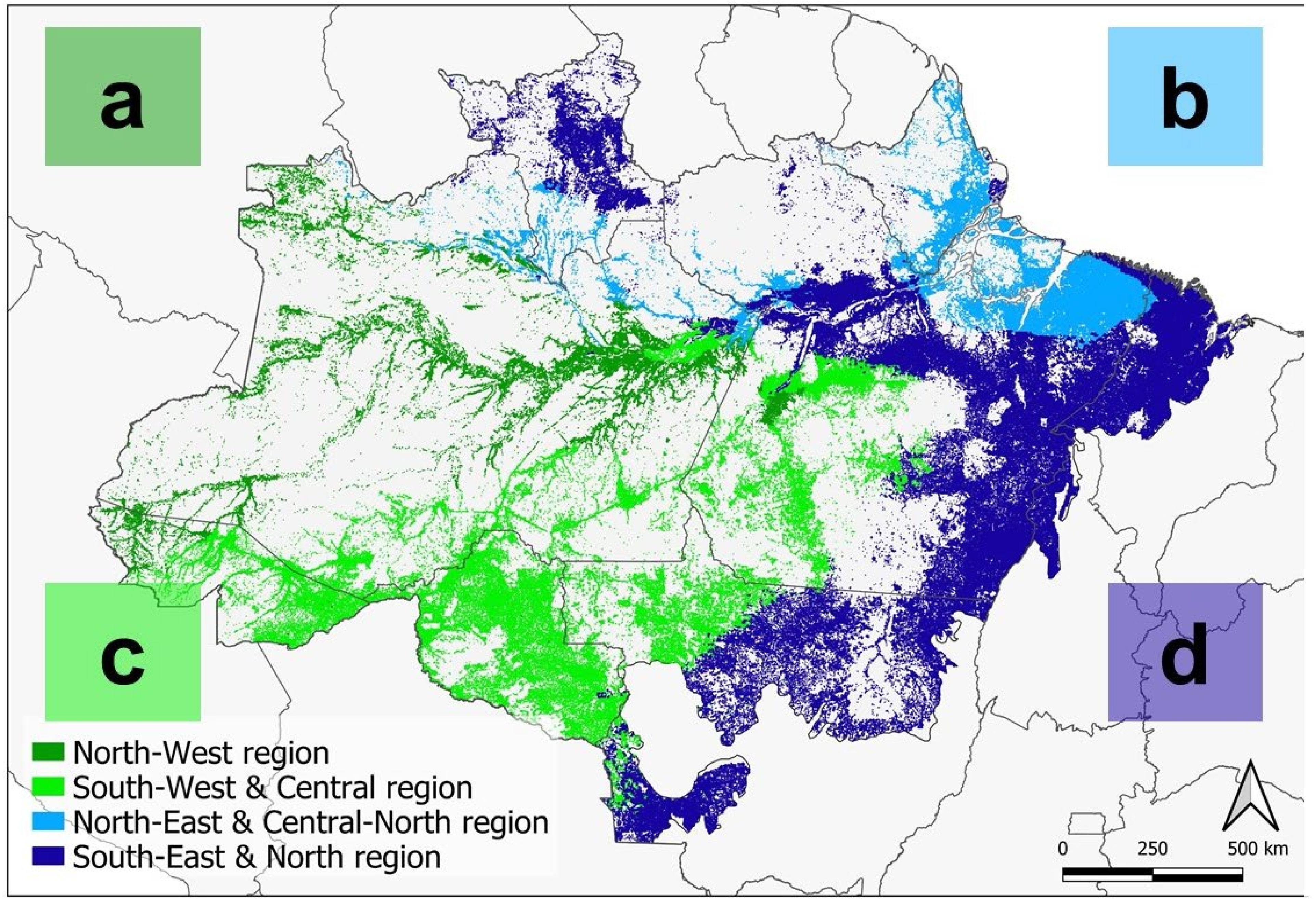
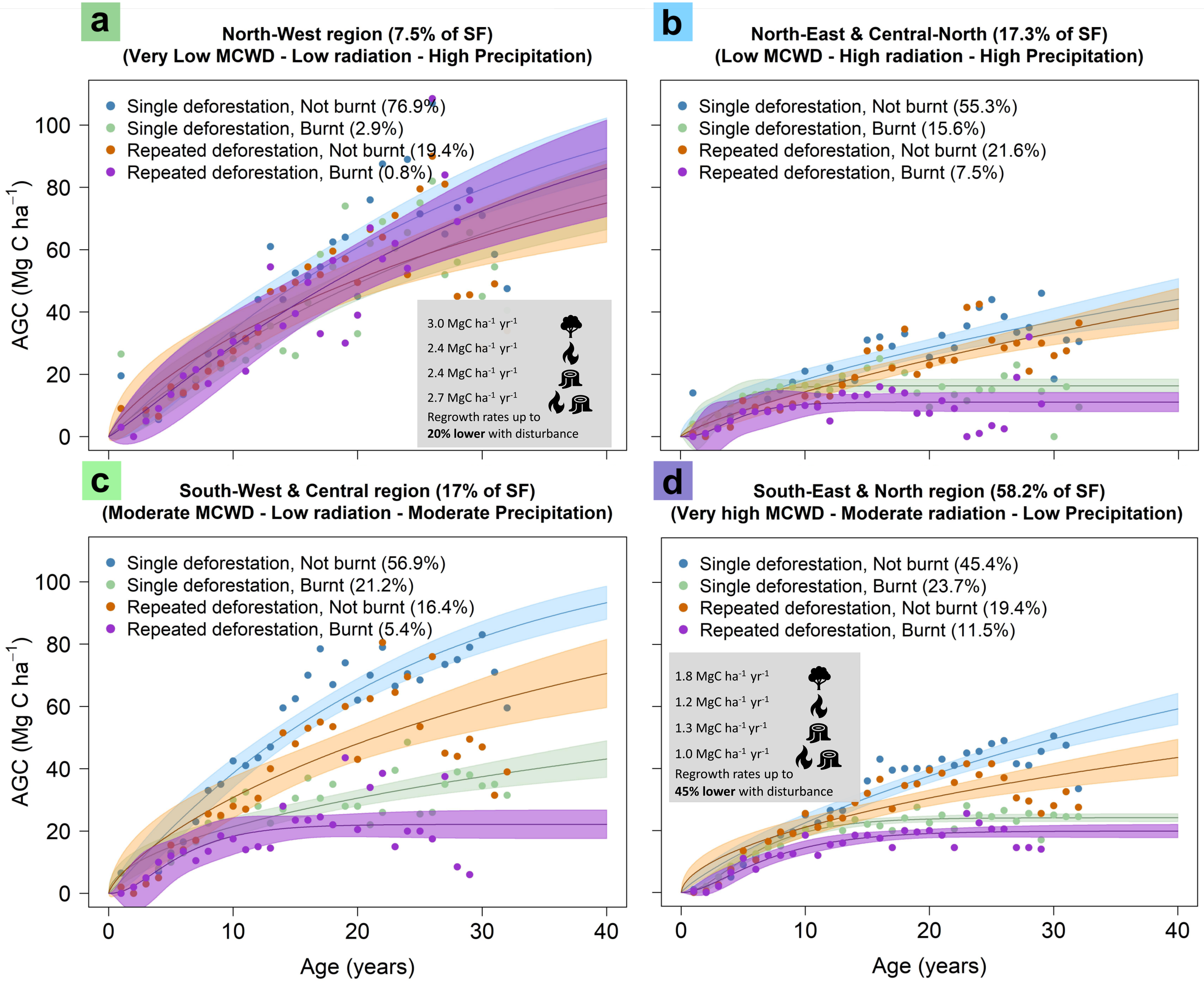
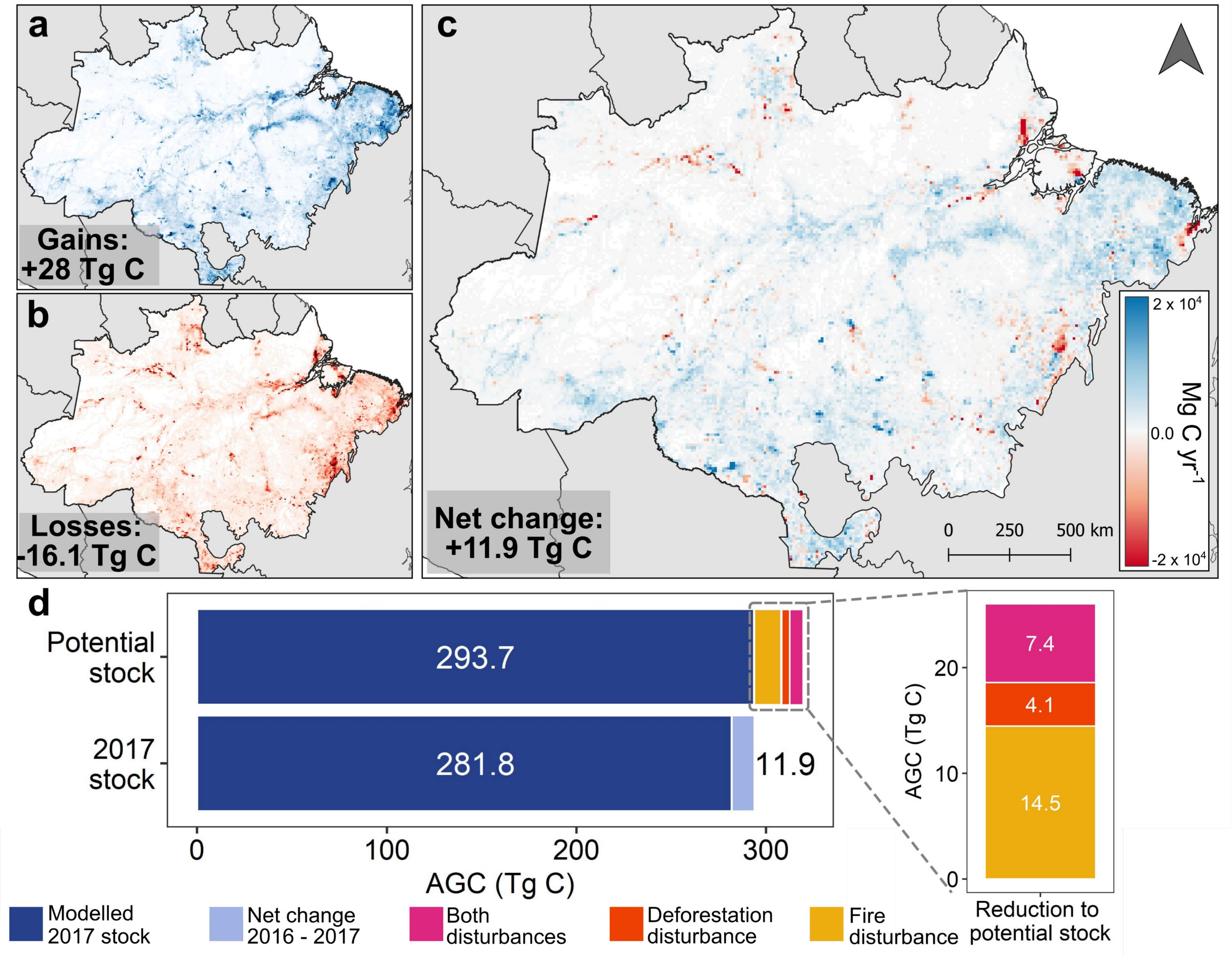




Avoiding secondary forest disturbances



- Spatially explicit map of average C changes on 0.1° scale between 2016 and 2017
- Gains from existing forests and new growing forests: 28 TgC
- Losses between 2016-2017: -16TgC
- Net change: 12TgC
- Estimated AGC stock for 2017: 294Tg C
- Potential AGC stored with no disturbance: 320 Tg C

Carbon sink could have been up to 8% higher if no secondary forests experienced any disturbance

Final remarks

- Human-driven disturbances and consequent forest degradation is a cumulative process, which may dominate Amazonian landscape in the future, changing ignitions sources, surface properties, climate and fire patterns.

- Degradation affects the C budget by increasing emissions, reducing C sequestration or both.

- Improving our understanding on the net additive effect of degradation on the Amazonian C budget is needed not only for reducing global uncertainty on terrestrial sources and sinks, but also for increasing the capacity of tropical countries to explore emergent forest emission reduction funding mechanisms.

- Reducing emissions from forest degradation and restoring forest cover (reducing fragmentation, improving climate and sequestering C) must be a global priority for tackling climate change and the loss of essential forest services.

THANK YOU!

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