Crossing Tipping Points in the Amazon Rainforest: The decisive decade*

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This article investigates whether the Amazon rainforest's destruction has reached a tipping point. Over the past 30 years, understanding of Amazon tipping points has improved, but the extent of these areas remains unclear. Scientists generally agree that the entire Amazon biome has not crossed a tipping point, but local-scale forest collapses could cause cascading effects on rainfall, wildfires, and continental forest loss. To gauge the imminence of massive forest loss, the study assessed six key anthropogenic processes: clear-cut deforestation, forest degradation, droughts, wildfires, regional warming, and conversion from a sink to a net carbon source. These processes amplify each other in a positive feedback loop posing significant threats to the environment. The study concluded that deforestation, forest degradation, and wildfires have accelerated in the last decade, pushing degraded areas to a point of no return. Other parts of the Amazon rainforest are already crossing no-return points, with Brazil and Bolivia responsible for 90% of combined deforestation and degradation. Regions damaged by fires, mining, logging, and clear-cut deforestation are showing irreversible loss of biomass and forest resilience. When a red line for other Brazilian Amazon rainforest areas could be crossed remains uncertain, but the possibility of a near-term forest tipping point by 2030 is real. The risk of crossing tipping points in the central and western Amazon increases as destructive processes continue. The authors recommend that Amazon nations and the international community reforest degraded areas and implement the 13 principles established by forest stewards, with indigenous populations playing a central role.

Keywords: agribusiness, Amazon biome, forest degradation, deforestation, indigenous people, tipping point, savannization, wildfire

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Introduction

On 8 and 9 August, 2023, the State Parties to the Amazon Cooperation Treaty (ACT) met for the fourth time, after meetings in 1989, 1992, and 2009, with the aim of once again strengthening common Amazon governance. This initiative is now more urgent than ever, given that the process of destruction and degradation of the largest tropical forest in the world is not only highly advanced but continues to advance, albeit at a slower pace than in the years 2018–2022. The meeting, an initiative of the Lula government, signals a clear reversal of the Bolsonaro government's policies. The priorities of the latter were to intensify the devastation of the Amazon and wage war on Indigenous Nations as part of the 'national security' doctrine implemented by the dictators in 1970 and driven mostly by agribusiness since.

The fact that this meeting happened was obviously positive. It is necessary to restore connectivity between the Amazon peoples, which is well attested not only archaeologically and historically but also in the living and pulsating Amazonian culture of today. The problem is that the 'Presidential Declaration of the Amazon Summit', signed on 8 August, 2023, by ACT's eight signatory countries, is incredibly empty.[2] Basically, the governments decided to continue discussing until they could decide something. In fact, all they managed to sign was an agreement that, in the indefinite future, there would be an agreement with an agenda. The 113-point Declaration recognizes the need for 'urgent action to avoid the point of no return in the Amazon'. It also recognizes that the Amazon rainforest is about to exceed the limits of environmental conditions, especially hydrological and temperature, that allow it to remain a tropical forest. But what 'urgent action' was taken in this regard? None.

In this article, we report on and analyze the crucial issue of 'points of no return' in the ongoing destruction of the Amazon rainforest, a question that increasingly mobilizes the scientific community and needs to occupy the centre of the regional, continental, and global political arena.[3] To what extent has the Amazon rainforest already passed a tipping point? A tipping point for this gigantic biome refers to an inability to continue sustaining itself once a limit of destructive anthropic interference in a warming world has been exceeded. A deeply degraded forest or even non-forest vegetation will then replace the rainforest. The term savanna is sometimes applied to such non-forest vegetation. However, the new ecosystem would be nothing like the biologically rich Brazilian Cerrado, also described as a savanna. Scientists hypothesize that the most likely types of vegetation that would replace the forest once it passed a tipping point would be 'the open-canopy degraded state and the closed-canopy secondary forest state as more likely to occur over broad areas'.[4] In a recent paper, discussed below (see Section 4). Bernardo Flores and colleagues added a third plausible alternative ecosystem that could replace the rainforest: a white-sand savanna. Although it is possible to come up with even worse scenarios, such as a massive forest dieback,[5] even these three possible post-rainforest equilibrium states in the Amazon would have catastrophic consequences for the climate, the biosphere, and, therefore, human societies on a global scale.

As more and more of the forest has been destroyed and degraded over the past 50 years, the understanding of the likelihood and imminence of tipping points in the Amazon has completely changed. In the 1990s, this issue appeared in the scientific literature only in the form of model-based projections.[6]

2. See <https://www.gov.br/mma/pt-br/declaracao-presidencial-por-ocasiao-da-cupula-da-amazonia-2013-iv-reuniao-de-presidentes-dos-estados-partes-no-tratado-de-cooperacao-amazonica>.
3. See, below, References in chronological order.
4. Cf. Marina Hirota, Bernardo M. Flores, Richard Betts, Laura S. Borma, Adriane Esquível-Muelbert, Catarina Jakovac, David M. Lapola, Encarni Montoya, Rafael S. Oliveira, Boris Sakschewski, "Resilience of the Amazon forest to global changes: Assessing the risk of tipping points". In Carlos Nobre, Andrea Encalada *et al., Science Panel for the Amazon*. Executive Summary of the Amazon Assessment Report 2021, Chapter 24, New York, 2021.
5. Cf. Isobel M. Parry, Paul D. L. Ritchie, & Peter M. Cox, "Evidence of localised Amazon rainforest dieback in CMIP6 models". *Earth System Dynamics*, 13, 4, 2022, pp. 1667-1675.
6. Cf. J. Shukla, C. Nobre, P. Sellers, "Amazon Deforestation and Climate Change". Science, 247, 4948, 1990, pp. 1322-1325.

In 2001, the Third Assessment Report of the IPCC still maintained that 'large uncertainties still persist on the quantitative impact of large-scale deforestation on the hydrological cycle, particularly over Amazonia'.[7] In 2007, the Fourth Assessment Report adopted the term tipping point for the first time and applied it to the Amazon rainforest: 'How close are we to tipping points/thresholds for natural ecosystems such as the Amazon rain forest? What positive feedbacks would emerge if such a tipping point is reached?' The Report warned that: 'By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia'.[8] In 2008, assuming 'business-as-usual' patterns of future deforestation and forest degradation, Daniel Nepstad and colleagues examined the dynamics that could lead the Amazon rainforest to cross a tipping point by 2030. We must quote them in full:[9]

> 31% of the Amazon closed-canopy forest formation will be deforested and 24% will be damaged by drought or logging by the year 2030. (...) If we assume that rainfall declines 10% in the future, then an additional 4% of the forests will be damaged by drought. (...) If we assume that (...) selective logging reduces forest carbon stocks by 15%, that drought damage causes a 10% reduction in forest biomass and that fire affects 20% of the forests damaged by drought or logging, releasing an additional 20% of forest carbon to the atmosphere, then 15–26 Pg of carbon contained in Amazon forest trees will be released to the atmosphere in less than three decades in a large-scale dieback without invoking the influence of global warming. (...) There is reason to believe that this scenario is conservative.

Given the resurgence of clear-cut deforestation and forest degradation after 2012, tipping points or early warnings of them have been clearly and abundantly detected in the Brazilian Amazon, mostly since 2018. Such early warnings have been making headlines in the non-specialized press for some years now.[10]

A state of war

After more than 60 million years of evolution and resilience, a short period of terror is the expression that best describes the war waged against the Amazon rainforest by the 1964–1985 military regime and by Brazilian agribusiness, whose devastating action in this region is inseparable from the global corporate network, involving Big Food, disastrous hydroelectric dams, mining, the financial system, and agrochemical megacorporations that control GMO seeds, pesticides, and fertilizers all over the world. This war is well characterized by the 'Belém's Panamazonic Declaration', drawn up by the 10th Panamazonic Forum (FOSPA) held in Belém in July 2022: 'The entire Amazon basin is experiencing a situation of unconventional war, with the participation of state military forces, paramilitary groups, militias, and drug traffickers, acting in connection with large economic interests'.[11]

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7. Cf. IPCC, Third Assessment Report, 2001, Chapter 7: T. F. Stocker (Co-ordinating Lead Author), "Physical Climate Processes and Feedbacks", p. 442.
8. Cf. IPCC, Climate Change 2007 – Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, 2007, pp. 78 and 14.
9. Cf. Daniel C. Nepstad *et al.*, "Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point". *Philosophical Transaction of the Royal Society B. - Biological Sciences*, 11/II/2008.
10. "The Amazon is approaching an irreversible tipping point". *The Economist*, 1st/VIII/2019; Stephen Eisenhammer, "The Amazon's Little Tipping Points. A Rainforest Retreat". Reuters, 21/X/2021; Alex Cuadros, "Has the Amazon Reached Its 'Tipping Point'?". *The New York Times*, 4/I/2023
11. Cf. "Declaração Pan-Amazônica de Belém": "6. Toda a bacia amazônica está passando por uma situação de guerra não convencional, com a participação de forças militares estatais, paramilitares, milícias e traficantes de drogas, agindo em conexão com grandes interesses econômicos". <https://www.fospabelem.com.br/pt_br/2022/08/01/declaracao-pan-amazonica-de-belem-x-forum-social-pan-amazonico/>.

There is mounting evidence that certain parts of the forest, growing in extent, have already reached an irreversible point. However, the size of the areas already doomed remains unclear. Furthermore, it is not yet possible to know the domino effects that the destroyed parts of the forest may have on other areas and eventually on the forest as a whole. Scientific literature generally acknowledges that:

(1) The Amazon rainforest biome as a whole, defined as a set of ecoregions, fauna, flora, and similar ecological dynamics and processes, has not yet crossed a tipping point;
(2) 'Local-scale forest collapses could trigger cascading effects on rainfall recycling, intensifying dry seasons and wildfire occurrence, and leading to massive forest loss at continental scales, particularly in the southwest of the basin'.[12]

That said, how far can we be from a massive forest loss? Possible answers to these questions should consider that throughout the Amazon rainforest, six anthropogenic processes are amplifying each other in a positive feedback loop: clear-cut deforestation, forest degradation and fragmentation, droughts, wildfires, regional warming, and the forest's conversion from sink to net carbon source. Let us briefly examine each of them, keeping in mind, however, the synergistic character of their impacts.

Anthropogenic processes generating a positive feedback loop

Clear-cut deforestation: beyond the 'arc of deforestation'

To begin with, we must pay attention to a singularity of Brazilian history that is rarely highlighted. No country or territory on the planet has at any point in human history destroyed nature as rapidly and devastatingly as the Brazilian dictators from 1970 on. Moreover, their destructive policies were followed by all the subsequent civilian governments (1986–2022).[13] The original area of the Amazon biome in Brazil was 402.7 million hectares. European colonization (1500–1822) and the successive 140 years of postcolonial history (1822–1962) in this region of the continent caused the deforestation of an area corresponding to only 2.2% of the Amazon biome, or an area smaller than Portugal (92,212 km^2).[14] Large-scale forest clearing in Brazil began in the 1970s, when the dictators opened the Trans-Amazonian Highway, killing at least 8,300 Indigenous People (according to a very conservative estimate[15]) and relentlessly attacking the world's largest tropical forest. Since then, according to Gilberto Câmara, former director of Brazil's National Institute for Space Research (INPE):[16]

12. Cf. Hirota *et al.*, in Nobre, Encalada *et al., Science Panel for the Amazon* (cit.) 2021, Chapter 24, New York, 2021.
13. Cf. L. Marques, "The legacy of slavery and environmental suicide". In, Peter Furtado (ed.), *Histories of Nations. How Their Identities Were Forged*, London, Thames and Hudson, 2012, pp. 163-169; Idem, *Capitalism and Environmental Collapse* (2015), English edition, Springer, 2020, Chapter 2, section 2.3: "Brazil (1970-2019): The Most Fulminating Ecocide Ever Perpetrated by the Human Species"; Idem, "Brazil, 200 Years of Devastation: What Will Remain of the Country After 2022?" *Estudos Avançados*, Bicentennial of Independence, 36, 105, May-Aug 2022. A photographic essay based on this text was published by Iara Vieira Guimarães and Silvia Aparecida Fernandes, "Brasil, 200 anos de devastação. Uma análise ilustrada". See <https://portaldobicentenario.org.br/wp-content/uploads/2022/10/BRASIL-200-anos-de-devastacao.pdf>.
14. Cf. Philip M. Fearnside, "Desmatamento na Amazônia brasileira: história, índices e consequências". *Megadiversidade*, 1, 1, July 2005.
15. Cf. "Comissão da Verdade: Ao menos 8,3 mil índios foram mortos na ditadura militar". *Amazônia Real*, 11/XII/2014; Ary Filgueira, "Massacre de índios pela ditadura militar". *Isto É*, 13/IV/2017; Rubens Valente, *Os fuzis e as flechas. A história de sangue e resistência indígenas na ditadura*. São Paulo, 2017.
16. Cf. Gilberto Câmara *et al.*, "Desafios do cumprimento da NDC brasileira no bioma Amazônia". Revista CEBRI (Centro Brasileiro de Relações Internacionais), 1, 4, Oct-Dec., 2022. <http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes>.

> Deforestation in the Brazilian Amazon has reduced the original forest cover of 402.7 million hectares (Mha) by 85.3 Mha [853,000 km^2], according to data from the National Institute for Space Research (INPE 2022). Twenty-one and two-tenths per cent (21.2%) of the forest has been cut down, which has been accentuated from the 1980s to date.

Also, since 1970, the Cerrado, the second-largest Brazilian biome, has had its natural vegetation extensively destroyed (Fig.1).

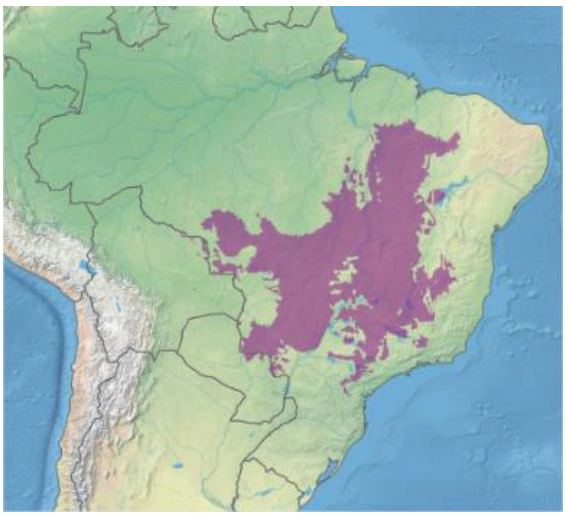

Figure 1: Map of the Cerrado ecoregion, measuring 1,910,037 km^2 (737,469 sq mi)

Although this essay focuses on the Amazon, it is crucial to stress that the Cerrado is also rapidly approaching a tipping point. It has already lost around 50% of its native vegetation to agribusiness. This is an ecocide comparable in extent and severity to what is being perpetrated in the Amazon, and has dramatic consequences for biodiversity, water resources, and the climate system, as numerous scientists have warned and forecast multiple times. Among them are Bernardo Strassburg and colleagues who stated seven years ago:[17]

> Despite its enormous importance for species conservation and the provision of ecosystem services, the Cerrado has lost 88 Mha (46%) of its native vegetation cover, and as little as 19.8% remains undisturbed. Between 2002 and 2011, deforestation rates in the Cerrado (1% per year) were 2.5 times higher than in the Amazon. (...) The combination of limited protection and marked pressure from agricultural expansion explains the projections that 31–34% of the remaining Cerrado is likely to [be] cleared by 2050. Our calculations based on the species–area relationship suggest that this projected deforestation will drive ~480 endemic plant species to extinction — over three times all documented plant extinctions since the year 1500.

In 2017, the Cerrado had already lost 880,000 km^2 of its native vegetation, as stated by Strassbourg and colleagues. Between 2018 and 2023, it lost another 48,067 km^2,[18] creating a total cumulative loss of over 928,067 km^2. In 2021, Gabriel Hoffmann and colleagues warned once again that 'the Brazilian Cerrado

17. Cf. Bernardo B. N. Strassburg, "Moment of truth for the Cerrado hotspot". *Nature Ecology & Evolution*, 23/III/2017.
18. Cf. Kátia Peha & Tasso Azevedo, "Não adianta chorar sobre o Cerrado derrubado". *Folha de São Paulo*, 13/I/2024.

is becoming hotter and drier'. The authors report 'monthly increases of 2.2–4.0°C in the maximum temperatures and 2.4–2.8°C in the minimum temperatures between 1961 and 2019', and conclude:[19]

> We believe that the regional climate changes described in this paper will impact directly or indirectly the biodiversity on different ecological levels (i.e., organism, population, and community), eventually resulting in cascade effects and causing ecosystems to collapse. Therefore, our results reinforce the alert issued by Strassburg et al. (2017) and highlight the need for urgent measures to avoid the collapse of the Cerrado hotspot.

In just over 50 years (1970–2023), the loss of native vegetation in the Cerrado and the Amazon has totalled 1,786,000 km^2 (858,000 km^{2,} + 928,000 km^2), or 21% of the Brazilian territory as a whole. Collapse looms for both of Brazil's two largest biomes.

Regarding the Amazon rainforest, its central, northern, and western regions have suffered much less deforestation than its northeast, eastern, and southern regions, which form the so-called arc of deforestation. The arc of deforestation covers a territory that goes from the west of the state of Maranhão and the south of the state of Pará towards the west, passing through the states of Mato Grosso, Rondônia, and Acre. As Antonio Oviedo, William Pereira Lima, and Cicero Augusto have pointed out, 'The Belém-Brasília and Cuiabá-Porto Velho highways began the design of this arc, which currently corresponds to the territory of 256 municipalities that concentrate approximately 75% of deforestation in the Amazon'[20] (Fig. 2).

Figure 2: The Amazon region showing the most heavily deforested areas, known as the 'arc of deforestation'. Source: 'Protecting Brazil's forests: Fiddling while the Amazon burns'. Brazil Institute, 5/XII/2011, from *The Economist*, 12/03/2011

Fig. 2 shows the state of clear-cut deforestation in the Brazilian Amazon 13 years ago. The Amazon rainforest's situation is now, of course, much worse. The northeastern area of the forest is already 36% deforested, 'with a 67% increase in deforestation in 2019 and a 45% increase in 2020 relative to the

19. Cf. Gabriel S. Hofmann *et al.*, "The Brazilian Cerrado is becoming hotter and drier". *Global Change Biology*, 15/IV/2021, pp. 1-14.
20. Cf. Antonio Oviedo, William Pereira Lima, Cicero Augusto, "O arco do desmatamento e suas flechas". Instituto Socioambiental, São Paulo, 2019.

2010–2018 period'.[21] Since the reform of the Brazilian Forest Code (*Código Florestal*[22]) in 2012, which pardoned previous deforestation crimes and consolidated agribusiness' influence in the National Parliament, clear-cut deforestation has increased by 190% (2012–2022), with a clear acceleration during the years 2019–2022 (+76%) under Bolsonaro's presidency (2019–2022), as shown in Fig. 3.

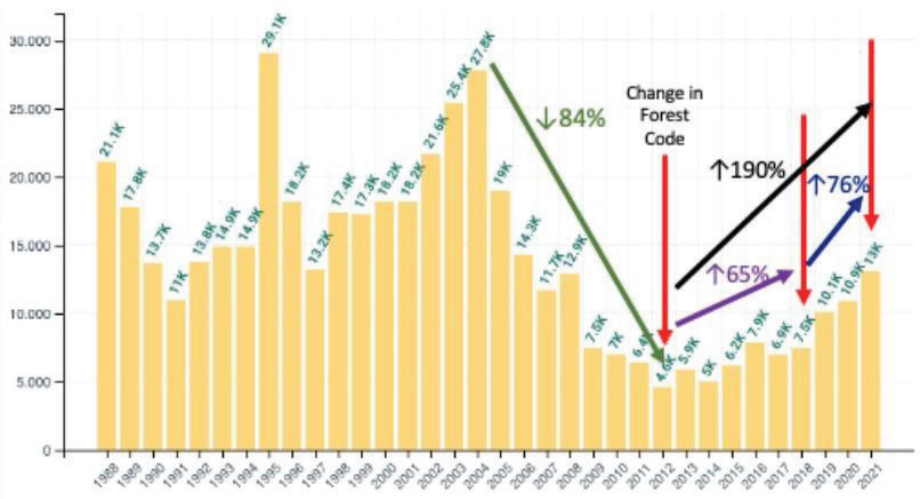

Figure 3: Clear-cut deforestation in the Brazilian Amazon (1988–2022), with absolute numbers by year (in thousands of km^2 and rates of decrease and increase during the following periods: 2004–2012 (-84%), 2013–2022 (+190%), 2013–2018 (+65%), and 2019–2022 (+76%). The year 2012, when the new legislation on forests comes into force, marks a turning point between a decrease and a new period of increase in clear-cut deforestation in the Brazilian Amazon. Source: Luciana Gatti (personal communication), based on INPE/PRODES[23]

Fig. 3 shows a clear difference between the government of Dilma Rousseff/Michel Temer (2014–2018) and that of Jair Bolsonaro. During the Dilma–Temer second term government (2014–2018), deforestation increased 65% in relation to 2012, its lowest point (4,571 km^2). This was due to a mixture of misunderstanding of the strategic importance of the Amazon rainforest, the weakening of environmental governance, and surrender to the pressures of agribusiness, which sees the forest as an obstacle to its expansion. Under Bolsonaro's leadership, his government prioritized deforestation, making it impossible to attribute the deforestation in the Amazon to a simple lack of governance. Two primary factors drove this policy:

(1) Bolsonaro represents the resurrection of the ideology of the military dictatorship (1964–1985), according to which the Amazon rainforest and the peoples who traditionally inhabit it constitute a threat to 'national security' and to 'development'. For the military mindset, mining is Brazil's major strategic issue. It was an old obsession of the dictators. As grotesque as it may seem, for the generals, the Amazon rainforest is less important than the mineral deposits that are found in its subsoil. Therefore, the forest must be destroyed to appropriate these deposits before other nations do so. This obtuse ideology combines quite well, paradoxically, with a de facto policy of opening up the Amazon to the global market. Indeed, the military has always been committed to attracting international capital to mining in the Amazon.

21. Cf. Luciana V. Gatti *et al.*, "Increased Amazon carbon emissions mainly from decline in law enforcement". *Nature*, 23/VIII/2023.
22. For the Forest Code (Law 12651, 25/V/2012), see https://www.embrapa.br/en/codigo-florestal>.
23. Figure 3, 5, and 12 were kindly provided for this paper by Luciana Gatti, Coordinator of the Greenhouse Gases Laboratory (LaGEE) in the CCST/INPE, Brazil.

Under the government of Michel Temer (2016–2018), already closely associated with the military agenda, approximately 30 Canadian companies were exploiting ore in Brazilian territory, especially gold in the Amazon.[24] In March 2019, under Bolsonaro's government, Brazil and Peru sponsored the annual meeting of the Prospectors and Developers Association of Canada (PDAC), the largest event in the world mining sector. In his speech at the opening of the event, Admiral Bento Albuquerque, then Minister of Mines and Energy, declared in relation to the Amazon: 'the extension of the offer of areas for the development of mineral research and new projects is another guideline of the Ministry of Mines and Energy for our sector'.[25] In 2020 alone, six states in the Brazilian Amazon extracted a recorded total of over 46 tons of gold, with immeasurable impacts on the Amazon's well-preserved indigenous lands, particularly those of the Yanomami, Munduruku, and Kayapó peoples. The main countries importing gold from the Amazon in 2020 were Canada, Switzerland, Poland, the United Kingdom, the United Arab Emirates, Italy, and India.[26]

(2) Since the 16th century, Brazil has supplied Europe and, subsequently, the global market with commodities. But over the last 30 years, its inclusion in the global economy has reached a much larger scale, as Brazil has become the largest or one of the largest producers and exporters of the following commodities:[27] soybean, beef, poultry, meat, corn, wood, oil, iron ore, gold, copper, bauxite, manganese, and other minerals. Given the growing international demand for these commodities, conservation policies for native vegetation and biodiversity in the Amazon, as well as in other biomes, appear as an obstacle to expansion in the eyes of the business sector.

Livestock offensive and opening of pastures

The opening of pastures for cattle ranching is by far the most destructive force unleashed against the forest. The perpetrators, who espouse a militaristic ideology, are the Brazilian agrarian elites who control the National Congress, financial markets, and global corporations.

Approximately 80% of deforestation in the Brazilian Amazon is caused by the opening of pastures.[28] In the Amazon basin as a whole (eight countries and the French Guiana), forest loss over the last 50 years was around 17% of its original area, of which 14% was converted mainly to agricultural land (89% pastures and 10% crops).[29] In 2020, 44% of all deforestation in the Brazilian Amazon occurred in public forests, where deforestation is prohibited, and pastures already opened for cattle ranching were the main land use in 75% of the deforested areas of public forests.[30] Land grabbers invade public forests, destroy them, forge rural property titles with the complicity of local authorities, and sell these recently deforested lands to large landowners, mainly cattle ranchers.

24. Cf. L. Marques, "Em defesa da Amazônia e do Cerrado". Jornal da Unicamp, 28/VIII/2017.
25. Cf. "Ministro de Minas e Energia vai ao PDAC 2019". Notícias de Mineração Brasil, 22/II/2019. See also "Ministro de Minas e Energia diz que cogita autorizar garimpo em terras indígenas". *Poder360*, 8/III/2019.
26. Cf. Dinamam Tuxá, Sonia Guajajara & Eloy Terena, "Complicity in Destruction IV: How Mining Companies and International Investors Drive Indigenous Rights Violations and Threaten the Future of the Amazon". Association of Brazil's Indigenous Peoples (APIB), Amazon Watch, Amazônia Minada Project, 2022; Jenny Gonzales, "From Wall Street to the Amazon: Big capital funds mining-driven deforestation". Mongabay, 22/II/2022; Larissa Rodrigues, "Brazil exports illegal gold". Instituto Escolhas, July, 2021.
27. Cf. Adalberto Aragão e Elisio Contini, "O agro no Brasil e no mundo: uma síntese do período 2000 a 2020". Embrapa, 2021
28. Cf. Catarina Barbosa, "Pecuária é responsável por 80% do desmatamento na Amazônia, afirma pesquisadora" *Brasil de Fato*, 5/IX/2019.
29. Cf. Gatti *et al.*, cit. (2023).
30. In this estimate of Public Forests, forests belonging to Indigenous Territories and Conservation Units are not included. Cf. Caroline S. C. Salomão *et al.*, "Amazônia em chamas. Desmatamento, Fogo, e Pecuária em Terras Públicas". IPAM, Nota Técnica, Number 8, October 2021.

Economic and fiscal mechanisms were created by the military dictatorship to encourage livestock in the Amazon. One of the most infamous slogans in government propaganda was 'Drive your cattle to the world's largest pasture'.[31] Civilian governments continued this policy of encouraging the replacement of forests by pastures, so that cattle herds began to concentrate in the Amazon. In 2017, there were 215 million head of cattle in Brazil; by 2021, that number had increased by 4.4% to 224.6 million.[32] In 2019, 15 of the 20 municipalities in Brazil that had the largest cattle herds were in the Amazon region. In 2021, the nine Brazilian states of Legal Amazon had over 96 million head of cattle. Fig. 4 shows this geographical concentration in the nine states of the Amazon region and in the country's Midwest, mostly in the states of Goiás and Mato Grosso do Sul (Cerrado and Pantanal).

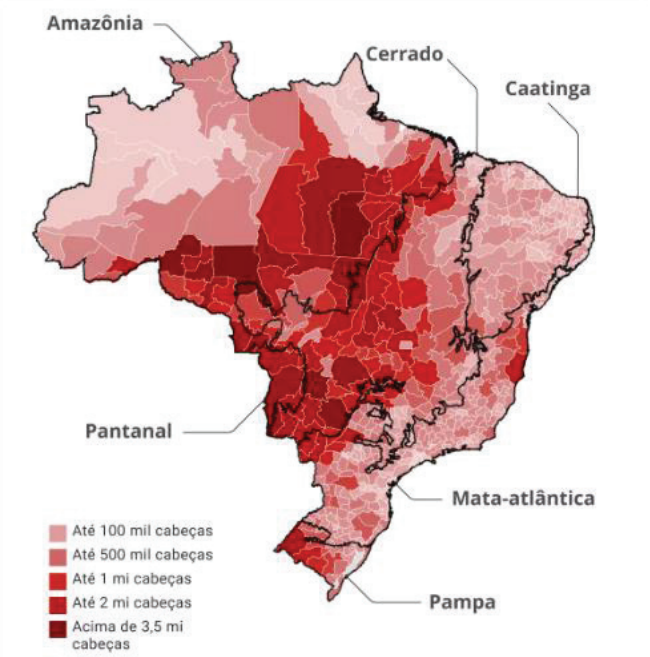

Figure 4: Cattle in Brazil by geographical concentration, showing highest concentrations in the Pantanal, Cerrado and Amazon regions. From 'Up to 100,000 head of cattle' (lightest color) to 'More than 3.5 million head of cattle' (darkest colour). Source: Rikardy Tooge, 'Por que tem tanto gado na Amazônia?' *G1*, 25/10/2020

This concentration of cattle in the Amazon intensified mainly during two periods. The first ran from 2013 to 2016, that is, from the moment Dilma Rousseff's government weakened environmental governance until her impeachment in a parliamentary coup. The second ran from 2018 to 2022, under the governments of Michel Temer and Bolsonaro. Fig. 5 shows data on cattle numbers from 2010 to 2020 and illustrates these trends.

By 2022, the biome contained 43% of the country's cattle herd, with more than 96 million head of cattle – triple the number of human residents.[33]

31. "Toque seu gado para o maior pasto do mundo". Cf. Rikardy Tooge, "Por que tem tanto gado na Amazônia?" G1, 25/10/2020.
32. IBGE, Instituto Brasileiro de Geografia e Estatística, "Rebanho de Bovinos", 2021. <https://www.ibge.gov.br/explica/producao-agropecuaria/bovinos/br>.
33. Cf. Nádia Pontes, "Como a Amazônia se tornou a maior área de pasto do Brasil". DW, 6/10/2023, based on data published by MapBiomas, coordinated by Laerte Ferreira (2023).

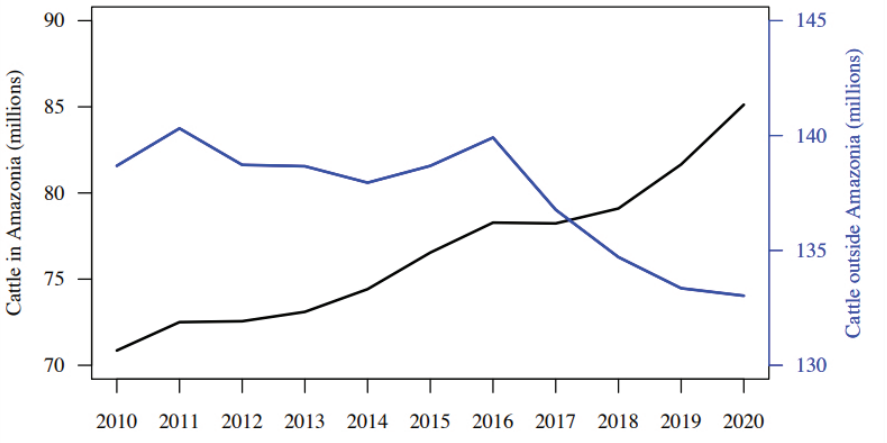

Figure 5: Trends in cattle numbers inside (black line) and outside Amazonia, i.e., in other Brazilian states (blue line). Source: Luciana V. Gatti et al., 'Increased Amazon carbon emissions mainly from decline in law enforcement'. *Nature*, 23/8/2023 (extended data Fig. 5b)

Three new vectors of deforestation in the Brazilian Amazon

This continued concentration of cattle ranching in the Amazon, as well as the expansion of soy plantations and mining activities, are the main reasons why clear-cut deforestation in the Brazilian Amazon is no longer restricted to the arc of deforestation (Fig. 2). It has advanced along three new vectors, especially since Bolsonaro took office in 2019, as shown in Fig. 6.

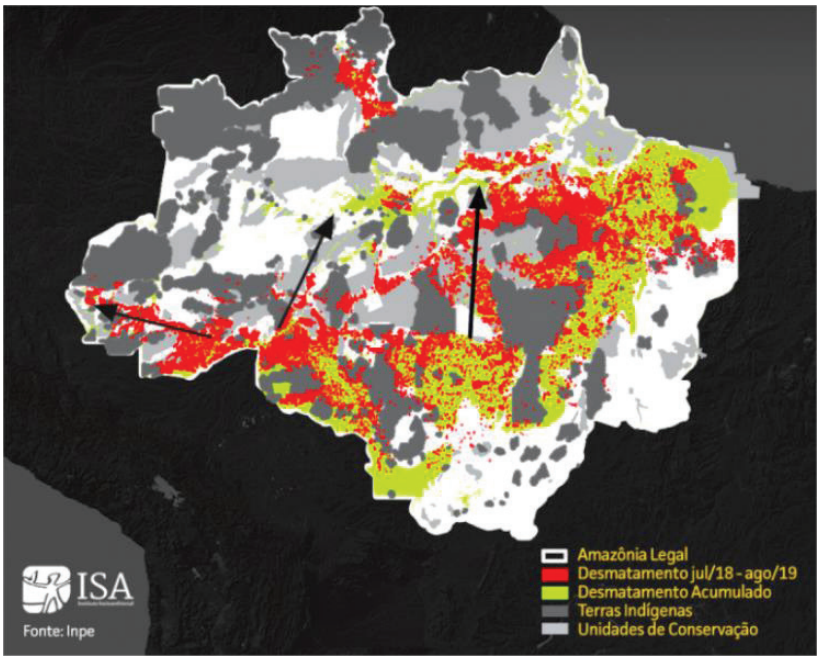

Figure 6: Three New Drivers of Amazon Deforestation. Green: accumulated deforestation since 1970; red: deforestation between July 2018 and August 2019; dark grey: Indigenous Territories; light grey: areas defined as Conservation Units. Source: 'New arc of deforestation: frontier of destruction advances in 2019 in the Amazon', Instituto Socioambiental (ISA), 17/10/2019, based on Antonio Oviedo, William Pereira Lima, and Cicero Augusto, 'O arco do desmatamento e suas flechas'. Instituto Socioambiental, São Paulo, 2019, with deforestation data from INPE

In Indigenous Territories (dark grey in Fig. 6), invaded by ranchers, land grabbers, loggers, and gold prospectors (*garimpeiros*) who built more than a thousand illegal airstrips in these lands to fuel the global mining industry,[34] there was a 157% increase in deforestation in the period 2019–2022 as compared to the period 2015–2018, demonstrating once again the war that Bolsonaro waged against the forest and its peoples.[35] The three arrows in Fig. 6 indicate three new vectors of deforestation, which can also be observed in the map below (Fig. 8). New frontiers of devastation are now advancing across: (1) the entire state of Acre (AC), (2) the state of Rondônia and the east part of the state of Amazonas (AM), and (3) the western part of the state of Pará (PA). In the second new deforestation vector that crosses central Amazon, particularly the eastern part of the state of Amazonas (AM), 'interactions between extremely wet and dry periods are increasing tree mortality rates and reducing growth'.[36] This new deforestation vector is stimulated by real estate speculation created by the expectation that BR-319 (the Manaus–Porto Velho highway) will be asphalted, one of the Bolsonaro government's main promises. In December 2023, President Lula postponed the BR-319 paving project until 2027, amid growing political pressure from agribusiness.[37] This road cuts through the heart of the forest, threatening several Indigenous Territories[38] (Fig. 7).

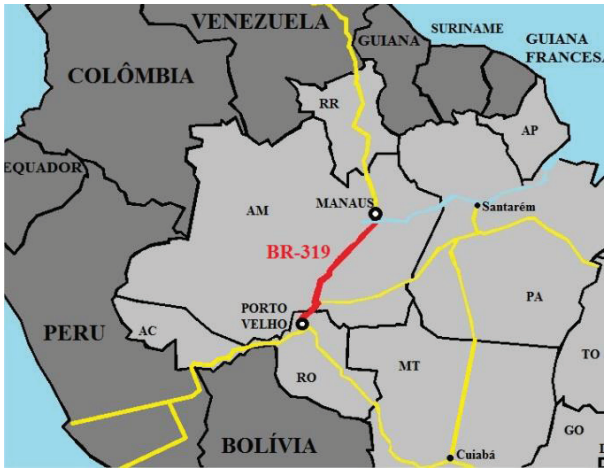

Figure 7: Road BR-319, Manaus–Porto Velho (885 km), opened in the 1970s and closed in 1988. The expectation of it being paved has generated strong real estate speculation

Furthermore, as shown in Fig. 6 and Fig. 8, recent deforestation can also be observed in the state of Roraima (RR). Fig. 8 shows clear-cut deforestation in the Amazon biome between 2018 and 2021, a period in which only 1% of rural properties were responsible for 83% of deforestation in the Brazilian Amazon.[39]

34. Cf. Manuela Andreoni, Blacki Migliozzi, Pablo Robles and Denise Lu, "The Illegal Airstrips Bringing Toxic Mining to Brazil's Indigenous Land". *The New York Times*, 2/8/2022.
35. Cf. Antonio Oviedo & William Pereira, "Nota Técnica: A Geografia do Desmatamento na Amazônia Legal". Instituto Socioambiental, 15/XII/2022
36. Cf. Hirota *et al.*, in Nobre, Encalada *et al., Science Panel for the Amazon* (cit.) 2021, Chapter 24, New York, 2021, p. 6.
37. "Governo Lula adia projeto de pavimentação da BR-319 até 2027 sem realizar ações concretas imediatas". *Poder*, 6/XII/2023.
38. Cf. Philip M. Fearnside *et al.*, "BR-319: O caminho para o colapso da Amazônia e a violação dos direitos indígenas". *Amazônia Real*, 23/II/2021; "A herança de Bolsonaro na Amazônia". *Observatório do Clima*, 7/I/2023.
39. Cf. Gilberto Câmara *et al.*, "Desafios do cumprimento da NDC brasileira no bioma Amazônia". Revista CEBRI (Centro Brasileiro de Relações Internacionais), 1, 4, Oct-Dec., 2022.

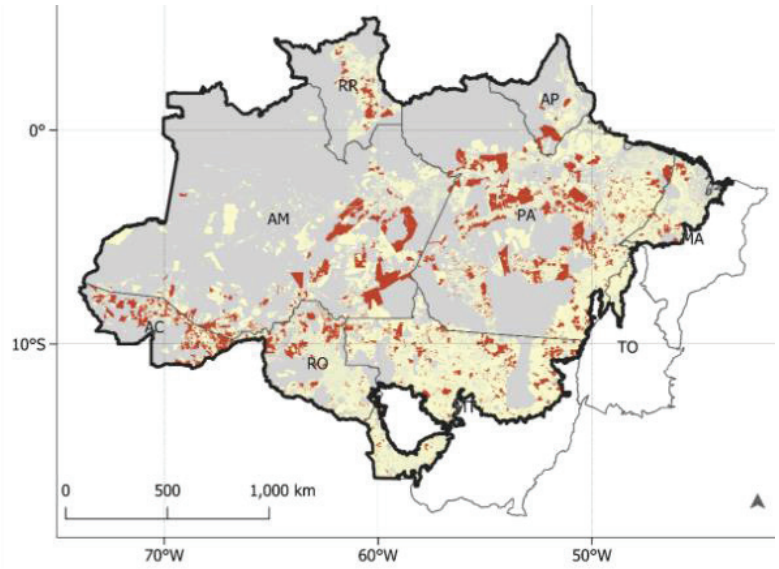

Figure 8: Spatial location of rural properties in the Amazon, highlighting in brown 5,054 rural properties (1% of the total) responsible for 83% of deforestation in areas registered in the Rural Environmental Registry (CAR) in 2021. In yellow, the other 99% of the rural properties registered in the CAR. Source: Gilberto Câmara et al., 'Desafios do cumprimento da NDC brasileira no bioma Amazônia'. Revista CEBRI (Centro Brasileiro de Relações Internacionais), 1, 4, Oct-Dec., 2022, based on data from Incra, CAR/SFB, FUNAI, ICMBio, and INPE
<https://cebri.org/revista/br/artigo/63/desafios-do-cumprimento-da-ndc-brasileira-no-bioma-amazonia>

During the period of Bolsonaro's government alone (more precisely, between August 2018 and December 2022), the Brazilian Amazon saw more than 55,000 km^2 of primary forest eliminated by clear-cut deforestation. This means, for European readers, an area about 33% larger than the Netherlands (41,543 km^2). But the reality is even worse because satellite measurements made by the National Institute for Spatial Research (INPE) do not register forest degradation and clear-cut deforestation in areas smaller than 6.25 hectares.[40] Thus, the planet's richest biome in terms of terrestrial biodiversity is being destroyed at relentless speed.

Forest degradation and fragmentation — logging, increasing droughts, and wildfires

Forest degradation and fragmentation occur due to a combination of many factors: logging, opening of clearings and roads for transporting wood and other commodities; exposure of the forest to higher solar radiation, which dries it out and makes it more vulnerable to fire (edge effect); and, finally, human-induced wildfires. In short, clear-cut deforestation eliminates the forest, while degradation, fragmentation, and wildfires doom it to a slow death.[41] In 2023, David Lapola and colleagues

40. Cf. INPE/PRODES, Monitoramento do Desmatamento da Floresta Amazônica Brasileira por Satélite: "Independente do instrumento utilizado, a área mínima mapeada pelo PRODES é de 6,25 hectares". <http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes>.
41. As Antonio Donato Nobre explains, "degradation is the phenomenon that occurs when the accumulation of disturbances in a stretch of forest (...) prevents that ecosystem from functioning normally". Cf. Camila Costa, "'A grande mentira verde': como a destruição da Amazônia vai além do desmatamento". *BBC News Brasil*, 13/II/2020.

reviewed the extent of the degraded area in the Amazon rainforest. According to this new assessment, 'approximately 2.5 × 10^6 square kilometres [2.5 million km^2] of the Amazon forest are currently degraded by fire, edge effects, timber extraction, and/or extreme drought, representing 38% of all remaining forests in the region'.[42] As pointed out by the authors, carbon emissions from forest degradation are estimated at 0.05 to 0.20 petagrams of carbon (PgC) loss per year. They are almost equivalent to annual carbon emissions from clear-cutting deforestation (0.06 to 0.21 PgC). Another study on forest degradation, by Celso Silva Junior and colleagues, shows that 'degraded forests [in the Brazilian Amazon] currently occupy an area larger than that which has been deforested'. They also warn that the CO_2 emissions resulting from this degradation are not accounted for in the carbon emissions inventories of the Amazonian countries:[43]

> Degraded forests continue to emit more CO_2 than they absorb for many years, becoming significant carbon sources. It is critically important for all Amazonian countries to halt these emissions. This requires reporting the whole range of CO_2 emissions to the United Nations Framework Convention on Climate Change (UNFCCC), including forest degradation.

In 2020, Antonio Donato Nobre aptly called forest degradation 'the big green lie', as degradation is only rarely included in assessments of the declining state of the Amazon rainforest.[44] In the Amazon, logging is often the first phase of clear-cut deforestation and anthropogenic fires. Fig. 9 shows how these destructive processes are intimately associated and also how the area of forest degradation ultimately ended up being of the same magnitude as the area of clear-cutting deforestation for soybean plantations.

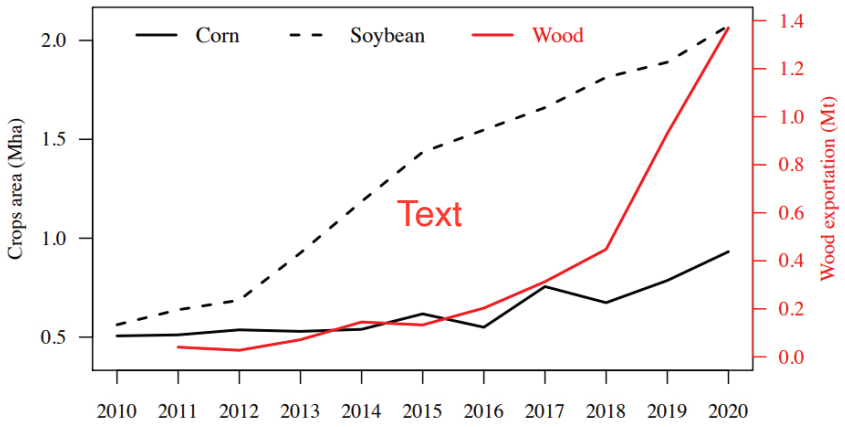

Figure 9: Evolution of harvested area of soybean (dashed line), corn (black line), and wood extraction for exportation (red line) in the Amazon region, in million hectares (left) and million tons (right). Source: Luciana V. Gatti et al., 'Increased Amazon carbon emissions mainly from decline in law enforcement'. *Nature*, 23/8/2023, Extended data Fig. 5a

Fig. 9 also shows how deforestation due to the expansion of the area under soybeans had already gained momentum during Dilma Rousseff's government (2010–2016) especially after the reform of the Forestry Code in 2012, while forest degradation through illegal logging, including in public forests, Conservation

42. Cf. David M. Lapola *et al.*, "The Drivers and Impacts of Amazon Forest Degradation", *Science*, 379, 6630, 27/I/2023.
43. Cf. Celso H. L. Silva Junior *et al.*, "Amazonian forest degradation must be incorporated into the COP26 agenda". *Nature Geoscience*, 14, 2/IX/2021, pp. 634-635. I am grateful to Philip Fearnside for kindly referring this "Letter to the Editor" of which he is one of the signatories.
44. Cf. Camila Costa, "'A grande mentira verde': como a destruição da Amazônia vai além do desmatamento". *BBC News Brasil*, 13/II/2020.

Units, and Indigenous Lands, accelerated strongly after 2015 and especially during Michel Temer's and Bolsonaro's governments (2016–2022). Between 2017 and 2021, exports of raw wood from Brazil, especially from the Amazon region, grew by a staggering 650%.[45] Fig. 9 shows that exports of raw wood in 2020 were almost 1.4 million tons. In 2021, they jumped to 2.36 million tons of raw wood. Data up to July 2021 show that raw wood exports more than doubled compared to 2019.[46] In the Amazonian state of Pará alone, wood exports increased by 23% in volume between January and July 2022 and by more than 100% in monetary value, mainly due to the recovery of the civil construction sector in the United States.[47] This strong acceleration of illegal logging under Bolsonaro is yet another demonstration that the breakdown of environmental governance was one of his administration's highest priorities.

The Amazon and the advent of the Pyrocene

The Pyrocene, a term widely discussed by Stephen Pyne, is one of the attributes that best characterize the Anthropocene. Like a plague or a pyric pandemic, the fires have spread across the continents.[48] According to Matt Jolly and colleagues, 'fire weather seasons have lengthened across 29.6 million km^2 (25.3%) of the Earth's vegetated surface', resulting in an 18.7% increase in global mean fire weather season length from 1979 to 2013.[49] In 2022, forest fires resulted in 30,000 more square kilometres of tree cover loss per year compared to 2001 and accounted for more than one-quarter of all tree cover loss over the past 20 years.[50] From 2016 to 2023, gigantic fires in Australia, Hawaii, and Eurasia (from Portugal to Siberia) and in the Americas (from Canada to the western United States, and in Chile and Brazil), especially in the Amazon, bear sound testimony to this age of more frequent and intense wildfires.

As explained by Ane Alencar, science director of the Institute for Amazon Environmental Research (IPAM), 'Fires in the Amazon usually are the last stage of deforestation. It is the most inexpensive method that people have to convert biomass into ashes so that they can use the land for pasture fields'.[51] The systematic and large-scale fires of primary forest in the Amazon are a practice introduced by the dictatorship. But subsequent civilian governments followed the dictators' example. According to the 'MapBiomas Fogo' Project, an area of 1,672,142 km^2, about one fifth (19.6%) of the Brazilian territory, has already burned at least once between 1985 and 2020, an average of 150,900 km^2 per year.[52] About two-thirds (65%) of the burned area was previously covered by native vegetation (8% of native forest formations). As shown in Table 1, the three biomes that burned the most in absolute and relative terms (percentage of the territory) were the Cerrado, the Amazon, and the Pantanal.

The Pantanal, one of the largest wetlands on the planet, is still home to at least 264 described species of fish, 652 of birds, 102 of mammals, 177 of reptiles, and 40 of amphibians (ICMBio). Since 1985, it has lost 74% of its water surface, mainly due to deforestation and recent human-induced megafires. In 2020,

45. Cf. "Exportação de madeira bruta do Brasil cresce 650% em cinco anos". *Canal Rural*, 11/I/2022.
46. Cf. "Exportações de Madeira em Bruto". Fazcomex, 25/XI/2022.
47. Cfr. Rafael Sobral, "Exportações de madeira atingem aumento de mais de 100%". Rede Pará, 18/08/2022.
48. Cf. Stephen J. Pyne, *The Pyrocene. How We Created an Age of Fire, and What Comes Next.* University of California Press, 2021.
49. Cf. W. Matt Jolly *et al.*, "Climate-induced variations in global wildfire danger from 1979 to 2013". *Nature Communications*, 14/VII/2015.
50. Cf. James MacCarthy, Jessica Richter, Sasha Tyukavina, Mikaela Weisse & Nancy Harris. "The Latest Data Confirms: Forest Fires Are Getting Worse". World Resources Institute, 29/VIII/2023; Alexandra Tyukavina *et al.*, Global Trends of Forest Loss Due to Fire From 2001 to 2019. *Frontiers in Remote Sensing*, 15/III/2022.
51. Cf. Ane Alencar, "Qual a diferença entre queimadas, incêndios e focos de calor?". IPAM Amazônia <https://www.youtube.com/watch?v=cf50yjKzTNM>.
52. Cf. "Projeto MapBiomas – Mapeamento das áreas queimadas no Brasil (Coleção 1). August 2021. <https://mapbiomas-br-site.s3.amazonaws.com/Fact_Sheet.pdf>.

Table 1: Accumulated area burned as a percentage of each biome, and extent of the area burned at least once between 1985 and 2020

	Area burned	**Area burned**
	as a % of the biome	at least once
Cerrado	36%	733,000 km^2
Brazilian Amazon	16.4%	690,000 km^2
Pantanal	57.5%	86,000 km^2

Source: Projeto MapBiomas Fogo (Collection 1)
<https://mapbiomas-br-site.s3.amazonaws.com/Infograficos/MBI-fogo-infografico-PTBR-aprovado.jpg>

criminal fires destroyed 39,030 km^2 in the Pantanal, immediately killing around 17 million vertebrates.[53] This incredibly rich biome is at risk of disappearing well before the end of this century. In 2023 alone, according to MapBiomas (Monitor do Fogo), more than 17.3 million hectares (Mha) were burned in Brazil. This area is equivalent to almost twice the area of Portugal (92,152 km^2), representing an increase of 6% in relation to the area burned in 2022 (16.3 Mha). According to Ane Alencar, 'In 2023, El Niño played a crucial role in the increase in fires in the Amazon, as this climatic phenomenon raised temperatures and left the region drier, creating favourable conditions for the spread of fire'.[54]

Interaction between fires, droughts, and agribusiness destructiveness

Fires in Brazil are exacerbated by increasing droughts across the Amazon, the Cerrado, and Pantanal, in part as a result of climate warming. Once-in-a-century droughts have followed each other in the Amazon since the 1980s in increasingly short time intervals: 1982–1983, 1997–1998, 2005, 2007, 2010, 2015–2016, and 2023–2024. The pace of these megadroughts has accelerated from once every 15–20 years in the final decades of the 20th century to two or three per decade in the 21st century. Indeed, no fewer than five megadroughts have occurred in the Amazon in fewer than 20 years, which is absolutely unprecedented in historical records. In 2013, the National Assessment Report of the Brazilian Panel on Climate Change (PBMC) projected a decrease in rainfall in the Amazon between 2011 and 2040 of around 10% in summer and winter.[55] These predictions were confirmed by the 2015–2016 megadrought (caused by the so-called 'El Niño Godzilla'[56]), which was greater in area and intensity than the previous ones, measured by the Palmer Drought Severity Index (PDSI). Up to 13% of the Amazonian rainforest was affected by extreme drought (PDSI = < -4) in February-March 2016, especially in its heavily deforested Northeast and Southeast regions. As pointed out by several scientists, the severity of the 2015–2016 drought was unprecedented and more severe than predicted by the models.[57] Regarding this catastrophic drought, Juan C. Jiménez-Muñoz

53. Cf. Walfrido Moraes Tomas et al., "Distance sampling surveys reveal 17 million vertebrates directly killed by the 2020's wildfires in the Pantanal, Brazil" *Scientific Reports*, 16/XII/2021.
54. Cf. MapBiomas, Plataforma Monitor do Fogo, "Brasil queimou área maior que o Acre em 2023". https://brasil.mapbiomas.org/2024/01/19/brasil-queimou-area-maior-que-o-acre-em-2023/#:~:text=Mais%20de%2017%2C3%20milh%C3%B5es,Monitor%20do%20Fogo%20do%20MapBiomas.
55. Cf. Tercio Ambrizzi & Moacyr Araújo (eds.), "Contribuição do Grupo de Trabalho 1 do Painel Brasileiro de Mudanças Climáticas ao 1° Relatório da Avaliação Nacional sobre Mudanças Climáticas". Volume 1, Chapter 9 – 9.1. PBMC, 2013, updated in 2016.
56. Cf. Eli Kintisch, "How a 'Godzilla' El Niño shook up weather forecasts". Science, 24/VI/2016.
57. Cf. Amir Erfanian, Guilling Wang & Lori Fomenko, "Unprecedented drought over tropical South America in 2016: significantly under-predicted by tropical SST". *Scientific Reports*, 19/VII/2017.

and colleagues stated: 'This is up to a fifth more extreme drought area than in previous events, where such an intense drought severity did not affect more than 8–10% of the rainforests'.[58]

Due to the combination of a strong El Niño and exceptional warming of the North Atlantic[59] (the latter being part of a structural acceleration of global warming) the drought of 2023–2024 has surpassed that of 2015–2016.[60] As pointed out by Costa and Marengo (2023), 'the current drought is the most extreme ever seen in the historical record, and somewhat unique since it started during the pre-rainy season, while in previous events, drought occurred during the peak of the rainy season'. Costa and Marengo also explain that the drought has been characterized by four heatwaves, which greatly reduced river levels, and state that 'several large rivers experienced the most extreme reductions in water levels since 1902'.[61] Indeed, in September, at least four of the six largest rivers in the Amazon Basin (the Negro, Branco, Amazonas, and Purus rivers) reached their lowest levels since records began.[62] In 2023, Manaus, the capital of the state of Amazonas, had the third-worst air quality in the world, mainly due to illegal fires. The 2023–2024 drought left the Rio Negro at its lowest levels in 121 years of records and exposed large areas of the riverbed, causing the death of more than 150 dolphins in a lake where water temperatures reached 39° C.[63] The level of the Negro River on February 16, 2024, was just 21.8 metres above sea level, that is, around 1.5 metres below its level on that date last year, which was already a record low. Table 2 shows the loss of depth in the Negro River over the last four years.

Table 2: Height of the Rio Negro above sea level on 16 February for the last four years

2021 – 25.35 m
2022 – 23.92 m
2023 – 23.18 m
2024 – 21.80 m

Source: Neuton Corrêa, 'Amazonas: rios enchem menos do que em 2023, ano de seca histórica'. BNC Amazonas, 18/1/2024

The cycle of dramatic droughts alternating with diluvian floods in the Amazon is a typical early warning of collapse. This combination indicates that the climate system in the Amazon is going through an unstable phase before reaching a new state of equilibrium. The forest will not be able to resist the increasing frequency of major droughts for much longer. Alarmed by an imminent tipping point in the Amazon, Nico Wunderling and colleagues titled a paper published in 2022: 'Recurrent Droughts Increase Risk of Cascading Tipping Events by Outpacing Adaptive Capacities in the Amazon Rainforest'.[64] The dire warning contained in this article is summarized by Liz Kimbrough in three statements:[65]

58. Cf. Juan C. Jiménez-Muñoz *et al.*, "Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016". *Scientific Reports*, 8/IX/2016.
59. Cf. Zeke Hausfather, "Are temperatures this summer hotter than scientists expected?" Berkeley Earth, 27/VII/2023; Andra J. Garner, "Observed increases in North Atlantic tropical cyclone peak intensification rates". *Scientific Reports*, 13, 2023.
60. Cf. Juliana Radler & Vanda Witoto, "2023: o ano em que a Amazônia secou". Instituto Socioambiental (ISA), 19/XII/2023.
61. Cf. Flávia Costa & José Marengo, "Statement on the 2023 Amazon Drought and Its Unforeseen Consequences". The Amazon We Want. Science Panel for Amazon, 23/XII/2023.
62. Cf. "4 rios da Bacia Amazônica chegaram ao menor nível histórico". *G1*, 7/X/2023.
63. Cf. Philip M. Fearnside & Rosimeire Araújo Silva, "Seca de 2023 indica futuro desastroso para a Amazônia e seu povo". *The Conversation*, 6/XI/2023.
64. Cf. Nico Wunderling *et al.*, "Recurrent droughts increase risk of cascading tipping events by outpacing adaptive capacities in the Amazon rainforest". *PNAS*, 119, 32, 2/VIII/2022.
65. Cf. Liz Kimbrough, "More droughts are coming, and the Amazon can't keep up: Study". *Mongabay*, 16/IX/2022.

- 'In severe droughts, when the forest loses more water to evaporation than it receives from rain, the trees begin to die. For every three trees that die due to drought in the Amazon rainforest, a fourth tree, even if not directly affected by drought, will also die.
- As trees are lost and the forest dries up, parts of the Amazon will rapidly approach a tipping point, where they will transition into a degraded ecosystem with few to no trees.
- The southern and southeastern Amazon are the most vulnerable regions to tipping. Here, deforestation and fires are at their most extreme, driven largely by cattle ranching and soy farming'.

That said, despite the obvious contributions of climate change and droughts, the increase in forest fires in the Amazon is mainly due to the actions of criminals. Marcus Silveira and colleagues studied forest fires in the Amazon biome from 2003 to 2020, with special attention to the year 2020. Here are the results of their research:[66]

> The annual extent of areas with fire anomalies was significantly associated with the annual extent of areas with deforestation anomalies, but not significantly associated with the annual extent of areas experiencing water deficit anomalies. In 2020, the total burned area in the Amazon was the greatest since 2010, and the ratio of burned area per active fire was the second greatest of the time series, despite a much lower extent of areas with anomalously high-water deficit in comparison to the 2015–2016 megadrought. (...) Our findings suggest that the majority of anomalously high fire occurrences in the Amazon since 2003 did not occur in anomalous drought conditions. The intensification of agricultural fires and deforestation aggravated the burning of Amazonian ecosystems in 2020.

For European readers, an area bigger than Cyprus [9,251 km^2] was destroyed in the Brazilian Amazon rainforest between August 2020 and July 2021, mainly by cattle ranchers.[67] Table 3 shows the number of fire outbreaks in the Brazilian Amazon in the month of August during the years 2011 to 2022. These numbers attest that during the four years of Bolsonaro's presidency (2019–2022), fire outbreaks remained at a clearly higher level than the average for the years 2011–2018.

As indicated in Table 3, 121,383 fire outbreaks were identified between 2019 and 2022.

In August 2022 alone, INPE (*Programa Queimadas*) identified 33,116 fire outbreaks (*focos de calor*) in the Amazon, the highest number in 12 years (an 18% rise from 2021). Between August 20 and 24, 2022, atmospheric concentrations of carbon monoxide (CO) released by fires in the Amazon hit a catastrophic level (Fig. 10).

During the first eight days of September 2022, more than 20,000 active fires were detected by INPE, which exceeded the total for this month in 2019 and 2021. 'Troublingly', as pointed out by Guilherme Mataveli and colleagues, 'the largest portion of the August and September 2022 fires (35% of them) were in vulnerable protected areas, Indigenous lands, and other public areas'.[68] Large farmers, especially cattle ranchers, are directly or indirectly responsible for the invasions and fires in these protected areas.

66. Cf. Marcus V. F. Silveira *et al.*, "Amazon fires in the 21st century: The year of 2020 in evidence". *Global Ecology and Biogeography*, 31, 10, 9/VIII/2022, pp. 2026-2040.
67. Cf. Bill McGuire, *Hothouse Earth*, Icon Books, 2021, p. 72.
68. Cf. Guilherme Mataveli *et al.*, "Record-breaking fires in the Brazilian Amazon associated with uncontrolled deforestation". *Nature Ecology & Evolution*, 6, December 2022, pp. 1792-1793.

Table 3: Number of fire outbreaks in the Brazilian Amazon in August from 2011 to 2022

Year	Number of fire outbreaks
2011	8,002
2012	20,687
2013	9,444
2014	20,113
2015	20,471
2016	18,340
2017	21,244
2018	10,421
2019	30,900
2020	29,307
2021	28,060
2022	33,116

Source: Isabel Dourado, 'Amazônia sofreu com 33 mil pontos de incêndio apenas em agosto'. *Correio Brasiliense*, 2/IX/2022, based on data from INPE.

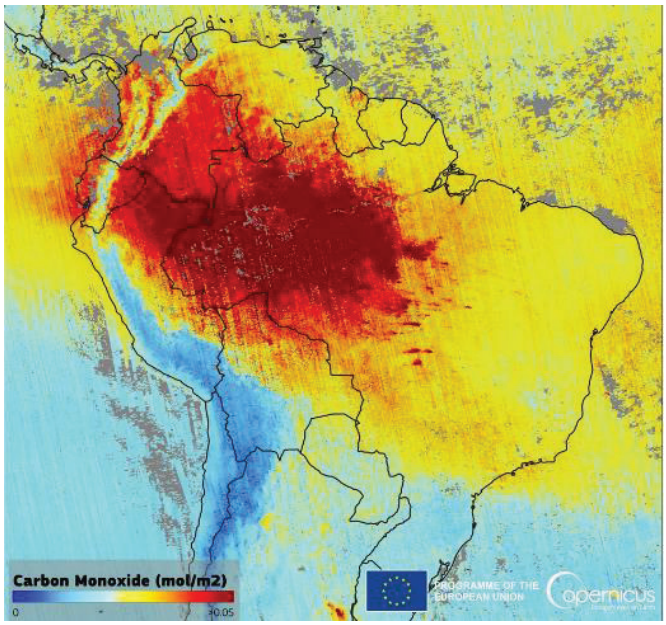

Figure 10: Carbon monoxide (mol/m²) in the atmosphere from Amazon fires
Source: Roberto Peixoto, 'Amazônia tem pior agosto de queimadas dos últimos 12 anos' G1, 1/9/2022, based on data from Copernic and the European Space Agency (ESA)

Fires, warming, and the threat of mass species extinctions in the Amazon

Although less often discussed in studies on the imminence of tipping points in the Amazon, the most excruciating and tragic effects of the ongoing destruction and degradation of the Amazon rainforest are the loss of biodiversity and the risk of species extinction. According to a highly conservative assessment, reported by the Science Panel for the Amazon (SPA) and the IPBES, more than 10,000 species of plants and animals could be at risk of extinction in the Amazon and at least 2,300 animals are at high risk of extinction. Victor Gomes and colleagues projected the increasing significance of climate change (warming

and droughts combined) in Amazon biodiversity loss, 'climate and deforestation combined could cause a decline of up to 58% in Amazon tree species richness, whilst deforestation alone may cause 19–36% and climate change 31–37% by 2050'.[69]

Unlike the Cerrado, the Amazon rainforest did not co-evolve with natural fires, and the impacts of these Amazonian fires on forest functionality and biodiversity are immense. According to Xiao Feng and colleagues, 'since 2001 (...), up to 93.3–95.5% of Amazonian plant and vertebrate species (13,608–13,931) might have been impacted by fires, if only to a minor degree'.[70] The authors estimate that, for every 10,000 km^2 of forest where fire spreads, 27 to 37 species of plants and two to three species of vertebrates lose more than 10% of their distribution areas. As the authors do not fail to warn, these are probably conservative estimates because they assess the impacts of fire only on vertebrates and also because they do not consider the history of forest losses and degradation prior to 2001. Between 2001 and 2019, the majority of nearly 15,000 plant and vertebrate species in the Amazon basin was affected by fire.[71] As explained by Paulo Brando, a researcher on the impacts of fires in the Amazon, 'many species of plants and animals in the Amazon have restricted distribution areas, which increases the chances of these forest fires causing great losses in biodiversity'.[72]

Conversion of the Amazon rainforest into a net carbon source

After 50 years of forest destruction, the age of consequences is now emerging. The temperature measurements in the Brazilian Amazon show average regional warming of much greater magnitude than average global warming. In addition, the Amazon rainforest is being converted into a net source of carbon.

Luciana Gatti and colleagues found a temperature increase of 2.5 °C at the peak of the dry season (August–October) in the Amazon basin during the years 1979 to 2018. As expected, warming in the southeast of the forest, located in the arc of deforestation, is greater than in the biome as a whole because it was already 29% deforested by 2020, and the deforestation increased 80% in 2019 and 87% in 2020 relative to the 2010–2018 mean. Between 1979 and 2018, the southeastern Amazon warmed by 2.54 °C (+/- 0.29 °C) and at increasing rates over the last 40, 30, and 20 years, as shown in Table 4.

Table 4: Rates of warming in the southeastern Amazon per decade over the last 40, 30, and 20 years (1979–2018) during the dry months (August–October), and the annual mean

	Period of time	**Temperature**	**Temperature**
		increase/decade	increase/decade
		August–September Mean	Annual Mean
Southeastern	last 40 years	0.64°C	0.37°C
Amazon (ALF)	last 30 years	0.79°C	0.51°C
	last 20 years	0.91°C	0.61°C

Source: Luciana V. Gatti et al., 'Amazonia as a carbon source linked to deforestation and climate change'. *Nature*, 595, 14/7/2021, pp. 388–393.

69. Cf. Victor H.F. Gomes *et al.*, "Amazonian tree species threatened by deforestation and climate change". *Nature Climate Change*, 9, 2019, pp. 547-553.
70. Cf. Xiao Feng *et al.*, "How deregulation, drought and increasing fire impact Amazonian biodiversity". *Nature*, 1/IX/2021.
71. Cf. Thomas W. Gillespie, "Policy, drought and fires combine to affect biodiversity in the Amazon basin". *Nature*, 597, 23/IX/2021.
72. Cf. "Estudo: queimadas afetaram 95% das espécies da Amazônia em 20 anos". *ClimaInfo*, 2/IX/2021.

Table 4 reveals that the monthly mean temperatures increased by 3.07 °C (+/- 0.29 °C) over 40 years in August and September, the months with the greatest changes in the historical series.[73] This alarming level of warming in the southeast region of the Amazon basin during two of the three dry months (August–September) from 1979 to 2018 jumped from an average warming of 0.64 °C per decade over the past 40 years to an average warming of 0.91°C per decade over the past 20 years. This regional warming rate during these two months of the dry season is more than three times greater than the average global land warming, which rose 0.27 °C per decade between 1970 and 2015, as shown in Figure 11.

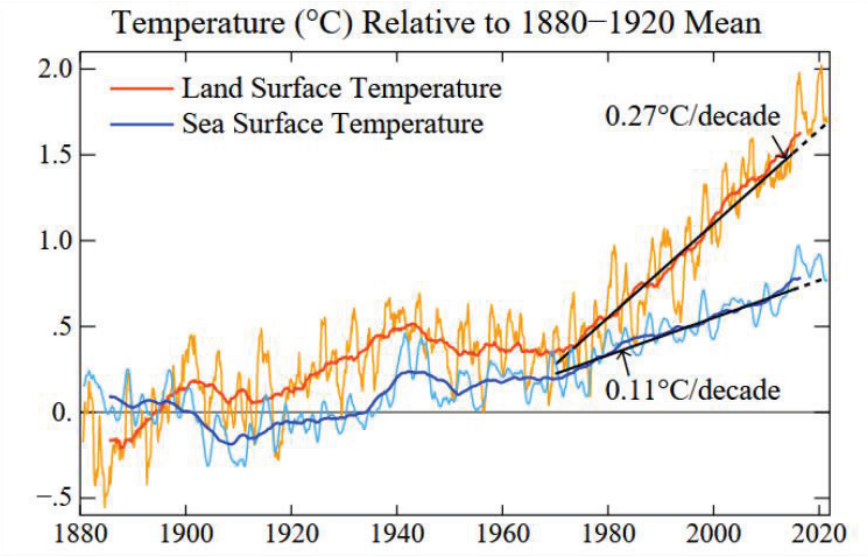

Figure 11: Land and Sea Surface temperature (1880–2020) relative to 1880–1920 Mean
Source: James Hansen, Makiko Sato & Reto Ruedy, 'Global Temperature in 2021', 13/1/2021 Figure 2. Climate Science, Awareness and Solutions Program. Earth Institute, Columbia University <http://www.columbia.edu/~jeh1/mailings/2022/Temperature2021.13January2022.pdf>

In 2021, Luciana Gatti and colleagues demonstrated that the northeast and southeast regions of the Amazon rainforest had become sources of CO_2 emissions. In 2023, another paper by Gatti and her team discovered a critical measure for assessing the current state of the Amazon rainforest. The imbalance between photosynthesis and respiration, or between the absorption and release of CO_2, jumped in 2020 to catastrophic levels:[74]

> We estimate that carbon emissions doubled in the years 2019 and 2020, compared with the previous study (2010–2018)[75], because of a reduction of law enforcement in Brazilian Amazonia, resulting in an important increase in deforestation during 2019, and in 2020 the climate stress was also an additional cause for carbon source.

It is important to understand that this recent increase in carbon emissions was observed across the entire forest, and not only in its eastern and southern regions:

73. Cf. Gatti *et al.*, cit. (2023). This section of the present paper owes a particular debt to researches coordinated by Luciana Gatti (INPE) on the carbon fluxes in the Amazon rainforest between 2010 and 2020.
74. Cf. Luciana V. Gatti *et al.*, "Increased Amazon carbon emissions mainly from decline in law enforcement". *Nature*, 23/VIII/2023.
75. Cf. Luciana V. Gatti *et al.*, "Amazonia as a carbon source linked to deforestation and climate change". *Nature*, 595, 14/VII/2021, pp. 388-393.

> Comparing the mean for 2010–2014 with 2016–2020 for the whole Amazonia, we observed 50% increase in total carbon emissions (...), 31% decrease in carbon sink (...), and 16% increase in fire emissions (...). This consistent increase in the last 5 years was accelerated in the last 2 years of the period, showing the importance of public policies to prevent deforestation, degradation, and fire occurrences.

Thus, the Amazon region has already switched from being approximately neutral, or a carbon sink, to being a net source of carbon. This assessment is based on the forest carbon sink and all emissions in the region. At the southeast, this switch indicates that the mortality of the trees is now greater than their regeneration capacity. In plain words, the Amazon rainforest is dying more than growing in this area.

Drivers of water stress in the Amazon rainforest — a new assessment

This interaction between fires, megadroughts, the destructiveness of agribusiness, and the conversion of the Amazon rainforest into a net carbon source recently received a new synthesis that deserves separate analysis. In February 2024, Bernardo Flores, along with 23 highly experienced researchers, published a prospective assessment of the Amazon rainforest,[76] which received perhaps the widest ever coverage in the non-specialized press for a study on this topic.[77] This new comprehensive study combines several metrics, paleorecords, observational data, and modelling studies on the forest's ecological response to the cumulative effects of a range of threats. The researchers explain their approach as follows, 'We analyse existing evidence for five major drivers of water stress on Amazonian forests, as well as potential critical thresholds of those drivers that, if crossed, could trigger local, regional, or even biome-wide forest collapse'.

Flores and colleagues reiterate the most important data and diagnoses proposed in scientific literature about the current and future situation of the Amazon rainforest:

(a) 86% of the Amazon biome may still present a state of stability, but some of the stretches that appear stable are exhibiting signs of fragility, with increased mortality and reduced carbon sequestration capacity.
(b) Droughts and fires are intensifying and proliferating across larger areas throughout the Amazon region due to several factors, including increasing deforestation.
(c) Up to 38% of the forest biome has been damaged by extreme droughts, fires, logging, and edge effects, showing many signs of degradation.
(d) The southeastern Amazon rainforest is already emitting more carbon than it is capturing, given the ever-increasing extent of deforestation, degradation, droughts, and fires.
(e) Paleoclimatic data do not significantly reduce uncertainties about the Amazon's critical thresholds. As the authors aptly note, drought periods in the Amazon within the past 65 million years coincided with cooler temperatures, which probably reduced water demand by trees: 'Past drier climatic conditions were therefore very different from the current climatic conditions, in which observed

76. Cf. Bernardo M. Flores *et al.*, "Critical transitions in the Amazon forest system". *Nature*, 626, 14/II/2024, pp. 555-564.
77. The paper received several reviews in the Brazilian press, as well as in French, Italian, Spanish, German and English. Here are some examples of reactions in the English-language press: Jonathan Watts, "Amazon rainforest could reach 'tipping point' by 2050, scientists warn". *The Guardian*, 14/II/2024; Manuela Andreoni, "A Collapse of the Amazon Could Be Coming 'Faster Than We Thought'". *The New York Times*, 14/II/2024; Rosa Rahimi, "The Amazon has survived changes in the climate for 65 million years. Now it's heading for collapse, a study says". *CNN*, 14/II/2024; Adam Vaughan, "Half of Amazon risks reaching tipping point to become savannah". *The Times*, 14/II/2024; Andrew Jeong, "Parts of Amazon rainforest could tip toward collapse by 2050, study warns". *The Washington Post*, 16/II/2024.

warming trends may exacerbate drought impacts on the forest by exposing trees to unprecedented levels of water stress'.

(f) In the coming decades, temperatures will become higher, and rainfall will decrease across the entire Amazon, particularly in the more deforested eastern and southern Amazonian regions. 'These areas could potentially warm by over 4 °C by 2050 (...), exposing the forest and local peoples to potentially unbearable heat. Rising temperatures will increase thermal stress, potentially reducing forest productivity and carbon storage capacity and causing widespread leaf damage'.

(g) Fertilization of the forest by increasing atmospheric concentrations of CO_2 is neutralized by several processes that, in reality, can increase tree mortality. Fertilization is not a valid reason to disregard the dieback scenario.

Based on this scientific consensus, Bernardo Flores and colleagues suggest five safe boundaries of water stress — global warming, annual rainfall, rainfall seasonality intensity, dry season length, and accumulated deforestation — that define a safe operating space for keeping the Amazon rainforest resilient, as well as five critical thresholds that can trigger transition scenarios to another state of the biome once those boundaries are exceeded.

(1) Critical threshold of average global warming above the pre-industrial period: 2 to 6 °C (*low confidence*). 'To avoid broad-scale ecosystem transitions due to synergies between climatic and land use disturbances, we suggest a safe boundary for the Amazon forest at 1.5 °C for global warming above pre-industrial levels, in concert with the Paris Agreement goals'. (This safe boundary of 1.5 °C is already impossible, as by the 2030s global warming will hit or exceed 2 °C above the pre-industrial period[78]).

(2) Critical threshold of annual rainfall: 1,000 mm (800 to 1,150 mm) (*medium confidence*). 'We confirm a potential threshold at 1,000 mm of annual rainfall, below which forests become rare and unstable. (...) For floodplain ecosystems covering 14% of the forest biome, a different critical threshold has been estimated at 1,500 mm of annual rainfall, implying that floodplain forests may be the first to collapse in a drier future. To avoid local-scale ecosystem transitions due to compounding disturbances, we suggest a safe boundary in annual rainfall conditions at 1,800 mm'.

(3) Critical threshold of rainfall seasonality intensity (maximum cumulative water deficit): 450 mm (*medium confidence*).

(4) Critical threshold of dry season: eight months (*medium confidence*). 'To avoid local-scale ecosystem transitions due to compounding disturbances, we suggest a safe boundary of dry season length at five months'.

(5) Critical threshold of accumulated deforestation: 20% deforested (20–50%) (*low confidence*).

We should take into account that the authors consider these critical thresholds to be of low or medium confidence. These uncertainties arise from the fact that the models are unable to adequately integrate at least two fundamental components that define the resilience limits of the Amazon rainforest: (a) the reverberation of impacts from one region to another, given the great connectivity between them; and (b) the unpredictable response of the forest to the various feedback loops at work in this immense biome's process of collapse. Given the synergy between these factors, transition processes in the forest can be triggered at lower levels of disturbance.

78. Cf. James Hansen *et al.*, "Global Warming in the pipeline". *Oxford Open Climate Change*, 3, 1, 2/XI/2023; James Hansen, Pushker Kharecha, Norman Loeb, Makiko Sato, Leon Simons, George Tselioudis & Karina von Schuckmann, "How We Know that Global Warming is Accelerating and that the Goal of the Paris Agreement is Dead". Climate Science, Awareness and Solutions Program. Earth Institute. Columbia University, 10/XI/2023; James Hansen, Makiko Sato, Pushker Kharecha, "Groundhog Day. Another Gobsmackingly Bananas Month. What's Up?". 4/I/2024.

In any case, the collapse of several regions of the Amazon rainforest does not depend on exceeding these critical thresholds. This process is already underway. The authors emphasize that 'forests across the Amazon are already responding with increasing tree mortality rates that are not simulated by these models [CMIP6], possibly because of compounding disturbance regimes'. In short, the authors' central projection is that 'by 2050, 10% to 47% of Amazonian forests will be exposed to compounding disturbances that may trigger unexpected ecosystem transitions and potentially exacerbate regional climate change'. But they also suggest that 'interactions and synergies among different disturbances (for example, frequent extreme hot droughts and forest fires) could trigger unexpected ecosystem transitions even in remote and central parts of the system'.

Tipping points in the Amazon rainforest are now being crossed

Bernardo Flores and colleagues added yet another major contribution to the sense of urgency that must prevail when assessing the imminence of tipping points in the Amazon. That said, the dizzying pace of the Amazon rainforest's destruction observed during the years 2018–2022 and the unprecedented magnitude and extent of the impacts of the 2023–2024 megadrought force us to admit the possibility of even worse scenarios.

Summing up the evolution of all these destructive processes in the Amazon rainforest after the military catastrophe of 1964–1985, Luciana Gatti and colleagues observe the *Blitzkrieg* waged against the forest since 2018:[79]

> Over the past 40 years, deforestation and global warming have been accompanied by reduced precipitation, and warmer temperatures have made the dry season drier, hotter, and longer. This shift promotes stress conditions in the forest. These conditions imply a strong stress for the trees, providing an imbalance between photosynthesis and respiration, increasing the flammability of the trees, which produces an intensification of degradation in these regions, as fire penetrates more and more in preserved forests areas. This process appears to have intensified since 2018.

Undoubtedly, this process has intensified since 2018, and this is the reason why Thomas Lovejoy and Carlos Nobre issued a warning that very year about the imminence of a tipping point in the Amazon rainforest, suggesting that it could be crossed much sooner than predicted by previous models:[80]

> 'We believe that negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to non-forest ecosystems in eastern, southern, and central Amazonia at 20–25% deforestation'.

At the end of 2019, probably in response to the new increase in deforestation in the Amazon, the same authors issued a second notice, stressing that Brazil was facing a 'last chance' to avoid a disaster on a planetary scale:[81]

> How much deforestation could the forest (...) withstand before there would be insufficient moisture to support tropical rain forests or before big portions of the landscape would convert to tropical savannah?[82] (...) The increasing frequency of unprecedented droughts in 2005, 2010, and 2015/16

79. Cf. Gatti *et al.*, cit. (2023).
80. Cf. Thomas E. Lovejoy & Carlos Nobre, "Amazon tipping point" (editorial). *Science Advances*, 4, 2, 21/II/2018.
81. Cf. Thomas E. Lovejoy & Carlos Nobre, "Amazon tipping point: Last Chance for Action" (editorial). *Science Advances*, 5, 12, 20/XII/2019.
82. By stating that the Amazon rainforest is transitioning to a savannah, the authors clearly do not intend to compare this new state of equilibrium with the Cerrado, which is a global hotspot of biodiversity. They refer to a new type of non-forest ecosystem, extremely biologically impoverished.

> is signaling that the tipping point is at hand. (...) Today, we stand exactly in a moment of destiny: the tipping point is here; it is now. The peoples and leaders of the Amazon countries together have the power, the science, and the tools to avoid a continental-scale, indeed, a global environmental disaster.

In 2018, deforestation of the Brazilian Amazon rainforest was on track to cross 20% of its original area. In 2022, as noted above by Gilberto Câmara, it had already lost 21.2% of this original area in Brazil. Given that 62% of the Amazon rainforest is located in Brazilian territory and that deforestation continues to increase in the other eight Amazonian countries,[83] we can assume that the forest as a whole is probably at high risk of crossing a tipping point. Once this threshold is passed, between 60% and 70% of the forest area[84] could cease to be a rainforest biome, with unspeakable and certainly catastrophic planetary impacts.

In 2020, Antonio Donato Nobre announced that an increasing part of the forest had already become incapable of regenerating itself:[85]

> 'Half of the Amazon rainforest to the east is gone — it's losing the battle (...). When you clear land in a healthy system, it bounces back. But once you cross a certain threshold, a tipping point, it turns into a different kind of equilibrium. It becomes drier, there's less rain. It's no longer a forest.

Taken together, the numerous lines of evidence discussed above allow for four tentative conclusions:

(1) The resumption in the last ten years (2013–2022) of an upward curve in clear-cut deforestation, forest degradation, and wildfires, and the intensification of all these processes over the last four years, have already pushed the most degraded parts of the Amazon rainforest in the arc of deforestation to a point of no return. Although some uncertainties in this regard may still remain, many scientists agree, more or less explicitly, with this perception.[86]

(2) Other parts of the Amazon rainforest are probably already crossing points of no return. In 2022, Marlene Quintanilla, Alicia Guzmán León, and Carmen Josse pointed out that in the Amazon, 'the tipping point is not a future scenario but rather a stage already present in some areas of the region. Ninety per cent of all combined deforestation and degradation is concentrated in Brazil and Bolivia. As a result, savannization is already taking place in both countries'.[87]

(3) The Amazon rainforest's loss of resilience as an early warning of a tipping point is being clearly detected. Research in some regions of the Amazon rainforest catastrophically damaged by fires,

83. Cf. Nicola Clerici *et al.*, "Deforestation in Colombian protected areas increased during post-conflict periods" *Scientific Reports*, 10, 2020; María Fernanda Ramírez & Juan Diego Cárdenas, "Felled and Burned: Deforestation in Peru's Amazon". *InSight Crime*, 2/VI/2022: "Today, Peru ranks as the country with the fifth highest rate of deforestation in the world and the third highest in the Amazon, behind Brazil and Bolivia". According to Carlos Nobre, the Amazon rainforest in these eight countries has already lost around 200,000 km^2 of its original area. See C. Nobre, "Está a Amazônia próxima de um ponto de não retorno?", 28/VII/2020 <https://www.youtube.com/watch?v=cg5Rh5CVm48&t=36s>.
84. Cf. Carlos Nobre, "Está a Amazônia próxima de um ponto de não retorno?", 28/VII/2020 <https://www.youtube.com/watch?v=cg5Rh5CVm48&t=36s>.
85. Cf. Jessica Rawnsley, "Amazon rainforest reaches point of no return". *Climate News Network*, 16/III/2020.
86. Cf. Antonio Donato Nobre, "A floresta está chegando muito próximo do ponto de não retorno". Repórter Eco, 7/X/2020: "Part of the forest already passed a point of no return". <https://www.youtube.com/watch?v=-g-JB0zWPV0&t=18s>.
87. Cf. Marlene Quintanilla, Alicia Guzmán León & Carmen Josse, "Amazonia Against the Clock. A Regional Assessment on Where and How to Protect 80% by 2025". Coordinadora de las Organizaciones Indígenas de la Cuenca Amazônica (COICA), Rede Amazônica de Informação Socioambiental Georreferenciada (RAISG) & StandEarth, 2022, p. 8

mining, and deforestation, such as the Baixo Tapajós[88] (in the western part of the state of Pará) and the Purus-Madeira interfluve[89] (central Amazon), already reveals signs of an irreversible loss of biomass or, at least, a loss of forest resilience, which is defined as the return rate from perturbations, reflecting a weakening of the negative feedbacks that maintain stability. Among the early warnings of the imminence of a tipping point in the Amazon rainforest beyond the arc of deforestation, we must seriously consider this progressive loss of resilience. In 2022, Chris Boulton, Timothy Lenton, and Niklas Boers warned that 'more than three-quarters of the Amazon rainforest has been losing resilience since the early 2000s, consistent with the approach to a critical transition'.[90]

(4) We still don't know when unabated deforestation in this crucial decade might cross a red line for other parts of the Amazon rainforest in Brazil. Daniel Nepstad and colleagues' gloomy prospects (published in 2008) for a near-term forest tipping point discussed above may indeed come true by 2030. In any case, we can state that the further one proceeds in the current process of massive biological destruction in the Amazon, the greater the risk of crossing other tipping points in the central and western Amazon.

Concluding remarks — crime, punishment, and the forest restoration war

That being said, it is still possible to take another path. We do not know how much of the more than 850,000 km^2 of forest already cleared in the Brazilian Amazon in the last 50 years can still be saved by waging another kind of war: one of forest restoration. And we will not know unless we attempt this path of recovery. This immense challenge must not only be taken up by the eight Amazon nations and the French Guiane, but must also involve the entire international community. In such a concert of collaborations, the role of Indigenous Populations certainly remains central. We must recognize and adopt the 13-point guidelines set by the peoples of the forest, who have been effective stewards of this biome for millennia. Among these 13 points, we should highlight:[91]

- Legal recognition and demarcation of Indigenous lands;
- An immediate moratorium on deforestation;
- Creation of intangible zones for areas that remain intact and roadless;
- Ecological restoration of degraded lands;
- Halting key drivers of current and future deforestation and industrial development pressures by suspending new licensing and financing for mining, oil, cattle ranching, large dams, logging, and other industrial activities.

Furthermore, in 2015, in the context of the Paris Agreement, Brazil's Nationally Determined Contribution (NDC) included 'Restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes'.[92]

88. Cf. Erika Berenguer *et al.*, "Tracking the impacts of El Niño drought and fire in human-modified Amazonian forests". *PNAS*, 118 (30), 27/VII/2021
89. Cf. Aline Pontes-Lopes *et al.*, "Drought-driven wildfire impacts on structure and dynamics in a wet Central Amazonian forest". *Proceedings of the Royal Society B. Biological Sciences*, 19/V/2021.
90. Chris A. Boulton, Timothy M. Lenton & Niklas Boers, "Pronounced loss of Amazon rainforest resilience since the early 2000s". *Nature Climate Change*, 12, 2022, pp. 271–278.
91. Cf. Quintanilla, Guzmán & Josse, "Amazonia Against the Clock" (cit.), COICA, RAISG and StandEarth, 2022, pp. 14-15.
92. Cf. Intended Nationally Determined Contribution Towards Achieving the Objective of the United Nations Framework Convention on Climate Change. 2016, p. 3.

With Lula's administration (2023–2026), the time has come to finally honour this commitment by the Brazilian State.

Until recently, the Amazon basin was able to mitigate global warming thanks to its ability to absorb CO_2, recycle hydrological flows, and export rain to the continent's south and southeast through its 'flying rivers'. Henceforth, instead of mitigating global heat, the forest will contribute significantly to it. As Timothy Lenton declared to Alex Cuadros, 'the Amazon feeds back to everything'.[93] From now on, the most degraded parts of the forest will act as positive feedback in the ongoing acceleration of global warming and its worldwide impacts. According to a model proposed by David Medvigy and colleagues, for instance, Amazon deforestation impacts precipitation in the northwest United States, and once the forest or parts of it collapse, the snowpack in the Sierra Nevada will experience declines of up to 50%.[94] Recent studies have explored what scientists call 'teleconnections among tipping elements in the Earth system'. Teng Liu and colleagues suggest, for instance, that rapid deforestation in the Amazon rainforest could have effects as far away as the Tibetan plateau and the West Antarctic ice sheet.[95] Therefore, even distant China, which imports huge amounts of soy and meat from the Amazon at the expense of its forest, has a direct and immediate interest in safeguarding it (Fig. 12).

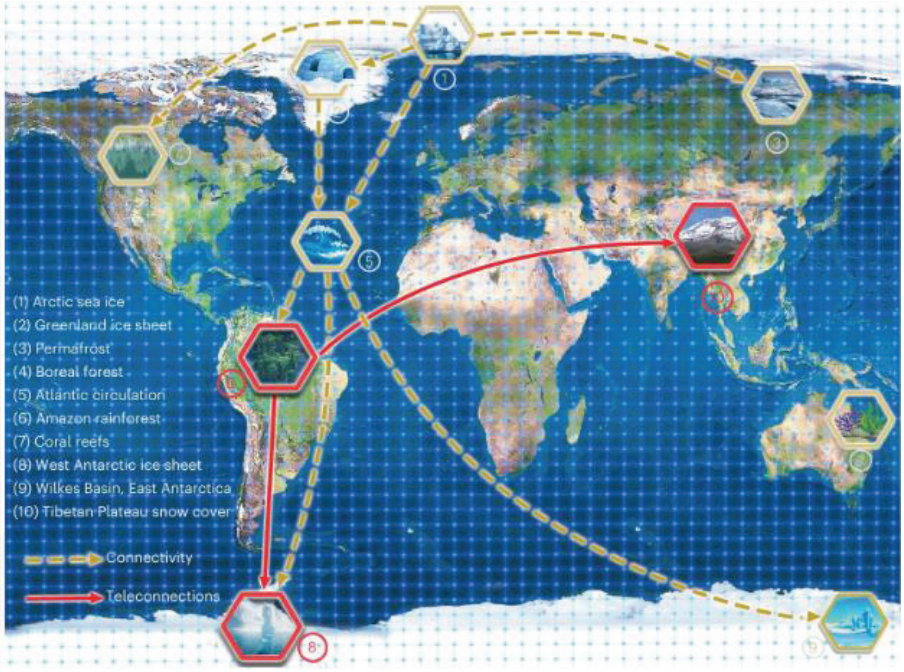

Figure 12: Connectivity and teleconnections between tipping elements of the Earth climate system. Numbered symbols show the potential tipping elements in the Earth system. Dashed yellow lines show the possible connections between these tipping elements, and solid red lines show their teleconnections. Arrows show the direction of the influence. Source: Teng Liu et al., 'Teleconnections among tipping elements in the Earth system'. *Nature Climate Change*, 5/1/2023.

93. Cf. Alex Cuadros, "Has the Amazon Reached Its 'Tipping Point'?". *The New York Times*, 4/I/2023.
94. Cf. David Medvigy *et al.*, "Simulated Changes in Northwest U.S. Climate in Response to Amazon Deforestation". *American Meteorological Society*, 15/XI/2013, pp. 9115-9136.
95. Cf. Teng Liu *et al.*, "Teleconnections among tipping elements in the Earth system". Nature Climate Change, 5/I/2023.

It is an inalienable right of humanity and a duty of Brazilian and international justice to punish those destroying the Amazon. In November 2022, Guilherme Mataveli and colleagues adequately highlighted what is at stake in the defence of the Amazon rainforest and its peoples:[96]

> Tackling the combined effects of deforestation, fire, grilagem [land grabbing] and misappropriation in the Brazilian Amazon, and holding to account those who are destroying the Amazon, are challenging tasks on the environmental agenda facing the Brazilian federal administration that will start in 2023.

So far, after one year of the Lula administration, deforestation by clear cutting in the Amazon has fallen by around 50%. This is obviously a huge achievement, but it is too early to say that this decrease represents a new trend, as the political power of agribusiness remains intact. Punishing all representatives of the broad deforestation coalition in Brazil, which includes the banks that fund the destruction, is equally urgent and necessary. if humanity is serious about surviving, total war on all fronts against the destroyers of nature can no longer be postponed.

(São Paulo, February 22nd, 2024).

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96. Cf. Mataveli *et al.*, cit. (2022), pp. 1792-1793.

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