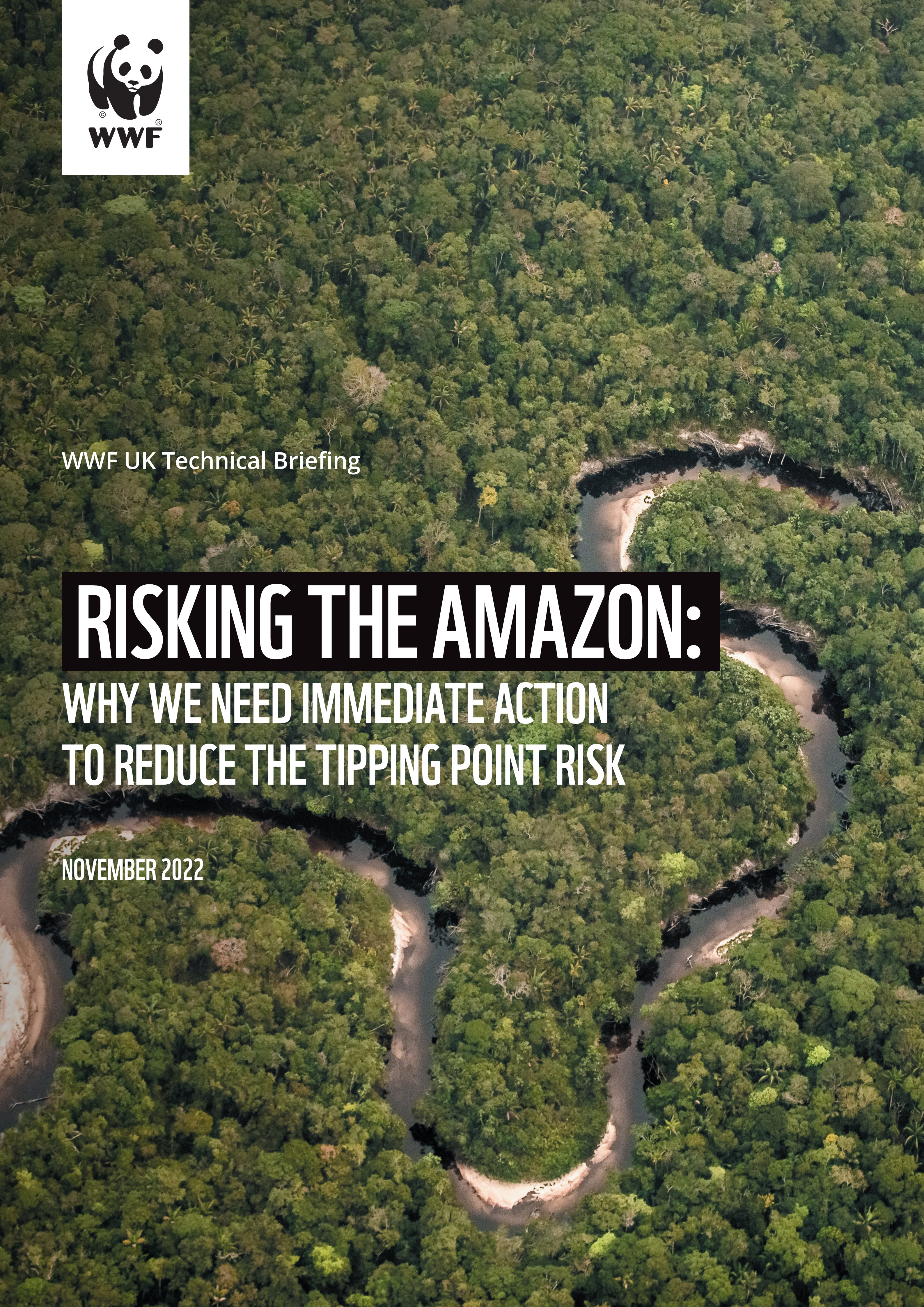

WWF UK Technical Briefing

RISKING THE AMAZON:

WHY WE NEED IMMEDIATE ACTION TO REDUCE THE TIPPING POINT RISK

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ACKNOWLEDGEMENTS

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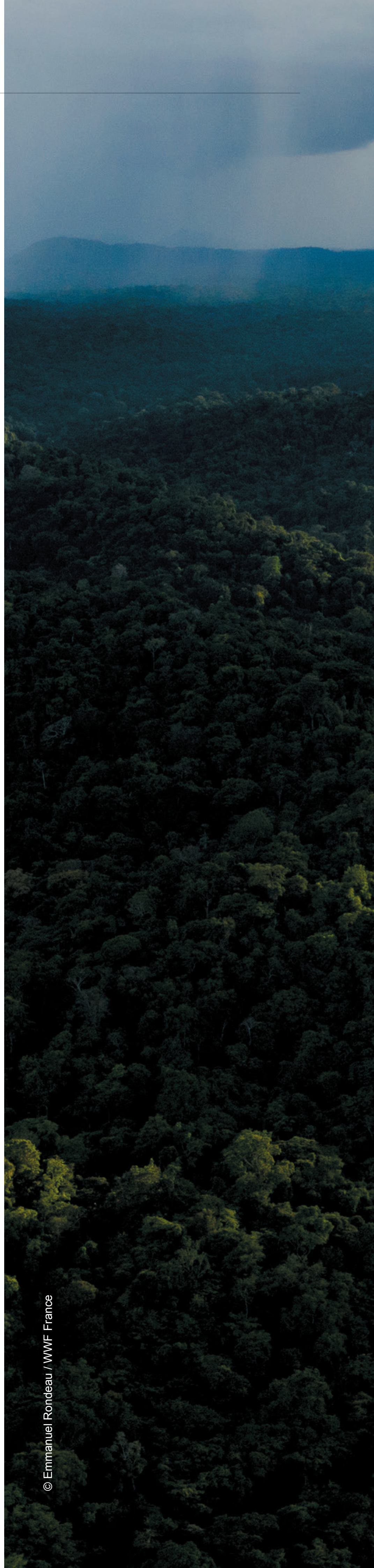

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EXECUTIVE SUMMARY

This technical note has been produced, by WWF UK, in collaboration with WWF Brazil and the WWF Amazon Coordination Unit, with the aim of bringing together the widespread evidence that we are facing a critical risk of abrupt vegetation change (a 'tipping point') in the Amazon biome. We bring together some of the many lines of evidence for the tipping point risk and discuss what reaching it would mean for the biome, the peoples of Amazonia, it's globally unique biodiversity, and the balance of our earth systems. We focus on the scientific and quantitative basis for the tipping point risk. For considerations of impacts to people and livelihood we signpost to the relevant literature base (see research and resources at COICA Coordinadora de las Organizaciones Indígenas de la Cuenca Amazónica, SPA Science Panel for the Amazon, RAISG The Amazonian Georeferenced Socio-Environmental Information Network).

We calculate the area of the Amazon which has already experienced at least one of three, theoretical, tipping point thresholds. from those defined by the Science Panel for the Amazon.

1. **Decreasing annual rainfall**
2. **Increasing dry season length and**
3. **Percentage of forest loss**

We find that around a third of the Amazon biome area (34.4%) has already experienced at least one theoretical tipping point threshold, with the climatic tipping thresholds accounting for the largest area.

Our timeframe to address the tipping point risk is rapidly shrinking. There is an urgent need to secure the government and private sector decisions required to reduce the risk. We stress the need to take a precautionary approach to the risk, because the consequences of reaching the tipping point would be grave; for the Amazon's 47 million peoples, for its unique biodiversity and, through the risk the carbon release would pose to our climate goals, to the entire planet.

Josiel from Associação Povo Indígena Tenharim (Tenharim Peoples Indigenous Association) APITEM, photographed at Kanindé Ethno-Environmental Defense Association, located in the surroundings of Porto Velho, Rondônia, Brazil

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The Amazon's facts inspire awe. Comprising approximately 6.9 [1] million km^2, the biome spans nine countries and territories, with just over half of the forest in Brazil. An incredible 15% of the photosynthesis which occurs on the entire planet, happens in the Amazon and around 17% of all vegetation carbon on earth is thought to be stored there.

The Amazon is so large, and located in the pathway of the Inter Tropical Convergence Zone, that the entire forest acts as a giant water pump, so powerful that each drop of rain can be recycled through the trees to fall 5 or 6 times, as it crosses the basin from east to west. A stable, short dry season length, adequate water being advected onto the land from the tropical Atlantic, and this cascade of donated water are all essential to maintaining the forest.

Despite the Amazon's awe-inspiring facts, multiple lines of evidence now show that it is possible to stress the forest to the point where it could become held in a permanent state of degradation. The risk is that evapotranspiration is significantly reduced, due to the twin pressures of climate change and forest degradation and loss, impacting even distant, and intact, areas of the forest, resulting in higher tree mortality rates and the reduction of forest humidity and resilience. The combination of pressures can reach a point where they cause an abrupt change in the vegetation state known as a 'tipping point'. If the forest reaches this point, it could be lost to a permanent, continuously degraded state.

Early warning signals of Amazon rainforest destabilization have been detected. Rainfall in the west has fallen by 20% in some areas, as forest is lost in the south and east. Deforestation has reached 33% in some parts of the biome, and the dry season length is increasing. Three-quarters of the forest has been losing its ability to bounce back from disturbance and extreme fire and climate events, since the early 2000's, consistent with an approaching critical threshold in forest resilience.

In drafting this technical note, we hope to address the increasing, observable, modelled and theoretical evidence that we could be approaching a critical risk of abrupt, irreversible vegetation change in the Amazon. Were this to happen, it would be catastrophic for the peoples of the region, for its globally unique biodiversity and could place the 1.5ºC climate target out of reach, releasing the entire remaining carbon budget for that target.

There is a limited timeframe left to reduce the tipping point risk, and avoid the loss of the forest under multiple and increasing climatic, land use, fire and socioeconomic pressures, both from within and outside the region.

The rate of forest loss and degradation in the biome changes over time, in response to policy and governance shifts as do the dominant loss drivers. It is critical that policies to protect the Amazon become stable across the region and through governance changes, safeguard and strengthen indigenous peoples' rights, and are matched by meeting global climate targets.

1 The precise area of the Amazon biome can be defined in a number of different ways, according to which watersheds and headwaters of the basin, and adjacent areas outside it, are included. For the purposes of this technical note the area of the biome is taken as 6.9 million km2 to reflect that area calculation used in the MapBiomas forest cover and loss data. This value reflects recent changes in the area calculations from IBGE 2019 (The Brazilian official Institute on Geography and Statistics) and is in line with the data we have used to define Figure 3, below.

The Amazon is currently living on borrowed time, but it is not too late to reduce the tipping point risk. Amazonian countries have dramatically lowered forest loss rates in the past. The turning point, needed to protect the biome, requires action across nine countries and territories, at a greater pace and ambition than ever before and a long-term commitment to preventing the assertion of harmful interests in the region. Such action needs to be matched by a global commitment to meeting climate targets in order to reduce both the significant tipping point threats to the biome – those from climate change and from forest loss and degradation.

Multiple NGOs and academic groups in the region have made it clear that these ambitions cannot be realised without a larger collaboration to protect and restore the Amazon than has ever been carried out before and one which includes all the voices of the region. Speaking at COP27, in November 2022, Dr Carlos Nobre, the Brazilian Earth System Scientist who brought the tipping point risk in the Amazon to the attention of the world, spoke of the need for an alliance working as one front, united against policies which favour deforestation.

WE DISCUSS THE FOLLOWING:

THE 1.5ºC CLIMATE TARGET WILL NOT BE POSSIBLE WITHOUT THE AMAZON FOREST

- The combined pressures of climate change and loss and degradation, in the south and east, has led to areas of the biome becoming a net carbon source in recent years. The forest is now emitting more than 1 billion tons of carbon dioxide annually. Historically, prior to widespread forest loss and degradation, this was not the case. Time is running out to halt loss, restore what has been lost, and return the biome to one which functions as a net carbon store.
- Published estimates of the Amazon's above and below ground carbon stocks range between 100 billion to 200 billion tonnes, which equates to 367-733 GtCO2 (Gigatons CO_2) stored in the Amazon. The model-estimated global carbon budget for staying within the 1.5ºC climate target is 360--510 GtCO2, meaning the total loss of the Amazon could use up the entire remaining 1.5ºC carbon budget.
- The origin of the climate stresses the Amazon is experiencing lie far beyond the limits and dynamics of the biome, in historical climate emissions. Losing the Amazon would impact the lives of 47 million people, and 10% of the world's biodiversity, and place the 1.5ºC degree climate target out of reach. We note that the 27% of the Amazon occupied by indigenous peoples' territories have the lowest rates of deforestation, and store nearly one third of the region's above-ground carbon.

WE CAN OBSERVE EVIDENCE THAT WE COULD BE REACHING CRITICAL TIPPING POINT THRESHOLDS, AND ARE RUNNING OUT OF TIME TO REDUCE THE RISK

- In ¾ of the forest the trees are losing resilience (their ability to bounce back from disturbances like fire and drought) consistent with the approach of a critical tipping point.
- If rates of forest loss and degradation continue, or accelerate, and what has been lost is not restored, we will rapidly run out of time to safeguard the Amazon.
- Between 13% and 18% of the Amazon biome is calculated to have been lost, dependent upon the reference time-period over which loss is estimated, the physical area of definition and the method of loss calculation.

Throughout this report we note that 'at least' 13% of the forest has been lost and that the percentage of loss is larger using some Amazon area definitions (see footnote 1).

- Over time, the rate of forest loss and degradation has changed, accelerating in recent years, particularly in the Brazilian Amazon. Current loss rates are about 2 Mha per year and, as such, we are continuing to lose an additional ~1%, of the biome area, roughly every 3 years (for values see MAAP, 2022). We are within a few percentage change of the lower end of estimated critical deforestation thresholds for triggering the tipping point (20%). However, 31% of the total lost forest has occurred in the critical water-donating regions in the eastern portion of the biome area (MAAP, 2022). Regrowth and restoration impact the balance of loss, and have increased in some areas of the biome, but secondary forest regeneration is thought to have offset less than 10% of the emissions from deforestation.
- We looked at three of the critical tipping point elements thresholds theorized in the literature – 1. percentage of forest loss, 2. dry season length and 3. average annual rainfall - the size of the area which has experienced at least on theoretical tipping point threshold is alarming. More than a third of the biome (34.4%) has experienced at least one of the critical tipping point thresholds, based on average values for the last 10 years – see Figure 3 below.
- The potential local, regional and global consequences of breaching the tipping point element thresholds, and crossing into a critical abrupt change of vegetation in the Amazon, are serious enough to argue for precaution.
- We need to look to novel and ambitious new avenues to achieving deforestation and conversion-free goals and financing pathways. Many internal commitments have fallen well short in recent years. Removing deforestation from supply chains must be an imperative, along with a suite of additional solutions.

WHAT IS THE CURRENT STATE OF THE AMAZON?

- Land-use change, agricultural production, mining, infrastructure building and illegal land grabbing all contribute to forest degradation and loss in the region. While the major drivers of loss and degradation tend to remain the same, their relative influence, and the dominant actors involved, shifts over time.
- Since 2002, over 27 million hectares of primary forest have been lost across the biome, with an additional 6.7 million hectares impacted by fire. In the Brazilian Amazon, loss is at ~30% in some areas and carbon loses from degradation can exceed those from deforestation.
- The acceleration of forest loss and conversion is particularly significant in the Brazilian Amazon, particularly in the last four years.
- Forest degradation also contributes to tipping point risk and may, in some areas, contribute a higher % of gross biomass loss than direct forest removal. Degradation often also leads ultimately to deforestation.
- Lands managed by indigenous peoples' shows lower average levels of deforestation, but faces numerous threats from land speculators, loggers, illegal miners, and other illegal activities.

REDUCING THE RISK: THE EVIDENCE OF TIMEFRAMES BETWEEN GOVERNMENT/PRIVATE SECTOR DECISIONS AND REAL-WORLD IMPACTS

- We have the benefit of historical experience with previous Amazonian forestry policies to know that time is of the essence if we are to reduce the tipping point risk. Following the introduction of Brazil's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) in 2004, a significant reversal of forest loss, from a very high rate, was achieved in eight years. Recent analysis suggests forest loss in the Brazilian Amazon could be reduced by 90% within a decade under full enforcement of Brazil's Forest Code.

- Historical perspectives allow us to theorise on what might underpin successful policy initiatives going forwards. Successful policy actions under phases such as PPCDAm included a combination of protected area creation, expansion of conservation units, effective deforestation monitoring, greater environmental control with increased public budgets for law enforcement, credit restriction mechanisms, and a rural property registry. Supply chain-specific voluntary agreements, such as the soy moratorium and regional cattle agreements were also involved in the phases of forest loss reduction in the Brazilian Amazon.
- Historically the rate of deforestation has varied in the region, reflecting policy changes from government to government, a situation that needs to change if we are to avoid the catastrophic abrupt change the Amazon is heading for. This will require action across all nine countries and territories, at a greater pace and ambition, then ever before. It is critical that policies to protect the Amazon become fully enshrined and not subject to damaging shots from one administration to the next.
- A coalition of NGOs and research organisations, under the framework “Amazonia for Life” call for at least 80% of the Amazon to come under protection by 2025 – less than three years away. The 80x25 Initiative, led by COICA (Coordinator of indigenous Organizations of the Amazon Basin) and its nine grassroots organizations was adopted as a motion by the IUCN World Conservation Congress in 2021.

WE CONCLUDE:

- Early warning indicators, based on observational data and modelling, reveal potential destabilisation of the Amazon forest is already happening. A third of the biome has experienced at least one of three, theoretical, tipping point thresholds, in the last ten years.
- It is critical that policies to protect the Amazon become time stable and enacted across all countries and territories of the biome and safeguard and strengthen the tenure and human rights of indigenous peoples and local and traditional communities.
- The drivers of forest loss and degradation are diverse and change over time and space. Currently much of the pressure is associated with cattle ranching expansion for beef production, largely aimed at domestic markets. Soy expansion, onto previously converted pasture, places indirect pressure on expansion further into the fringes of forestlands and other habitats within the biome.
- International commodities markets are an additional contributing factor, and it is vital that deforestation, conversion and degradation-free commodities chains are improved and become inclusive of all commodities associated with loss, including extractives such as gold which accounts for 25% of the total value of goods exported from Brazil to the UK.
- Expansion of infrastructure, including informal road development, associated with land speculation, places additional pressure on forests and brings people to frontier lands, which are often areas associated with mining and farming expansion. This frontier land development is also placing pressure on indigenous peoples’ territories and established protected areas.

In responding to the tipping point risks, it would be easy to focus efforts just on deforestation or just on global warming. Neither the Amazon nor the globe can afford such an approach. There is uncertainty in every estimate of future loss, temperature threshold for tipping point risk, feedback and climate projection. We must take a precautionary approach to acting on every one of the tipping point risk elements, despite uncertainty, because of the severity of threat which the Amazon tipping point poses. Uncertainty should not be an excuse to fail to act on the tipping point drivers.

- Stepping back from the current precipice of the tipping point risk means addressing a complex mosaic of drivers and threats. A full analysis of drivers, and the socio-economic contexts in which they operate, is beyond the scope of this paper. We point to recent asks from the Science Panel for the Amazon which focus on halting deforestation and beginning to restore what has been lost.
- We summarise here some potential points of leverage with the hope of furthering discussions to identify those with the highest potential to achieve tipping point risk reduction impacts, at scale.
- Climate change.
    - The tipping point risk is increased by rising global temperatures and climate change, which impact large scale climate features in the region, reducing rainfall. Meeting global climate targets is critical to reducing the tipping point risk.
- Forest loss, conversion and degradation.
    - Deforestation and conversion should be rapidly cut from commodities supply chains, reaching zero deforestation targets, at pace.
    - Zero deforestation and conversion policies should be implemented in all countries and territories covering the Amazon biome, in both forest and non-forest ecosystems.
    - Restoration and natural regeneration should expand at scale and pace.
    - Harmful drivers of loss and degradation, including encroachment of protected and conserved areas and land grabbing of public forested lands, to be eliminated.
- Indigenous people and traditional and local communities.
    - Indigenous people and traditional communities' rights to their lands and territories must be protected and respected, and pending tenure claims attended.
    - Indigenous peoples' and local communities' leadership must be recognised as key to addressing climate change and biodiversity loss.
    - Support must be given to the empowerment of indigenous people and local communities and the means and conditions for effective local territorial governance facilitated.
- Finance and production.
    - Deforesting finance should be eliminated as soon as possible, and no later than 2025, and innovative finance mechanisms be put in place.
    - The relevant commodities-related drivers in the region should be addressed, for example by enhancing market-incentives rewarding sustainable performance of producers.
- Monitoring and policy.
    - Strengthening of the monitoring and enforcement of systems to control deforestation, with lessons on best practices, should be shared.
    - Improved infrastructure planning and socio-environmental impact considerations are needed, while enabling sustainable and natural infrastructure options.
    - Stable and strong environmental institutions and policy arrangements capable of robustly protecting the Amazon through time, regardless of government transitions, are needed.

BACKGROUND

A tipping point in our global environment is a critical threshold, above which a small, further perturbation can alter an entire system, in a way we might not expect (Lenton et al, 2008). In the context of the earth system, tipping points are irreversible on human timescales. We point to Armstrong McKay (2022)[2] for a recent definition.

The Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6) identified fifteen possible global tipping points (see Armstrong McKay, 2022), including such risks as the collapse of the Greenland and West Antarctic ice sheets and widespread, abrupt permafrost thaw. IPCC AR6 did not go as far as to explore the temperature thresholds for tipping points in details and requests have been made for the Panel to explore tipping points in more detail in the future[3]. At a recent UK scientific conference on tipping point risks (https://global-tipping-points.org/) the participants, leading scientists in the field of abrupt change, were surveyed on which tipping points they considered to pose the greatest, current risk. The responses given placed the Amazon at the centre of the area of concern.

Figure 1. Adapted from https://global-tipping-points.org/ and CarbonBrief, 2022

2 "A tipping point is a threshold in a controlling factor, at which point a small additional perturbation can cause a change in the future state of the system. Tipping points occur when the change becomes self-perpetuating beyond a threshold (for example a threshold in the global average temperature) as a result of a non-linear, or asymmetrical, response in the relevant feedback. Tipping points lead to substantial and widespread impacts on the earth system" Armstrong McKay (2022)

3 The Geneva Environment Network, 2022. https://www.genevaenvironmentnetwork.org/events/climate-tipping-points-irreversibilty-and-their-consequences-for-society-environment-and-economies-switzerlands-proposal-for-an-ipcc-special-report/ "The government of Switzerland considers it timely and pertinent to ask the IPCC to elaborate a Special Report on "Climate Tipping Points and their Implications for Habitability and Resources", which will be prepared in the framework of the IPCC's 7th Assessment Cycle, scheduled to start in 2023"

In drafting this technical note, we hope to address the increasing, observable, modelled and theoretical evidence that we could be approaching a critical risk of abrupt, irreversible vegetation change in the Amazon. The consequences, were this to happen, would be catastrophic for the peoples of the Amazon, for the region's globally unique biodiversity and the resultant carbon release could place the 1.5ºC global climate target out of reach. There is a limited timeframe left to secure the government and private sector decisions required to reduce the risk of abrupt change and avoid the loss of the forest under multiple climatic, land use, fire and socioeconomic pressures.

THE 1.5ºC CLIMATE TARGET WILL NOT BE POSSIBLE WITHOUT THE AMAZON FOREST

The Amazon's facts inspire awe. Comprising 6.9 million km^2, the biome spans nine countries and territories, with just over half of the forest in Brazil. It is the source of 15% of the photosynthesis which occurs on the entire planet (Fu et al, 2013) and 20% of the planet's freshwater. The biome stores approximately 17% of the vegetation carbon on the planet (Gorgens et al, 2020).

The Amazon region is presently home to 47 million people including 2.2 million indigenous peoples from more than 511 distinct groups. The quality of life of Amazonian indigenous peoples is intimately linked to the protection of their territories (COICA, 2022 'Amazonia For Life')

The Amazon forest acts as a giant water pump, so strong that any drop of rain falls 5 or 6 times, recycled through the trees, as it crosses the basin via 'flying rivers' which move enormous amounts of moisture across the forest (Zemp et al, 2017; Lovejoy and Nobre 2019) . Yet, despite these awe-inspiring facts possible early warning signals of Amazon forest destabilization have been detected (Armstrong McKay 2022). There is now evidence that it is possible to stress the forest to the point where it could tip to a continuously degraded[4] state (see recent reports from the Science Panel for The Amazon[5], Monitoring of the Andean Amazon Project, and COICA, 2022 'Amazonia For Life').

The Amazon is often described as the world's largest intact tropical forest, and it is a key component of the global climate system. We can legitimately ask whether we can still refer to the forest as 'intact', with at least 13% of the original Amazon forest now lost (Monitoring of the Andean Amazon Project)[6] and a further 17% in a degraded state (Science Panel for The Amazon), with climatic pressure and fire at record highs[7]. The second descriptor serves as a stark reminder of what could happen if we continue to lose and degrade a key component of the global climate system.

Under the combined pressures of climate change, extreme droughts, loss and degradation, concentrated in forests and the Cerrado[8], in the south and east, the biome has become a net carbon source in recent years (Armstrong McKay 2022), with emissions of more than 1 billion tons of carbon dioxide, annually (Gatti et al, 2021). Historically, prior to widespread forest loss and degradation, this was not the case. The intact Amazon was one of the most powerful carbon pools on earth, with an uptake of 0.5 PgC (Peta-grams of carbon – 500,000,000 tonnes) per year (Ritchie et al, 2022). Furthermore, carbon dioxide emissions are only one part of the story, non-CO_2 greenhouse gas emissions (such as methane and nitrous oxide) are also offsetting the draw down of carbon by the forest, such that the net radiative forcing of the biome, in recent decades, has been positive (causing additional warming) (Covey et al, 2021). At this point it has been observed, from airborne measurements, that CO_2 emissions, in some parts of the biome, are a net positive source of greenhouse gas flux, a change from the past (Gatti et al, 2021). It has also been modelled, and estimated, that the various sources of other (non-CO_2 greenhouse gases, CH_4 and N_2O) in the entire Amazon basin is likely to be

4 We define degradation after Vásquez-Grandón et al, (2018). "Degradation is the result of a progressive decline in the structure, composition and functions upon which the vigor and resilience of a forest is based. A degraded forest is one whose structure, function, species composition, or productivity have been severely modified or permanently lost as a result of damaging human activities".

5 The Science Panel for the Amazon (SPA) is made up of more than 240 scientists, including leaders of indigenous peoples. The SPA aims to be a global authority on the Amazon and provides scientific analysis on its status, current trends, and recommendations for long-term sustainable development of its ecosystems and communities. The SPA issued a first Amazon Assessment Report at COP26.

6 Estimates of the percentage of the Amazon biome that has already been lost vary, dependent upon the baseline reference time-period used, the method, and data sets used in calculating loss, the area and habitat types defined as the Amazon biome, and rounding up/down differences. Estimates range from 13% loss (Monitoring of the Andean Amazon Project) to 17% (Armstrong McKay 2022; Science Panel for The Amazon) to 18% (Vergara et al, 2022 and RAISG, 2020). An additional 17% of degraded land area is also estimated (Science Panel for The Amazon). Throughout this note we refer to the loss being at least 13%, with consideration of the potential proximity to the forest loss tipping thresholds in reference to higher % loss figures. If an aggregate of the Amazon basin, Tocantins basis and the western northeast Atlantic basin is used, the loss area is found to be 17% to 18% (see https://amazonia.mapbiomas.org/en, Science Panel For The Amazon Executive Summary, Vergara et al, 2022). If a the Amazon biome area definition is used a loss of 13% (MAAP, 2022) to 14% (Science Panel For The Amazon Chapter 19) is estimated from the data, between 1985 and 2018. When the same area definition is used the different methodologies adopted give rise to within a 1% difference.

offsetting the CO_2 draw down. In addition to the other anthropogenic impacts in the basin, this is likely dominating the net radiative forcing, but there is a much greater level of study needed to fully understand the total greenhouse gas balance of the basin (Covey et al, 2021).

There is widespread evidence for a loss of resilience [9] in the forest, and is not surprising that we now consider Amazon loss and degradation to pose a risk to global climate targets. If rates of loss and degradation continue, or even accelerate, we will rapidly run out of time to safeguard the Amazon, and its vital carbon store.

Historically, up to 200 petagrams of carbon (200,000,000,000 tonnes) has been stored in the Amazon, in above and below ground biomass and soils (Li et al, 2022; Brienen et al, 2015; Ritchie et al, 2022). Due to increased fires, climate change, agricultural conversion, and broader land use pressures, parts of the Amazon are now a significant source of carbon emissions. With 1 ton of carbon dioxide contributing 0.0000000000015ºC of global temperature change (Matthews et al, 2009), the current release of carbon dioxide from the Amazon can be calculated as contributing, 0.00165ºC of additional global warming annually [10].

Estimates of Amazon carbon stocks range between 100-200 petagrams of Carbon (100,000,000,000 to 200,000,000,000 tonnes), this equates to 367-733 GtCO2 (gigatons of CO_2) stored in the Amazon (Brienen et al, 2015; Gatti et al, 2021). The model-estimated carbon budget for staying within the 1.5ºC global average warming target is 360-420 GtCO2 (median for 66% likelihood from WG1 and WG3 [11]) to 460-510 GtCO2 (median for 50% likelihood from WG1 and WG3). This means that the theoretical loss of the Amazon, in its entirety, has the potential to use the entire remaining 1.5ºC carbon budget, in addition to the impacts for biodiversity and humanity that a catastrophic loss of the Amazon forest would bring. If the entire biome were changed to a degraded state, around 75 GtC would be released to the atmosphere. Even this, rather than a total loss, has the potential to cause global warming of an additional 0.1°C to 0.2°C (Armstrong McKay 2022).

Of the world's three largest tropical rainforests (in Southeast Asia, the Congo River basin and the Amazon) only the Congo is still functioning as a strong net carbon sink (WRI, 2021). The emerging shift from an Amazon that is a net planetary cooler, to one where the biome has been degraded to the point where it is warming, not cooling, the planet, is one of the most powerful, observable signs of its damage. It is often said that humanity needs the Amazon (Vergara et al, 2022), and we could see our global climate targets slip out of reach without it. The potential impacts on the region's unique biodiversity, should the tipping point be reached are substantial. They would include impacting 76% of the estimated global jaguar population that lives within the Amazon biome boundary (derived from Jędrzejewski, et al 2018) significantly hindering the conservation of the species as a whole.

TIPPING POINT RISK EVIDENCE AND THE TIMEFRAMES FOR AVERTING IT

The Amazon tipping point refers to the risk that forest loss in one part of the region could lead to loss and degradation of forest in other, distant parts of the biome (Boulton et al, 2022; Lenton et al, 2008; Boers et al, 2017; Lovejoy and Nobre, 2019). In such a case the forest could 'tip' to a state where the Amazon as we know it was lost and replaced by a landscape of degraded forests and grasses, held in a permanently degraded form by frequent drought and fire, even where the forest has not being removed under land use change. More than 76% of the forest has already had its ability to bounce back from fire and drought ('resilience') reduced, since the early 2000s, consistent with the approach to a critical tipping point (Boulton et al, 2022).

The nature of how systems creep towards a tipping point poses a challenge to policy making. There are many unknowns. Long term observations, experiments and model simulations - the full toolkit of research - all indicate that the forest may not change gradually as pressure mounts, but could rather change abruptly in response to the non-linear way different pressures (from climate, fire and land use) interact (Wunderling et al, 2022).

What the tipping point could look like in reality is unknown, it is possible that the most stressed portions of the forest could change to a permanently degraded state, whilst more highly conserved areas, where protection is better and pressure less, remained as forest. For example, there is evidence that the flooded forest might be particularly susceptible to degradation by fire, becoming converting to white sand savannas as fire-disturbed soils lose their clay and nutrients and become increasingly sandy (Flores et al, 2021). Figure 2 describes some of the processes which the scientific evidence suggest are involved, and what the emerging habitat types of a 'tipped' Amazon might look like.

How, and when, the tipping point will progress is an open question (Nobre, 2021). That the tipping point poses a significant risk to humanity, with global consequences if it is reached, are certainties (Armstrong McKay 2022) [12] and require us to follow a precautionary approach to the need to reduce the tipping point risk (Lenton et al, 2019). The uncertainty should not be an excuse to fail to act on the theorised and evidence-based risk drivers.

Heating of the tropical North Atlantic impacts the atmospheric moisture inflow from the Atlantic Ocean to the Amazon

Rising global mean temperature has a decreasing effect on rainfall sums in the Amazon

Deforestation reduces the water pump, the removal of 'water donor' forests in the South and East impacts the forests in the Western half of the basin

GLOBAL AND HISTORICAL

PHYSICAL RISKS

REGIONAL AND CURRENT

Drivers of loss and degradation:
Climate change, agriculture and cattle ranching, land grabbing and speculation, policy shifts, illegal logging, uncontrolled forest fires, poorly planned infrastructure, mining and extractives, domestic and international commodities markets.

Processes in a 'tipped' forest (forming feedback loops)
Breakdown of the 'aerial rivers' reduces evapotranspired water from 'donor' to 'recipient' forests across the basin, east to west. Fire and drought suppresses growth of a mature forest. Seed limitation, competition and generalist species reduces the natural flora and fauna (grasses replace trees).

The 'tipped' Amazon biome
A range of degraded landscape types from 'white sand' savannah, to open or closed canopy degraded forests remain. In the tipped savannah and forests species competition, regeneration and landscape processes such as soil erosion, wildfire and seed bank processes are damaged and in feedback loops which hold the degraded state in place (e.g. fire limits the growth of trees, promotes soil erosion and limits regeneration). Forest specialist species are lost to generalists and habitats are held in a degraded state by frequent fire and extreme climate events.

Evidence from climate models

In early climate model simulations, the forest died solely due to climate change feedback processes. As the modelled climate warned and dried, via feedbacks, less moisture was recycled through the forest and regional abrupt vegetation change began.

In more recent, fire enabled models, abrupt change to degraded forest occurred in grid cells where the dry season intensified over time. The change occurred as a mosaic, with patches 'tipping' at local scale, consistent with multiple land use pressures.

Figure 2: Table of theoretical and observed drivers and processes involved in the Amazon tipping point risk.

7 https://amazonwatch.org/assets/files/2022-amazonia-against-the-clock.pdf report that since 2000 an area the size of Bolivia has burned across the Amazon biome.

8 The Cerrado (also known as neotropical savannah) is a habitat of global biodiversity importance for its grassland natural vegetation. The Cerrado has become severely impacted by soybean cultivation which has seen the loss of nearly 50% of the Cerrado's native vegetation cover (Hofmann et al, 2021)

9 Resilience in this context refers to the forest's ability to recover from disturbances such as drought and fire (Brienen et al, 2015; Zemp et al, 2017; Boulton et al, 2022)

10 Based on Gatti et al, 2021, using data from the period 2010 to 2018 and based on carbon emissions calculations after Matthews et al, 2009. WG1 and WG3 are the IPCC working groups looking at the physical scientific basis for climate change and how human-caused climate change can be mitigated, respectively.

11 WG1 and WG3 are the IPCC working groups looking at the physical scientific basis for climate change and how human-caused climate change can be mitigated, respectively.

12 "Given the size of the region affected by even partial die back and its global impacts we categorize the Amazon forest as a global core tipping element (medium confidence)" Armstrong McKay 2022.

Figure 2: The physical scientific processes, and socio-economic drivers theorised and observed to be involved in the tipping point risk, and the stages by which it might be observed in the forest. All are complex and multiple. Climate model evidence also gives insight into what the 'tipped' Amazon biome might look like.

The physical processes involved in the tipping pint risk include - the aerial transportation of precipitation via evapotranspiration; the level, frequency and intensity of fire; how moist the understory is and how frequent and intense droughts are; the average annual temperate and precipitation; and how long the dry season is (see Science Panel for the Amazon for a full discussion).

Precipitation is recycled by the Amazon, powered by the onshore winds of the Inter Tropical Convergence Zone. The forest recycles, on average, around a third of the basin's rainfall, via evapotranspiration, with each raindrop falling 5 or 6 times as it crosses the forest (Armstrong McKay 2022; Zemp et al, 2017; Staal et al, 2018). But in some areas of the basin, up to 75% of the rainfall returns to the aerial river via evapotranspiration (Lovejoy and Nobre, 2019). Far downwind of the eastern forest areas, more than half of an area's rainfall could depend on evaporation passed from the east (Barlow 2018, Van der Ent et al, 2010). Essentially - the forest maintains the forest; thus loss can cause further loss. When the forest is lost to degradation, or conversion, this has a huge impact on evapotranspiration. Evapotranspiration from agricultural pasture is around 60% that of rainforest, and in cropland it can be as low as 10% that of primary rainforest (Miralles et al, 2014).

Deforestation in eastern Amazonia is already thought to be reducing evapotranspiration, which in turn is reducing the recycling of transported water vapour to western Amazonia. Gatti (2021) find that a possible reason for a 20% decrease in rainfall in western central regions of the Brazilian Amazon could be the loss of this 'cascade effect' water.

This evaporative recycling of the Amazon's rainfall means a disrupted forest is susceptible to a positive climate feedback loop as illustrated in Box 1.

THE AMAZON POSITIVE FEEDBACK LOOP:

Adapted from Zemp et al, 2017; SPA, 2021.

1. Forest loss
2. Decreased evapotranspiration and water recycling
3. Reduced rainfall
4. Increases in the length of the dry season
5. Reduced relative humidity
6. Increased fire frequency, severity and duration, increased forest flammability
7. Further increases in forest loss

Box 1. The Amazon positive climate feedback loop.

The Science Panel for the Amazon (SPA) report the following values for tipping point risk elements involved in the positive feedback loop:

1. Annual rainfall falling below 1000-1500 mm/yr
2. Dry season length increasing to above seven months
3. Average global warming of 2ºC
4. 20-25% accumulated deforestation

These four set points are associated with observations which allow us to track how much of the biome has experienced these theorised, critical thresholds.

THE AMAZON ACTS LIKE A GIANT WATER PUMP

So powerful that each drop of rain can be recycled through the trees to fall 5 or 6 times, as it crosses the basin.

This cascade of water is essential to the biome.

1. RAINFALL REDUCTION

Observations show rainfall reductions of 20 to 40% downwind of deforested areas within the basin (Zemp et al, 2017, Gatti et al, 2021) . This might seem surprising – why should loss of forest in one area, reduce the rainfall in another? The mechanism responsible is the breakdown of the forest-to-atmosphere feedback and the 'flying rivers' it supports, which cascade evapotranspired (recycled) water downwind across the basin.

One of the many unique features of the Amazon is the forest's ability to influence the regional climate. It was long thought that climate influenced vegetation in biomes, but not the other way around. As scientists started to understand the relationship between the Amazon forest and its atmosphere, it was realised that, in a very large tropical forest, the reverse could also be true, and the forest could also influence its own climate.

The Amazon lies in the path of the easterly trade winds which bring moist, warm air from the tropical Atlantic over the forest. As the forest transpires water, something all trees must do to cool their leaves, heat is released into the atmosphere – a natural process that occurs when the transpired water condenses. This extra heat release sucks even more moisture off the Atlantic because the warm air rises, reducing air pressure and the space is filled by incoming airflow off the ocean. This process, in which evapotranspiration from trees is a critical step, powers a feedback – more evapotranspiration, more moist, warm air advected onto land, more moisture available to be passed on across the basin. And so, the water pump is powered.

This process is thought to enhance the westerly movement of moist air, into the forest from the Atlantic, by a factor of two to three, during the monsoon (Boers et al 2017). But the process is dependent upon the trees being present to transpire water and power the pump. The reduction in rainfall we are now observing occurs when deforestation reduces transpiration to a point where the amount of available moisture in the atmosphere is not enough to maintain the feedback (Boers et al, 2017). Heating of the tropical north Atlantic, via global warming, is also impacting the atmospheric moisture inflow to the basin (Ciemer et al, 2021).

Average annual precipitation in the basin is around 2000 mm, ranging from 3000 mm in the west, to around 1700 mm in the southeast (Nobre 2016). The Science Panel for the Amazon have concluded an average annual precipitation level of around 1000 to 1500 mm is a critical threshold for maintaining the forest. We can observe where this critical tipping point threshold is being reached in the biome, via the region's rainfall records. Large areas of the southwestern fringe of the biome have now experienced years with an average annual precipitation level under 1500 mm more than a dozen times in the last few decades, with parts of the south and central forest biome having experienced between 1 and 5 years with rainfall below this critical threshold in the last 20 years *(CRU TS v4.06, 2000 to 2020 gridded precipitation data).*

The western edge of the Amazon biome is the area though to be most dependant on the forest for moisture delivery, passed on from the donor forests in the east (Weng et al, 2018), making it the natural place to look for early warning signs of the rainfall tipping point threshold. Between 2014 and 2016 Bolivia's second largest lake, Lake Poopó, which supported a vital fishery, dried out completely. Although multiple pressures were involved, the lake drying is said to be a 'canary' for the Amazonian rainfall level tipping point threshold (Bush, 2020; Farthing, 2017; Perreault 2020).

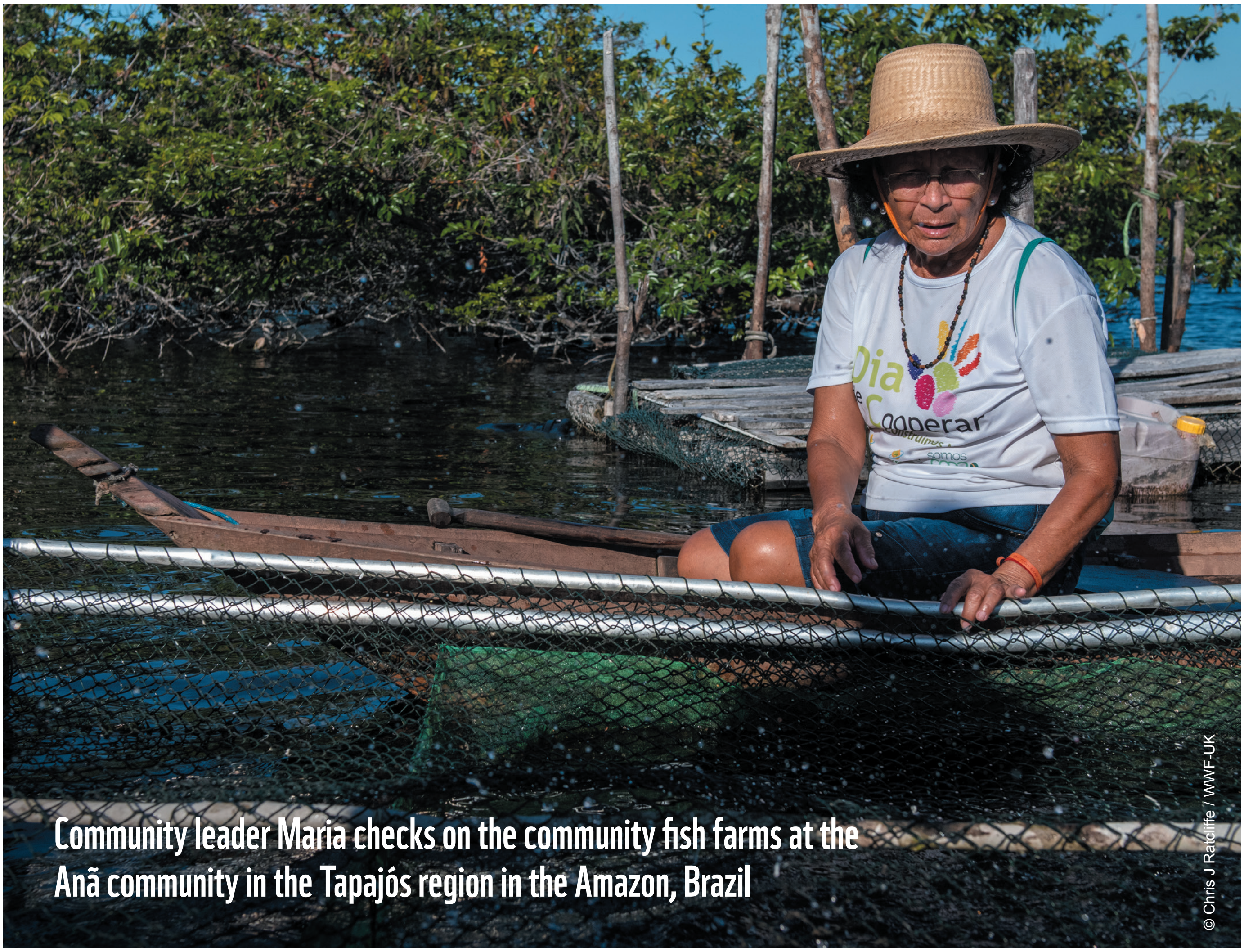
2. DRY SEASON LENGTH

(Fu 2018) observe that dry-season length has increased over southern Amazonia since 1979, via a delay in its end date. Over this period, dry-season length has increased by approximately 6.5 days per decade. The Amazon experienced a very long dry season (of over 8 months, well over the Science Panel for The Amazon tipping point threshold of 7 months), in the 2005 drought. If the rate of drying continues at only half that of the historical past, the 8-month dry season of 2005 will be the new norm by the late 21st century (Fu et al, 2013).

A range of observations suggest large scale climate change features, such as the poleward shift of the South Atlantic convergence zone, have been partially responsible for reducing rainfall in the region (Wainwright et al, 2022). However, deforestation has also played a part, reducing the latent heat flux needed to keep the water pump working and increasing surface temperatures; deforestation is associated with longer dry spells (Wainwright et al, 2022; Li et al, 2016). In response to this pressure, three-quarters of the rainforest has been losing resilience since the early 2000's, consistent with an approaching critical threshold (Barkhordarian et al, 2018; Wainright et al, 2022; Boulton et al, 2022; Ritchie et al, 2022).

We now have observable, and model-derived, evidence that deforestation can trigger irreversible changes in the Amazon hydrological cycle (Xu et al, 2022). Higher rates of forest loss have been observed to coincide with greater atmospheric moisture reduction, particularly in the dry season, with consequential reduced precipitation, in recent decades. Precipitation declines in deforested areas can be up to -2.9 mm per year, above the regional average decline (Xu et al, 2022; Fu et al 2018). The larger the deforested area, the larger the area that is observed to be drying out. Since 2000, drought over the Amazon has been observed at a higher incidence than during the last century (Machado-Silva et al, 2020).

The impact of the Amazon drying out, reducing the aerial river water transportation, is now so severe that it is adding to environmental impacts in areas outside the basin. Up to 70% of the rainfall in the 3.2-million-km2 Rio de la Plata catchment, in Uruguay, is estimated to come from evaporation in the Amazon biome (Barlow et al 2018, Van der Ent et al, 2010). In extremis, drying in the region could reduce the action of the water pump to such an extent that the South American monsoon circulation, which provides water to millions of people, could become weakened (Boulton et al, 2022). It is of huge concerns that, due to the coupling of the forest and atmosphere, widespread deforestation has the potential to see climate impacts cascading westwards, into relatively undisturbed parts of the forest, and even further south into the subtropics, impacting the monsoon system in other regions of South America (Boers et al 2017).



Community leader Maria checks on the community fish farms at the Anã community in the Tapajós region in the Amazon, Brazil

3. AVERAGE GLOBAL WARMING

The SPA identifies 2ºC as a tipping point threshold. However, any increase in global average temperatures makes the tipping point more likely and also has negative consequences for other elements, such as dry season length. As the average global temperature rises, the risk of abrupt vegetation change in the Amazon, increases. It is important to note that global climate change has altered the circulation and large-scale climatology of the region, as the tropical Atlantic has warmed. These global climate pressures are likely to continue to act, in conjunction with land use pressures, within the region itself. It is deforestation, in combination with global climate change that are pushing the Amazon towards a critical threshold (Boulton et al, 2022). Early model-based studies, on the Amazon tipping point, all found the region to be particularly sensitive to change inflicted by global average temperature rise (e.g. Cox et al, 2000; Cox et al, 2004, World Climate Research Programme, 2021, Cox 2013, Nobre 2016).

The IPCC's AR6 report identified fifteen tipping points in the earth system but the report was not able to be explicit about the global temperature thresholds that would trigger each (Armstrong McKay 2022). However, two subsequent studies have explored this. Parry (2022) explored the fire-enabled climate model simulations in the AR6 suite for evidence of abrupt down shifts in carbon, in the Amazon, as simulated warming progressed in the model world. They found that patches of the forest would be converted to a degraded 'tipped' forest, totalling an area of a further 20% of the Amazon, at 1.7ºC of average global warming (in some models). We expect to breach 1.5 ºC of warming during the next twenty years, irrespective of future emissions scenarios (Marotzke et al, 2022), although we have a 40% chance of breaching 1.5ºC, at least once, between now and 2025 (Hermanson, 2022). Seen in this way the temperature threshold for the tipping point element feels alarmingly close. Moreover, the loss and degradation of the Amazon forest is itself contributing to greenhouse gas radiative forcing as parts of the biome become net CO2 emitters (e.g. Gatti et all, 2021).

Armstrong McKay (2022) have assessed evidence to identify the temperature thresholds at which tipping points around the globe could be triggered. Their findings, which are based on the observed, modelled, and theoretical evidence from published literature, are in Table 1. The authors conclude that the minimum global climate threshold for Amazon dieback is 2ºC (with an average of 3.5ºC and a maximum of 6ºC) with a minimum likely time scale of 50 years (with an average likely time scale of 100 years and a maximum of 200 years). Whilst these predicted timeframes might appear distant, the impacts of the global temperature increase will not act in isolation but will interact with other tipping point threshold elements with the potential for positive feedbacks.

Threshold ºC (average)	Threshold ºC (Min)	Threshold ºC (Max)	Threshold (Years – av)	Threshold (Years – min)	Threshold (Years – max)	Maximum Global Impact
3.5ºC	2.0ºC	6.0ºC	100	50	200	75 Gigatons Carbon, 0.2ºC of additional warming

Table 1. Potential global temperature thresholds for the Amazon tipping point, and maximum global impacts of it. Adapted from Armstrong McKay (2022)

WHAT DOES THE CURRENT PICTURE OF AMAZON TIPPING POINT RISK LOOK LIKE?

(Boulton et al, 2022) find evidence of rising dieback in more than three-quarters of the Amazon forest, since the early 2000s, consistent with a loss of resilience. Exploring past growth rates in trees from their rings, has also revealed that rates of growth (measured via net above-ground biomass) have declined by one-third during the past decade, compared to the 1990s (Brienen et al, 2015). This is a consequence of tree growth rate levelling off in recent years, as moisture has become a growth limiting factor, and tree longevity has shortened.

When we bring this picture of change together, we observe:

- A higher rate of drought in recent decades than over the last century (Machado-Silva et al, 2020)
- Three-quarters of the rainforest to have lost resilience since the early 2000's, consistent with an approaching critical threshold (Boulton et al, 2022)
- The length of the dry season over southern Amazonia to have increased (Ritchie 2022)
- The fire season to be longer (observations since 1979) (Fu 2013)
- Up to 70% of the rainfall in areas to the west and south of the forest to be dependent on evaporation from the forest (Barlow 2018, Boers 2017, Van der Ent et al, 2010)

Figure 3 shows three observable, climate and forest loss tipping point elements and which areas of the biome have already experienced at least one of them in the last ten years. Three critical tipping point thresholds are layered across the map of the biome. These elements were selected from the Science Panel for The Amazon, Amazon Assessment Report, as having the most accessible, and fullest available, observational data, and as the three most critical regional climatic and forest cover components [13]. These are: 1) areas where average annual rainfall has fallen under 1500 mm, 2) areas where the dry season length has gone over 7 months and, 3) areas in which accumulated forest loss covers more than 20% of the grid cell. When we look at these three critical tipping point thresholds 34.4% of the Amazon biome has experienced at least one threshold in the last ten years, with the two climatic thresholds dominating the area.

To build the spatial representation of the two climate tipping point thresholds (annual rainfall and dry season length), we used CRU TS4.06 monthly data (0.5º grid), available at High-resolution gridded datasets (uea.ac.uk). Accumulated annual rainfall was averaged over a 10-year period (2012-2021) for each 0.5º grid cell. To estimate dry season length, we subtracted the 10-year average evapotranspiration for each month from the 10-year average precipitation, to obtain the 10-year average surface water availability, for each month. We then extracted the number of consecutive months where this average surface water availability was lower than zero, which represented the average dry season length. To estimate accumulated forest cover loss, we used the land cover transition of the MapBiomas Platform up to 2021, available at Mapbiomas Amazonia Site, and extracted the share of the total area of each 1.0º grid cell where the original vegetation has been removed. The South American Amazon biome limits available on the MapBiomas Platform were used as a spatial extension to cover the biome region.

13 See Chapter 24, Amazon Assessment Report 2021, page 4. https://www.theamazonwewant.org/wp-content/uploads/2022/05/Chapter-24-Bound-May-11.pdf "Systemic tipping points for which there is evidence; four climate-related: (1) annual rainfall value below 1,000-1,500 mm/yr, (2) dry season length above seven months, (3) for Amazon lowlands, a maximum cumulative water deficit above 200 mm/yr, (4) a global increase of 2o C on the equilibrium temperature of the Earth; and one associated with human-induced changes: (5) 20-25% accumulated deforestation of the whole basin." Systemic tipping point thresholds 1, 2 and 5 are mapped in Figure 3.

To build Figure 3, we overlapped the three data layers in the same 0.5º grid cell. For each grid cell we applied the following thresholds: annual precipitation lower than 1500 mm, dry season length equal, or higher than, 7 months and natural vegetation loss of at least 20% of the original area [14] (2012 to 2021). We represented grid cell areas where at least one threshold has been experienced within the ten years to 2021.

There are many different methods by which we could illustrate the observed rainfall, dry season and vegetation loss tipping thresholds, and none are perfect. We chose to show a course resolution, representative of the coarsest data grid and to use a time period for which data across the biome was available. However, regardless of its limitations, we are able, for the first time, to see what a map of theoretical tipping point threshold experience across the biome, over the last ten years, looks like.

With such a large area of the Amazon already experiencing at least one tipping point threshold, it would be easy to imagine the time to reduce the risk is past. This is not the case. Records of how tipping points have behaved in the past, and model experiments, indicate that a tipping point threshold might be exceeded for a short period of time without prompting a permanent change of state. However, analysis of such tipping point threshold 'overshoots' suggest we could have only years, with regards to Amazon overshoot, in which the system could safely be returned to stability, because of the fast onset pace of Amazon forest dieback (Ritchie et al, 2021) [15]. This fast pace has the potential to make the Amazon tipping point one of the most significant and highest risk. The Amazon is living on borrowed time with a closing window of opportunity to return to a safer state, by reducing the climatic and multiple environmental pressures it is under (Hughes et al, 2013, Ritchie et al, 2021).

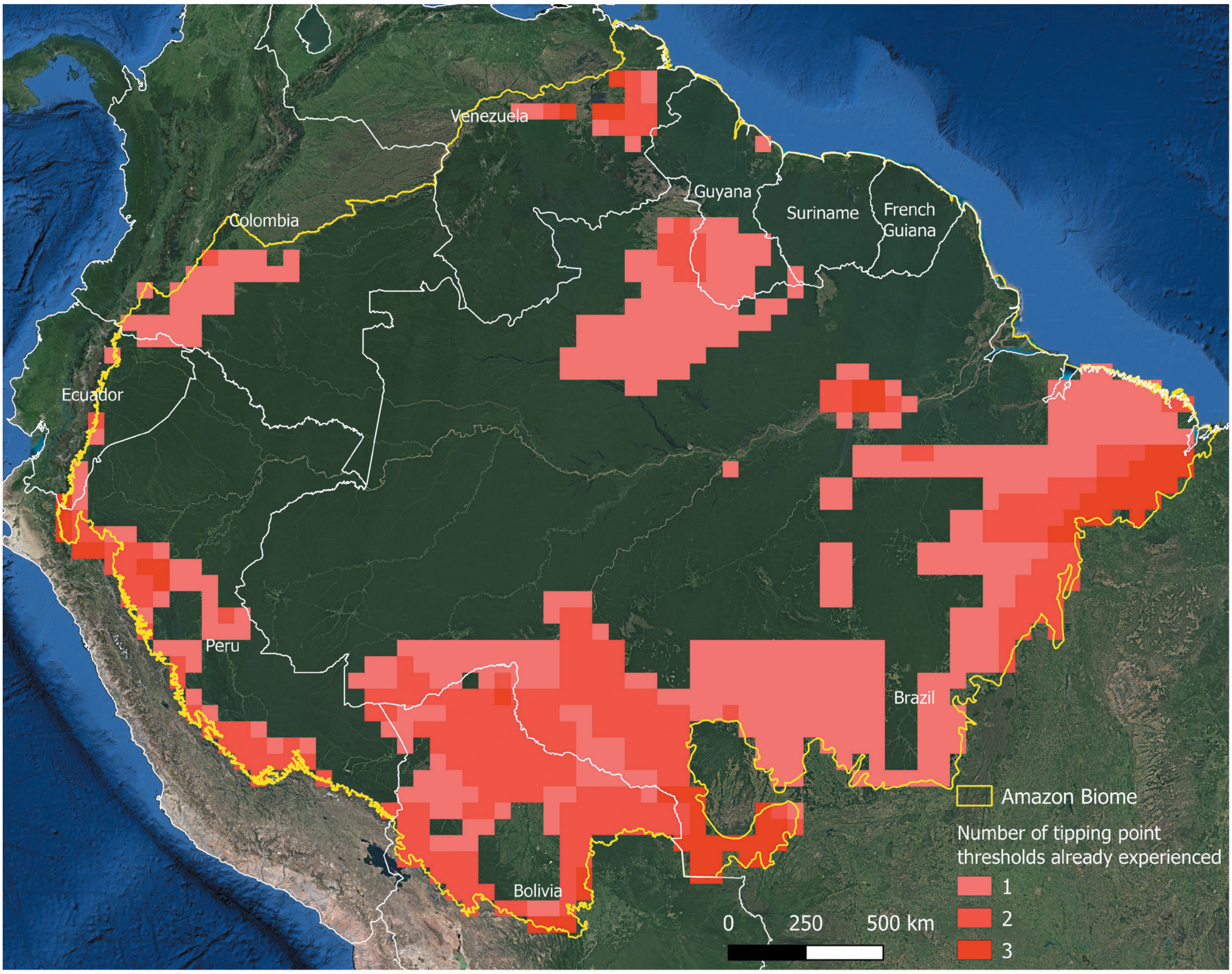


Figure 3 - The areal extent of the Amazon that has experienced less than 1500mm annual rainfall, dry season of more than 7 months, or accumulated deforestation and conversion of natural ecosystems of at least 20% of the original cover (filled in red, with three intensity levels depending on overlapping thresholds). Areas that have experienced one critical tipping point threshold are in palest red, and areas that have experienced all three are in darkest red. 34.4% of the biome area has experienced at least one critical tipping point threshold. The two first regional climatic thresholds are based on CRU TS v4.06 monthly data (0.5º grid) and on average annual rainfall values between 2012-2021, available at High-resolution gridded datasets (uea.ac.uk). The accumulated vegetation cover loss is estimated from land cover transitions of MapBiomas Platform to 2021, in a 1.0º grid cell, available at Mapbiomas Amazonia Site. All data refers to the period 2012 to 2021.

14 20% accumulated forest loss is the lower end of the estimated critical tipping point threshold for forest loss based on model derived estimates. Widespread dieback, consistent with a tipping point, was originally projected at approximately 40% deforestation based on model estimates (at either 3 to 4°C of warming or ~40% deforestation (Armstrong McKay 2022, Nobre et al, 2016) but later model-based estimates exploring feedbacks lowered 20% to 25% (Lovejoy and Nobre, 2018, SPA, 2021) and most recently fire-enabled model estimates have found patches of 'tipped' forest at 1.7°C of average global warming, in some models (Parry et al, 2022)

15 Ritchie et al, (2021) conclude, based on an exploration of model evidence and past climate change evidence explored via dynamical systems theory that "a (tipping point) threshold may be temporarily exceeded without prompting a change of system state, if the overshoot time is short compared to the effective timescale of the tipping element". They indicate tipping thresholds in the Amazon can only be overshot for decades or even years before tipping could be induced.

THE EVIDENCE OF CURRENT ACCELERATION IN DEFORESTATION IN THE AMAZON

DIRECT FOREST LOSS

Since 2002, over 27 million hectares of primary forest have been lost directly across the biome, with an additional 6.7 million hectares impacted by fire (MAAP, Amazon Conservation, 2022). Secondary forest regeneration has offset less than 10% of the emissions from deforestation, despite occupying 28% of deforested land (varying across the biome from 9% in Brazil to 24% in Guyana) (Smith et al, 2021). Regrowth is occurring, and restoration can contribute to the net loss and degradation figure with, for example, forest regrowth in the Brazilian Amazon increasing by at least 70% (2004 – 2014 - from 10 million to 17+ million ha) (Assunção et al, 2019).

The rates of deforestation and conversion across the region have varied through time. Within the Brazilian Amazon, there was a significant reduction in forest loss, from a rate peak in 2004, to 2012 (in line with Brazil's Action Plan for the Prevention and Control of Deforestation in the Legal Amazon, PPCDAm). However, the acceleration of loss and conversion is particularly significant in the Brazilian Amazon in recent years. In 2010 the extent of natural forest in Brazil was 492Mha, covering 59% of its land area. In 2021, 1.55 Mha of 'primary forest'[16] was lost in Brazil (Global Forest Watch, GFW, 2022). The rate of forest loss, in the first half of 2022, was stated by the Amazon Environmental Research Institute (IPAM) as 'breaking all records' (CNBC, 2022), involving the loss of an area of forest 80% bigger than the same time period in 2018 (Brazilian National Space Agency and IPAM Figures).

Elsewhere in the biome a recent analysis of loss estimates, carried out by conservation NGO MAAP (Monitoring of the Andean Amazon Project) found 13% (see footnote 5) loss from the original Amazon area (taken as 647 Million ha by MAAP), with 61.4% of this loss having taken place in Brazil, 12% in Peru, 7% in Colombia, 6% in Venezuela and 5% in Bolivia with the remaining countries and territory (Ecuador, Guyana, Suriname, and French Guiana) share the loss of the remaining 8%.

In addition to loss, forest degradation also contributes to tipping point risk and may, in some areas, contribute a higher percentage of gross biomass loss than direct forest removal. Qin et al, (2021) found forest degradation in the Brazilian Amazon to have contributed 73% (compared to 27% via direct forest loss) to the gross Above Ground Biomass loss, and to be the largest process driving total carbon loss. This is because the areal extent of degradation is much larger than the deforested area. Land degradation also tends to be a precursor to deforestation, placing land at risk of clearance once the forest has been structurally degraded.

There is an important geographical element to the tipping point risk, in terms of where the areas with greatest loss are located. Whilst the forest is known to recycle a huge amount of the basin's rainfall, the work done by the trees to power the 'flying rivers' is not evenly spread. Forests in the southern and eastern areas of the basin contribute most to the stability of other forest areas, whilst forests in the south-western Amazon have the opposite role – they are particularly dependent on transpired water 'subsidies' from the south and east (Staal et al, 2018). For the stability of the forest as a whole, the concentration of loss in the biome's southern 'deforestation arc' (where loss is up to 31%, MAAP, 2022) is the worst possible geographical scenario.

16 Differences in quote forest loss figures are often related to the different types and definitions for forest the various monitoring platforms use. Natural forest generally includes a calculation of secondary regrowth, as opposed to primary forest which does not. There are three main types considered. "Forest", generally refers to tree cover (>5m height), including both natural forest and plantation. "Natural forest" generally considers tree cover without plantation but including secondary regrowth. "Primary forest" is that which is mature and has not been completely cleared and regrown in recent history. Further information is available at Global Forest Watch, GFW, 2022

FIRE RELATED FOREST LOSS

During the 2000s, ~85,000 km2 of primary forests burned in the Amazon (Brando 2020). The forest is becoming more flammable as the climate dries out, land surface change adds pressure, and extreme weather intensifies. Such pressures combine to dry out the understory, making the forest more flammable (Brando et al, 2020). The regional droughts of 2007 and 2010 burned up to 12% of the eastern Amazon forests, compared with <1% in non-drought years. In 2019, an increase of 60% in the cumulative fire count in Brazil, Bolivia and Peru was observed [17].

Fires were involved in 22% (436,000 ha) of the total forest lost in the Amazon biome, in 2022; the 4th highest fire-loss total on record (Amazon Conservation, 2022). In the first seven months of 2022, the number of fire outbreaks increased by 14% in the Brazilian Amazon, and 6% in the Cerrado, compared to the same period in 2021 (Queimadas Program of the National Institute for Space Research, INPE). Regional climate projections and model simulations indicate that climate change will double the area burned by wildfires, affecting up to 16% of the Southern Amazon by 2050 (Brando 2020).

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17 In comparison with the same period in 2018, see WG2, AR6 and GFED, 2019 [GFED, 2019 Fire Season Updates, Global Fire Emissions Database, GFED] available at: https://www.globalfiredata.org/forecast.html#totals

UNDERSTANDING DEFORESTATION DRIVERS AND TIPPING POINT THRESHOLDS

Amazonian environmental data network RAISG (Rede Amazônica de Informação Socioambiental) recently shared additional estimates of loss and degradation via a 36-year data series (1985-2020) on land cover and use. They conclude that by 2020, 26% of the Amazon had undergone a transformation of some kind, either loss or degradation (Quintilla et al, 2022). Considerable impacts are also seen within the Cerrado, where conservation of forest elsewhere has resulted in leakage of loss to the Cerrado. Satellite data from Brazil's National Institute for Space Research (INPE) revealed a loss of 8,500 km2 to agriculture (primarily soy expansion)in the 12 months between July 2020 and 2021 (FT, 2022).

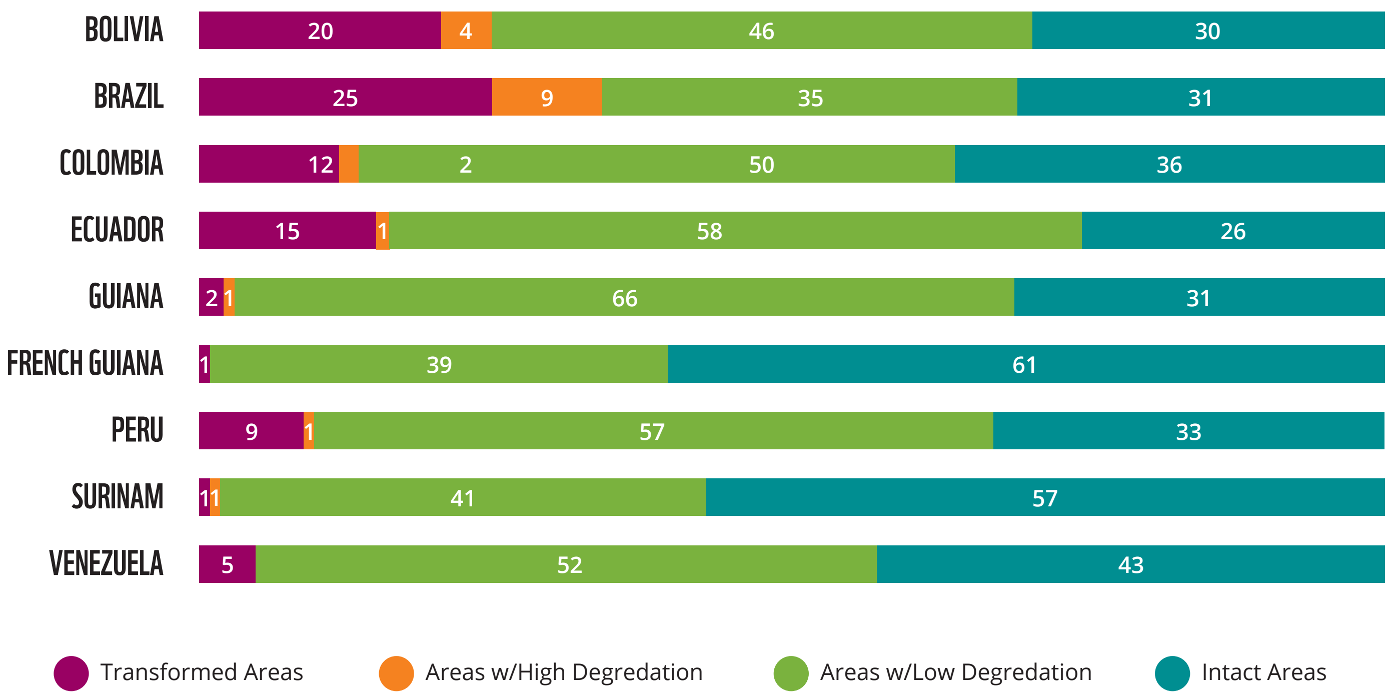

Figure 4 - Area percentages by land use, by Amazonian country/territory. Transformed areas are those that have undergone irreversible land use change, high and low degradation area percentage, and intact forest are also indicated. RAISG 2022 data (adapted from Quintilla et al, 2022, see for definitions) based on MapBiomas Amazonia v 3.0.

Drivers of forest loss, conversion and degradation in the Amazon are associated with the expansion of cattle ranching and agricultural production, for both global and domestic markets. These have been stimulated by the expansion of roads, logging, meat processing and gold mining activities, and the infrastructure development that accompanies the expansion of such activities are also key drivers.

Land occupation has also resulted from speculation and grabbing of public lands, as well as a progressive expansion of smallholders into forest frontier lands. Transient socio-political processes, and different governance phases, are associated with changes in the rate of forest loss over time. While the major drivers of loss and degradation tend to remain the same, their relative influences, and the dominant actors involved, shift over time, for example from a dominance of large-scale landholders to smallholder farmers, to illegal mining operations.

Major road building in the Brazilian Amazon began in the 1960s, driven by a state-led process of land occupation, and notably the construction of the Belen-Brasilia Highway, followed by the Transamazon Highway, accompanied by incentives to private landowners to stimulate land occupation (Binswanger 1991) and private and state-sponsored colonization programs (Browder 1988). A similar process, of a lower magnitude, unfolded in other Amazon countries, creating a new development frontier around agriculture, mining and logging and intrinsically linking the biome's trajectory to human activities. Most infrastructure expansion was confined to the countries, yet a second major road building phase, in the 2000s was triggered by a regional initiative in South America to develop transport corridor across countries, known as IIRSA (Killeen et al. 2007). During this time there has also been a continuous building of spontaneous, or informal, roads by loggers, miners and ranchers, often associated with public land grabs, which represents a significant biome threat because such roads have a land footprint 13 times larger than the official road system (Souza et al, 2020; Barber et al, 2014).

There are approximately 274,000 km of highways in the Brazilian Amazon (Souza et al, 2022). In 2014, nearly 95% of deforestation in the Brazilian Amazon was found to occur within 5.5 km of a road or 1 km of a river (Barber et al, 2014), whilst 95% of fires were found to occur within 10 km of a road or river (Kumar et al, 2014; Insidescience 2021; Souza et al, 2020). Unsurprisingly, greatest forest impacts are found in proximity to the expansion of grey infrastructure. Eleven major road projects are expected to enter the most remote parts of the Amazon in the near future, representing a serious threat to the integrity of the forest (Quintilla et al, 2022). Some of the infrastructure projects were financed by the Brazilian development bank, and others relied on overseas finance such as development bank loans from China (to finance infrastructure projects in Ecuador, Bolivia, and Peru). Such loans have allowed expanded infrastructure development (Myers et al, 2019).

Forest conversion to pasture and agriculture, both commercial and family farming, has a complicated and changeable history in the Amazon combining into the mosaic of deforestation and degradation patterns we see in the region at any one time. Approximately 66% of the biome is now under some sort of fixed or permanent land use pressure (Amazon Watch, 2022) delivered via a progressive process of land occupation (see Pokorny et al. 2021). Nonetheless, forest loss slowed down in the Brazilian Amazon when aggressive public policies were adopted linked to the PPCDAm implementation (Assuncao et al. 2015). Policy actions included a combination of protected area creation, expansion of conservation units, effective deforestation monitoring, greater environmental control with increased public budgets for law enforcement, credit restriction mechanisms, and a rural property registry (Aguiar et al, 2016; Boucher et al, 2014).

We are also able to see, in recent years, the impact of the loss of enforcement of policies such as Brazil's Forest Code. Since 2015, forest loss and degradation in the Brazilian Amazon has followed an upwards trend to maximums in 2021, and the first part of 2022. This has been fuelled by the dismantling of policies and institutions, and lower budget allocation to the environment (da Silva and Fearnside 2022). In addition, Brazil's soy moratorium has displaced potential soy expansion from the Amazon into the Cerrado (Moffette et al, 2019). The major driver of deforestation is cattle ranching. It may still be used as the cheapest way to justify illegal land appropriation and speculation, since land tends to be the ultimate commodity (Killeen 2022).

Elsewhere, the driver-biome pattern is slightly different. Soy and beef expansion have been associated with forest loss in Bolivia (Pacheco, 2006; Muller et al, 2013), and palm oil expansion has impacted forested areas in Peru (Furumo et al, 2017). There is persistent pressure from smallholders in frontier lands who depend on a range of agricultural crops for subsistence and commercial purposes. Unsustainable logging and the expansion of mining operations are persistent problems as well (Killeen 2022). Loss levels in Bolivia are at the lower end of the theoretical critical forest loss tipping point threshold (20% deforestation and 4% high degradation, Amazon Watch, 2022).

In the Brazilian Amazon country-wide policies, such as PPCDAm, and supply chain-specific voluntary agreements, such as the soy moratorium and regional cattle agreements, were put in place to attempt to halt deforestation (Gibbs et al, 2016; Gibbs et al, 2015). The latter involved sub-national agreements to encourage deforestation-free cattle ranching in some states including Para, Mato Grosso, Rondônia and Amazonas. Gibbs et al, (2015) examined the impact of such agreements, finding evidence that they provoked attempts by businesses to try and avoid purchasing from deforestation-associated ranches. More recently, West et al, (2022) found evidence that cattle production inside Brazil's protected areas was still present in supply chains, more than a decade after the signing of deforestation-free cattle agreements. In their analysis of cattle production and supply chains, between 2013 and 2018, they found that most cattle were traced to "sustainable-use" areas, where some grazing is permissible, but nearly 925,000 cows came from strictly protected areas and indigenous peoples' territories where commercial grazing is illegal and 2.2 million cattle spent at least part of their lives grazing in protected areas and indigenous peoples' territories (Mongabay, 2022).

In 2022, the Brazilian cattle sector is expected to expand production by 2.5%, driven by global demand, elevated beef prices, and the recovery phase that the sector is going through (FAS, 2022). Controlling commercial cattle ranching in Brazil's protected areas and public undesignated lands needs to become crucial to Brazil's access to international beef markets (West et al, 2022). Soy production is forecast to reach around 124 million metric tons in 2022, a decrease of around 10% in comparison to the previous period. However, since the beginning of the decade, annual production has increased by nearly 65% and is set to keep increasing in the next decade, reaching more than 140 million tons by 2029 (Statista, 2022)

Whilst domestic markets are important in understanding commodities drivers in Amazon forest loss, international demands also influence land use change. A recent study found that eliminating deforestation from the supply chains of all firms exporting Brazilian soy to the EU or China (based on 2011-2016 figures) could have reduced Brazilian deforestation by 9% (Villoria et al, 2022).

In the Brazilian Amazon's ever-changing landscape of forest loss, a significant driver has become land grabbing and speculative clearance (in the belief that cleared lands will receive amnesty and a higher land price in the future). Speculation often associates with the encroachment of low productivity cattle ranching onto public undesignated lands (Fearnside, 2008; Amazon Watch, 2022). Amazon Watch (2022) raise concerns that policy frameworks in Brazil may even underpin the process of land grabbing in undesignated public land areas, by granting amnesty to those who illegally occupied rural public land between 2005 and 2011 (Brito et al, 2019). Newly deforested land is often left degraded, with the prospect of speculation, or is ranched with minimal inputs. In addition, available data suggest that, in same locations, deforested land is more expensive than forested land, so deforestation is regarded as an (economic) improvement to the land (Pokorny and Pacheco 2014). At least 20% of recently converted land in Brazil is unproductive, and up to 1/5th of the deforested area in undesignated public lands is abandoned after a few years (Amazon Watch, 2022; Salomão et al, 2021)

It is important to recognise that currently, 27% of the Amazon is occupied by indigenous territories, which have the lowest rates of deforestation compared to other parts of the Amazon and store nearly one third of the region's above-ground carbon (Vergara et al, 2022). For indigenous peoples, the lands of the Amazon represent their home, their source of healing and food, their life. The indigenous peoples of the Amazon have called for legal security for their territories; recognition of their right to free, prior, and informed consultation; protection and respect for their traditional knowledge systems as solutions; an end to the threats to indigenous land defenders; and direct financing with permanent technical support for human and economic resource management (Vergara et al, 2022).

It is critical to understand the drivers contributing to loss and degradation of the biome, because these drivers become potential levers for change to move us away from the precipice of the tipping point risk. A road is not built without a purpose, but to access economic activity. The road opens up access to further economic activity and so the fronts of loss progress. The driver was not the road, but the economic activity it serves. Forest loss and degradation drivers, currently in the frame can be summarised to be (Vergara et al, 2022):

- **Infrastructure development**
- **Global and domestic commodities markets**
- **Land speculation and law enforcement/land policy shifts**
- **Expansion of extractive industries (mining)**
- **Fire and forest loss and degradation**

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TIMEFRAMES FOR THE GOVERNMENT AND PRIVATE SECTOR DECISIONS THAT COULD LOWER THE TIPPING POINT RISK

Whilst we have estimates of the rates of forest loss that are likely to lead to irreversible change in the biome, critical knowledge is missing on what pace reductions in that loss need to take in order to steer us away from the tipping point risk. This knowledge is critically needed in order to set targets for the government and private sectors over the next few years. Between the extremely high land occupation and clearance rates of the 1960s, to the start of new land use and environmental regulations in 2004, deforestation rates in the Brazilian Amazon decreased, thanks to a convergence of synergistic policies. However, following the introduction of the PPCDAm in 2004, a significant reversal (80%) of forest loss took eight years to achieve. Initial progress, under the PPCDAm, was linked to improved control and notifications linked to large-scale deforested areas, yet it proved more difficult to control deforestation in more scattered patches linked to smallholders (Godar et al. 2014). Such elements increase the operational costs of enforcement as well. Authors point to the different actors involved in forest loss at that time (dominated by large cattle ranching, for example) compared to the higher percentage of smaller scale ranchers and smallholders in later time periods.

A similar rate of loss reduction, as that seen under the PPCDAm, going forwards would need to tailor approaches to smallholders, including better monitoring of small-scale loss and degradation, and tactics such as incentive-based conservation policies (Godar et al, 2014). Progress is likely to involve a suite of considerations, including; expected costs of enforcement and monitoring (versus the available funding), alignment between the national and sub-national levels, coordination between public and private sector and meaningful international progress on deforestation-free commodity controls.

Analysis of the likely pace at which we could see reductions in loss and degradation in the Brazilian Amazon , should Brazil's new administration return to the full enforcement of Brazil's Forest Code, along with progress on loss and degradation drivers, restoration and protection and protecting remaining forest, are on a similar time scale to the pace at which loss reduced under the era of PPCDAm. There is the potential to reduce forest loss in Brazil by 90% within a decade (Carbon Brief, 2022)[18]. Whereas, under weak governance, the southern Brazilian Amazon could lose 56% of its forests by 2050 (Leite-Filho et al, 2021).

In terms of overseas action, the Forest Declaration Platform (2022) have recently stated that deforestation-free commodity regulations could have significant positive impact on deforestation in the biome, but only if they are associated with mandated policies that level the playing field for companies. Weak policies, or relying on voluntary action, is not likely to see the reductions in loss that we need to reduce the tipping point risk. Business pledges not to buy soy from land deforested after 2006 (the Brazilian Soy Moratorium) have reduced tree clearance in the Brazilian Amazon by just over 1.5% between 2006 and 2015 (Gollnow et al, 2022). Deforesting commodities need removing from international and national supply chains and deforesting finance pathways eliminated and innovative ones put in place, which support a switch to sustainable production.

Comparisons are possible with the timescales involved in previous international policies, such as the EU's Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan, to eradicate illegal logging and trade in tropical countries. FLEGT's establishment began in the early 2000s, however, 12 years on from its formation several countries were still to sign voluntary partnership agreements and the European Court of Auditors found that no partner country had obtained fully approved FLEGT licensing (Levy-Abegnoli 2020). By 2022 multiple countries have signed Voluntary Partnership Agreements but, to date, Indonesia is the only country in the world issuing the FLEGT licenses which give timber a 'green track' in to the EU timber market (Hansen et al, 2022). The new phase of EU deforestation-free legislation is no more speedy or successful, with Ministers in the EU Environment Council recently voting to weaken the law before it has even been signed (WWF, 2022). The New York Declaration on Forests identified its own failure to evidence goals being on track, five years after its signing (NYDF, 2019) and it's 2022 assessment (Forest Declaration Platform, 2022) concludes that the world is still not on track to meet it's 2030 forest goals and concludes that voluntary action is not enough.

It takes decades to make and enforce new directions in forest policy and practice, time the Amazon is rapidly running out of. There are calls for at least 80% of the Amazon to come under protection by 2025 before the opportunity to restore the Amazon runs out (Quintilla et al, 2022, Home - Amazonia 80 X 2025). Any policies for the reduction of deforestation should be consistent with protecting the livelihoods and wellbeing of the Amazon's urban and rural populations, and incentivizing economic activities that support conservation and sustainable development pathways. Policies must be implemented within a framework of equity and respect for diversity, based on the joint construction of a shared agenda with local communities and indigenous peoples; one that incorporates their visions, respects their rights and includes their interests and needs in decision-making.

CONCLUSIONS

Early warning indicators, based on observational data and modelling, reveal potential destabilisation of the Amazon forest (Armstrong McKay 2022; Boulton et al, 2022; Boers et al, 2017). When we examine the observations of critical tipping point thresholds for annual rainfall, dry season length and average deforestation, a third of the biome has already experienced at least one critical tipping point threshold.

Published estimates of Amazon carbon stocks range between 100 billion to 200 billion tonnes, which equates to 367-733 GtCO2 (Gigatons CO2) stored in the Amazon. The model-estimated global carbon budget for staying within the 1.5ºC climate target is 360--510 GtCO2, meaning the total loss of the Amazon could use up the entire remaining 1.5ºC carbon budget. This avoidable tragedy would not only impact the lives of 47 Million people, and 10% of the planet's terrestrial biodiversity, but could place the 1.5ºC degree climate target out of reach.

Historically the rate of deforestation has varied in the Amazon, from government to government, a situation that needs to change if we are to avoid the catastrophic abrupt change the Amazon is heading for. We know such turnarounds are possible, with Brazil drastically cutting forest loss previously.

18 In the few days after the 2022 Brazilian election figures were widely shared which looked at Brazil's forest losses over different administrations, sharing that forest loss levels fell by 20,000 km2 in Silva's 2003 to 2020 term of office, e.g. https://twitter.com/_HannahRitchie/status/1586955748420059136?s=20&t=l_O4fpAWbZHEphS8bEazKQ

The Amazon is currently living on borrowed time, but it is not too late to reduce the tipping point risk. Any solution to Amazon conservation, including a drive to reduce the tipping point risk, must include safeguarding and strengthening indigenous peoples' rights and be mindful that indigenous peoples' forested lands have the lowest rates of deforestation in the Amazon, and store nearly one third of the region's above-ground carbon (Vergara et al, 2022).

The turning point needed to protect the biome requires action across nine countries and territories at a greater pace and ambition, then ever before and a long term commitment to preventing the assertion of harmful interests in the region (Pokorny et al, 2021). Novel and ambitious new avenues are need to achieving deforestation and conversion-free goals and financing pathways. Many internal commitments are falling well short of their goals at present. Removing deforestation from supply chains must be an imperative, but along with a suite of additional solutions.

Budget changes, within Brazil, over recent administration terms, exemplify how the long-term stability of national bodies is linked to the Amazon's deforestation and degradation trajectory. In 2017 the Brazilian government cut its environment ministry budget by 51% as part of a bid to limit the country's spiralling deficit, with further cuts in 2021. At the time of writing, Brazil's supreme court had ruled to reactivate the Amazon Fund under its existing operating structure. The fund was paused under the Bolsonaro administration, in 2019. It is critical that policies to protect the Amazon become stable across space and time and are supported by functioning forestry and environmental administration units in all nine countries and territories. Such action would need to be matched by a global commitment to meeting 1.5ºC aligned climate targets in order to remove both of the dominant tipping point threats to the biome – climate change and forest loss and degradation. In the past, institutional reforms that led to protection of the forest have not been robust over time, lending an impermanence to positive Amazon policies that must be addressed so the Amazon's protection systems are non-transitory. Ultimately, the forest needs to function as the 'Living Amazon' (Vergara et al, 2022) which requires both strong systems of protection, and a stable climate.

We continue to learn more about the uniqueness and global importance of the Amazon. Western scientific understanding of its forests used to be that the biome supported shorter trees, and lower amounts of carbon per hectare, than the rainforests of tropical Africa and Asia, we know now that is not true, as the Amazon's remaining giant trees are slowly recorded from above for the first time (Gorgens et al, 2020). Just as we record more and more of the biome's unique trees, we are also detecting their stress levels increasing as the effects of heat, drought and disturbance pile up (Anderegg et al, 2022).

The tipping point thresholds are uncertain. We do not even know for certain how the abrupt change would occur, it might occur as a cascade, with the most degraded portions changing first. The details of the tipping point remain an open question even to those who first raised international concerns about it. It would be easy to shift blame around, ignoring the risk from deforestation because it might be outweighed by that from global warming, or vice versa. Neither the Amazon nor the globe can afford such an approach. There is uncertainty in every estimate of future loss, temperature threshold for tipping point risk, feedback and climate projection. However, we must take a precautionary approach (Lenton et al, 2020) to acting on every one of the tipping point elements, despite them being uncertain, because of the severity of threat which the Amazon tipping point poses. Uncertainty should not be an excuse to fail to act on the drivers pushing the Amazon towards irreversible loss.

Multiple NGO's and academic groups in the region have made it clear that these ambitions cannot be realised without a larger collaboration to protect and restore the Amazon than has ever been carried out before and one which includes all the voices of the region. Speaking at COP27, in November 2022, Dr Carlos Nobre, the Brazilian Earth System Scientist who brought the tipping point risk in the Amazon to the attention of the world, spoke of the need for an alliance working as one front, united against policies which favour deforestation.

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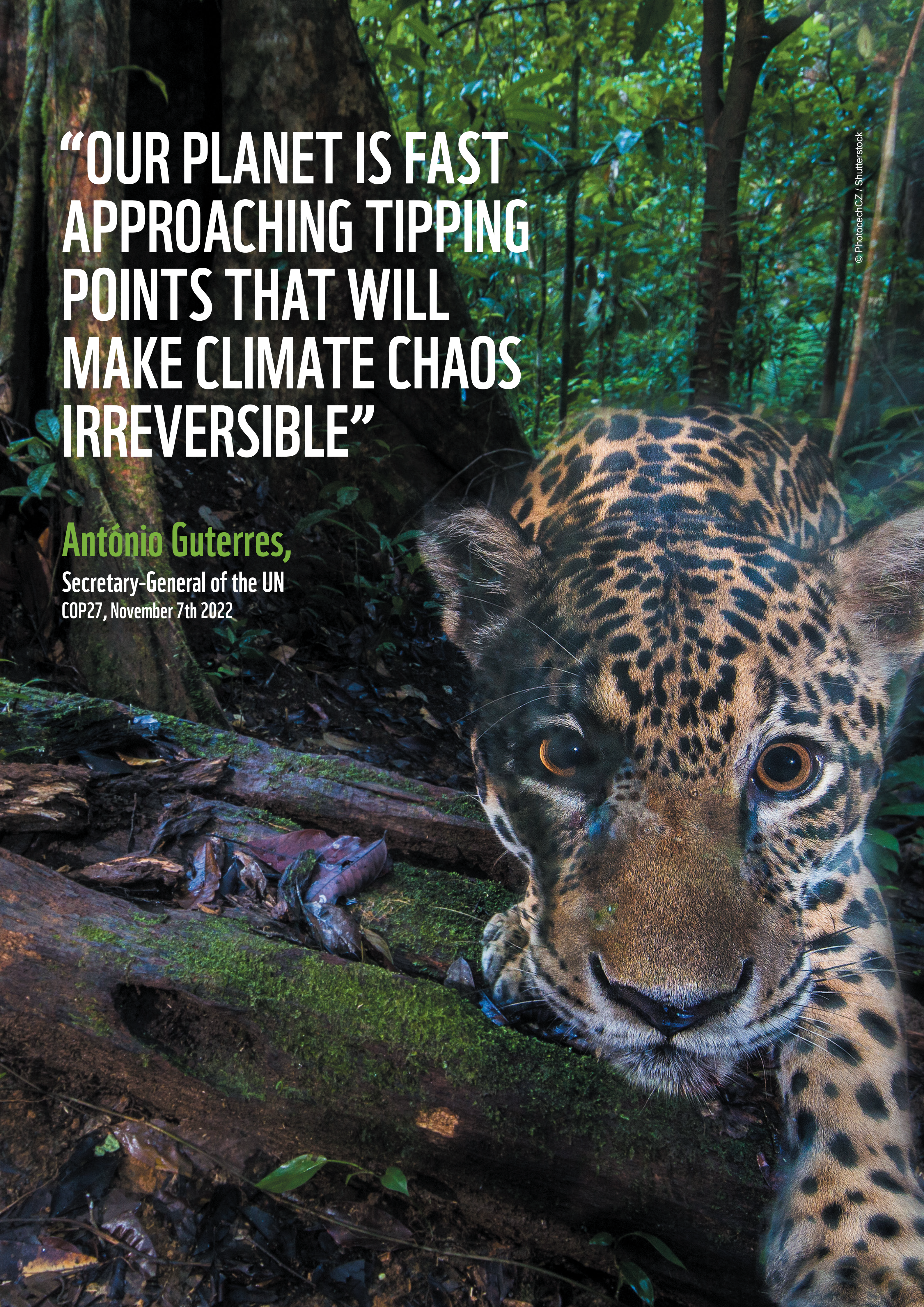
“OUR PLANET IS FAST APPROACHING TIPPING POINTS THAT WILL MAKE CLIMATE CHAOS IRREVERSIBLE”
António Guterres,
Secretary-General of the UN
COP27, November 7th 2022
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