Global issues seen from the Southwestern Amazon

A review on impacts and drivers of climate change in the MAP region

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Contents

Executive summary

- Increasing dry season temperatures and length, mega-flood, and drought frequencies, as well as reduced water availability, are some of the observable impacts of climate change in the MAP (Madre de Dios/Peru, Acre/Brazil and Pando/Bolivia) region of the Southwestern Amazon.

- The MAP region has already experienced a loss of over 10% of intact forests. Although slash and burn practices are the leading threats to the Amazon, market failure (when prices do not match reality) and reduced environmental restrictions are the root causes of accelerated deforestation in the Southwestern Amazon.

- Indigenous people are the best stewards of the Amazon, but native communities need empowerment, as well as financial and educational capacity building to be able to preserve their native lands. Surrounding intact forests also need increased legal enforcement to ensure their protection from deforestation or unsustainable fruit harvesting techniques.

- Continued encroachment on wild areas and the degradation of ecosystems create an environment in which pandemics can emerge and thrive. Climate change, viral pandemics and the loss of biodiversity are closely linked.

Resumen

- Las estaciones secas más prolongadas, el incremento de temperaturas durante las mismas, mayor frecuencia de las mega inundaciones y sequías, así como una menor disponibilidad de agua, son algunos de los impactos observables del cambio climático en el MAP (Madre de Dios/Perú, Acre/Brasil y Pando/Bolivia) región del suroeste de la Amazonia.

- La región MAP ya ha experimentado una pérdida de más de 10% de bosques intactos. Aunque las prácticas de tala y quema son las principales amenazas para la Amazonía, las fallas del mercado (cuando los precios no coinciden con la realidad) y la reducción de las restricciones ambientales son las causas fundamentales de la deforestación acelerada en el suroeste de la Amazonía.

- Los pueblos indígenas son los mejores administradores de la Amazonía, pero las comunidades nativas necesitan empoderamiento, así como capacitación financiera y educativa para poder preservar el área de su territorio. Los bosques intactos circundantes también necesitan una mayor aplicación de la Ley para garantizar su protección contra la deforestación o las técnicas no sostenibles de recolección de fruto

- La invasión continua de áreas silvestres y la degradación de los ecosistemas crea un entorno en el que las pandemias pueden surgir y prosperar. El cambio climático, las pandemias virales y la pérdida de biodiversidad están estrechamente vinculados.

Resumo

- O aumento das temperaturas da estação seca, frequências de mega-inundações e secas, estações secas mais longas, bem como a redução da disponibilidade de água, são alguns dos impactos observáveis das mudanças climáticas no MAP (Madre de Dios/Peru, Acre/Brasil e Pando/Bolívia) região do sudoeste da Amazônia.

- A região do MAP já sofreu uma perda de mais de 10% das florestas intactas. Embora as práticas de corte e queima sejam as principais ameaças à Amazônia, falhas do mercado (quando os preços não correspondem à realidade) e as restrições ambientais reduzidas são as principais causas do desmatamento acelerado no sudoeste da Amazônia.

- Os povos indígenas são os melhores administradores da Amazônia, mas as comunidades indígenas precisam de empoderamento, além de capacitação financeira e educacional para poderem preservar suas terras nativas. Os arredores de florestas intactas também precisam de maior fiscalização legal para garantir sua proteção contra o desmatamento ou técnicas de colheita de frutas insustentáveis.

- A invasão contínua de áreas selvagens e a degradação dos ecossistemas criam um ambiente no qual pandemias podem surgir e prosperar. Mudanças climáticas, epidemias virais e perda de biodiversidade estão intimamente ligadas.

1. Introduction

Climate change is one of the biggest challenges humanity is currently facing, as well as causing. Regional and global climate systems are being altered and these changes are experienced by communities of all sizes. Intensified land use, unsustainable consumption of natural resources, habitat destruction and a growing world population stress the natural systems of our planet and lead to changes in regional and global climate. The rising concentrations of greenhouse gases in the atmosphere, reinforced by anthropogenic emissions, lead to constant warming of the earth with consequences that can already be observed (IPCC, 2014).

The contributing effect of anthropogenic emissions to global warming has been widely acknowledged. The Paris Agreement is a global framework to limit the earth's warming to well below 2°C, that has been developed by the United Nations Framework Convention on Climate Change (UNFCCC, 2015). To reach this ambitious goal, the way we treat our environment and use nature has to change drastically. Economies, policies, and societies need to focus on sustainability and switch to technologies and activities with less or no influence on climate.

Not only our natural environment is affected by climatic extremes, such as droughts, floods, storms, permafrost thawing and glacial retreat. Inevitably, human communities suffer from the consequences of climate change via agricultural losses, water scarcity and climate variability, with extreme cases forcing entire communities to leave their native lands (Sherbinin, 2020). Climate change already is and increasingly will be a driver of human migration, which together with the climbing world population can be expected to reach dramatic dimensions (Xu et al., 2020). Global warming will impact ecosystems – on land, in water, and also in soil (Ortiz-Bobea et al., 2021). Being under increasing stress, components of the climate system, as well as ecosystems, could reach points of sudden and extreme changes, so-called tipping points (Lenton et al., 2019). Such drastic and quick switches from, for example, one vegetation type to another, would impact people and the environment from a local to global scale. In every region, country and continent, biomes and societies are facing challenges that can be linked to climate change and human land-use changes. The Amazon is an important part of the global water (Marengo et al., 2018) and carbon cycle (Lovejoy & Nobre, 2019), and its fate is not only relevant for people in the Amazon region, but for the entire planet.

1.1 The MAP region of Southwestern Amazonia

What is hereafter referred to as the MAP region, is the tri-national area in the Southwestern Amazon that includes Madre de Dios (Peru), Acre (Brazil) and Pando (Bolivia). While the region is governed by three different countries, it shares the geographical attributes of the Southwestern Amazon, characterized by a large extent of still intact forest cover and recent drastic changes in infrastructure (Myers et al., 2000). The forest is rich in biodiversity and contains lowland moist forest types. It is also home to many indigenous, migrant-indigenous, and colonist farm families, logging firms, large scale ranchers, as well as indigenous groups in voluntary isolation (Brown et al., 2002; Perz et al., 2008; Southworth et al., 2011). The MAP region is considered a critical area for the Initiative for the Integration of the Regional

Infrastructure of South America (IIRSA) (Perz et al., 2015), where the transboundary Inter-Oceanic Highway was paved and highly impacted land-cover (Dablin, 2014). Concurrently, land-use, settlement structure and population density vary between the three countries that comprise the region (Perz et al., 2013). The MAP region reflects one of the greatest challenges of confronting climate change: universal problems require transboundary solutions and collaboration across borders.

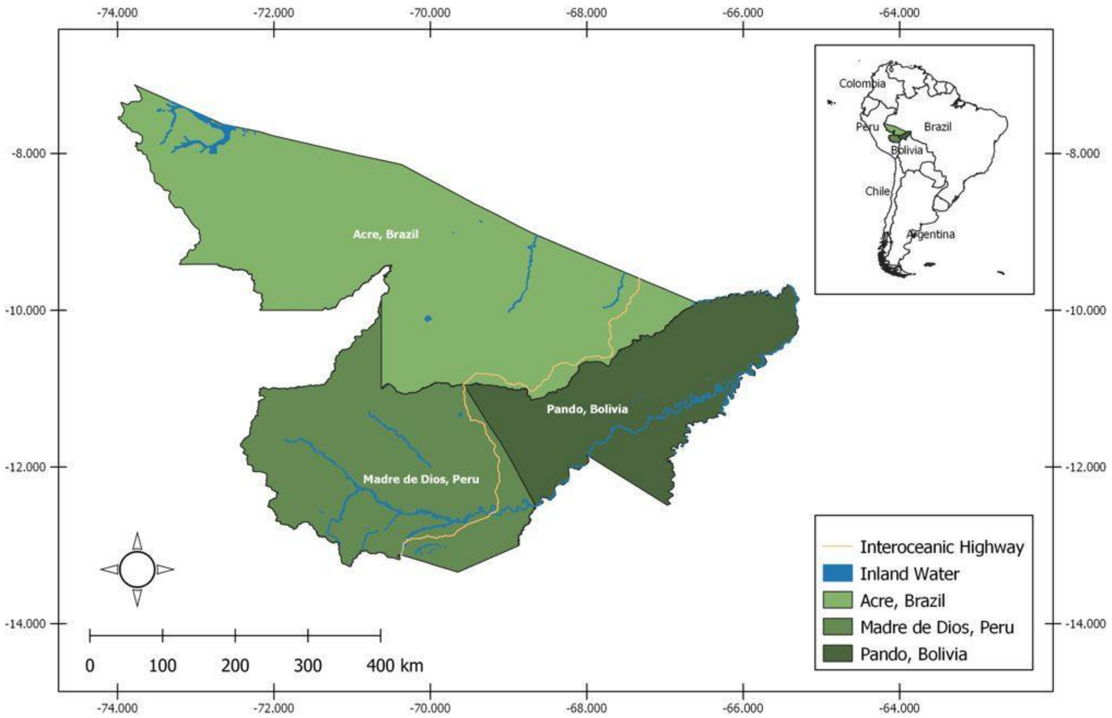

Figure 1. Tri-national MAP region in Southwestern Amazonia (Source: Lewis Swadling).

Here, we will reflect on climate change observed from the MAP region in the Southwestern Amazon.

2. Observed impacts of climate change in Southwestern Amazonia

Growing impacts of climate change can be observed in the Southwestern Amazon (Lapola et al., 2018) that can be linked to increasing heat and reduced water availability due to regional deforestation and fire. In Amazonia, a warming of 0.5 - 0.7 °C was measured over the last decades (Jiménez-Muñoz et al., 2013; Gloor et al., 2015; Marengo et al., 2018).

The Amazon is facing a triple threat of deforestation, fires, and climate change, with all of them being closely linked (Marengo et al., 2018). Extreme events like floods and droughts already occur with increased frequency in the MAP region (Dolman et al., 2018). While the actual costs of extreme events are not yet fully assessed, actions taken now to prevent further destruction of the Amazon are up to a hundred times cheaper than the costs of a die-off of the forest (Lapola et al., 2018).

One-third of the rainfall in the Amazon originates from evapotranspiration within the basin (Staal et al., 2018), and the standing forest moderates seasonal droughts by recycling moisture, especially during the dry season (Marengo et al., 2011; Staal et al., 2018). However, moisture from the Amazon is not only important for the forest itself, but also for the drier, agriculture-dominated southern parts of the continent and the La Plata Basin (Zemp et al., 2014; Lovejoy & Nobre, 2019; Walker, 2021). The forests' water recycling and transport is therefore a crucial part of the continental climate system (Marengo et al., 2011; Arraut et al., 2012; Marengo et al., 2018) and explains why deforestation leads to excessive water runoff (Lovejoy & Nobre, 2019) and increased drought frequency and severity (Marengo et al., 2018).

The Southwestern Amazon, and concurrently the MAP region, was the driest area of the Amazon in the years 2003 to 2014 (Staal et al., 2018). Three mega droughts occurred within just over a decade (2005, 2010, 2016), in comparison to the expected occurrence of one such drought per century (Marengo et al., 2018). Furthermore, longer dry seasons in the MAP region were reported (Espinoza et al., 2019) and Lenton et al (2008) noted the potential for more extreme El Nino events that could affect climate across the Amazon.

While several severe droughts occurred during the last decades, growing variability in climatic events is demonstrated by the simultaneous occurrence of mega-floods in the years 2009, 2012 and 2014 (Gloor et al., 2015; Marengo et al., 2018). In 2015, Rio Branco, the state capital of Acre, experienced the most severe flood in its recent history, which affected about a third of its population. In 2021, another mega-flood occurred in Madre de Dios, displacing over 15,000 people. It was the worst flood in history for Madre de Dios (Bnamericas, 2021). In addition to the economic impact on people, administrative departments incur high costs in response to floods. Major economic (goods, buildings, agriculture, services, and income lost or damaged) and social (violence, trauma, increased diseases) impacts are associated with extreme cases (Dolman et al., 2018).

3. Deforestation driving climate change in the MAP region

The earth's climate is regulated by the Amazon biome due to the buffering effect of greenhouse gases and radiation by trees. Studies point out that a loss of intact forests contributes to increasing regional and global temperatures and the intensifying of extreme weather events (Ellwanger et al., 2020). Esquivel-Muelbert et al (2018) suggest that the Amazon is likely already experiencing a regime shift with hotter and more variable climate.

3.1 Deforestation in the MAP region

Southworth et al (2011) reported a loss of intact forest by 9% for the entire MAP region. Recent findings would suggest a higher figure, especially with regards to Madre de Dios and Acre. However, a scarcity of large-scale deforestation analyses in the MAP region does not allow thorough understanding of the extent of standing intact forest in all three regions.

3.1.1 Pando, Bolivia

Pando is the only Bolivian department that lies entirely in the Amazon. Despite major deforestation occurring in Cobija, Pando's capital, Marsik et al (2011) reported that areas outside of the city have almost completely maintained forest cover, with 95% of its vegetation cover still being intact. Consequently, it is the least deforested area in the MAP region. Global Forest Watch (2020) reports approximately 180 thousand hectares deforested from 2000-2020, reducing forest cover from 95% (Marsik et al., 2011) to an approximation of 91%. Hence, Pando is the last frontier of intact evergreen forests in the Bolivian lowlands and will require continued protection to safeguard the large expanses of primary rainforests.

3.1.2 Acre, Brazil

In Brazil, between 2004 and 2012, pressure from governmental and international institutions helped to de-accelerate deforestation by 80%, offsetting 3.2 Gt CO_2 and landing Brazil as the global leader in climate change mitigation (Nepstad et al., 2014; Silva Junior et al., 2021). However, since 2013, Brazil's deforestation rate has skyrocketed again, with the period of greatest deforestation of the decade occurring in 2020 (a 9.5% increase from the previous year) (Silva Junior et al., 2021; Walker, 2021). In 1985, demands from a consortium of rubber-tappers and local governance in Rondonia and Acre initiated a plan to establish extractive reserves in Brazil. In 1990, the first Extractive Reserves (RESEXs) were created on the basis that intact forests within RESEXs were protected by the state and that extractivist resources were diversified and not confined to rubber tapping activities. Harvesting of "Non-timber forest products" (NTFPs) such as brazil nuts, bamboo, weevil grubs, acai, and buriti were encouraged, and individuals from residing communities had permissions to hunt certain animals such as tapirs and peccaries (Moreira & Hebette, 2006). One of the first RESEXs created, called the Chico Mendes Reserve (CMER), was implemented in Acre. Although deforestation has occurred within the RESEX itself, Milien et al (2021) reports that deforestation within the CMER increased by 14% from the years 2000-2018, with a 78% increase in deforestation just outside the CMER. This supports the notion that implementing protected areas is an effective strategy to decrease deforestation over a longer period. The CMER has a greater deforestation rate than other RESEXs due to the availability of roads connecting to the CMER, as well as nearby land access by the pastureland expansion. The Tapajos-Ara-Piuns RESEX in Pará experiences less deforestation and does not have features such as those surrounding the CMER (Kröger, 2019).

3.1.3 Madre de Dios, Peru

In the late 19th century, Iquitos (Peru) and Manaus (Brazil) were epicenters for rubber extraction activities. Numerous quinine and caucho (rubber) explorers tried to navigate the Madre de Dios River to allocate new areas for rubber tapping activities, but a combination of turbulent rivers, extreme weather, a lack of food and hostility of indigenous groups left the explorers either quitting the expedition, injured, or deceased. When the rubber boom collapsed in the middle of last century, brazil nut harvesting accelerated and agriculture and cattle farming steadily increased. Rubber patrons created rural holdings and hired individuals from nearby Ese Eja or Amahuaca native communities to cultivate and maintain them (Moore, 2019). Roads that connect Cusco with Iñapari were implemented in 1987, supposedly due to the upsurge of soybean production in Brazil and to help generate a local economy. However, the road network opened the region to subsidized Andean colonists, who were financed to expand agriculture and cattle farming activities in the region (Moore, 2019; Nicolau et al., 2019). As sawmills appeared, populations of timber species, such as mahogany, tropical cedar and tornillo started to reduce drastically due to selective logging activities and large-scale deforestation for agriculture (Moore, 2019). Agricultural expansion is the main driver of deforestation in the Amazon, but the beginning of the gold mining boom in 2000 has led to the annually devastation of thousands of hectares of primary rainforest in Madre de Dios since.

3.2 Causes of deforestation in the MAP region

Land use changes in the Amazon are often linked to neoliberal agrarian policies, resettlement of small farmers, large scale illegal land acquisition, road and infrastructure development, cattle farming, the cultivation of crops such as coca for drug traffickers (Geist and Lambin, 2002; Marengo et al., 2018; Blundo-Canto et al., 2020) and gold mining activities (Householder et al., 2012). Yet cropland expansion is identified as the predominant driver of land cover change, and current agricultural practices in the Amazon are highly specialized and market-oriented (Blundo-Canto et al., 2020).

3.2.1 Farming and infrastructure

Livestock and soybean production are the leading causes of deforestation in the Amazon (Marengo et al., 2018), as the global market heavily relies on Brazilian beef and soybean products (Nepstad et al., 2006). Deforestation via slash and burn techniques is the main immediate threat to the Amazon rainforests (Marengo et al., 2018), while the root causes are market failure (Dablin, 2014) and reduced environmental restrictions (Pereira et al., 2020).

The Interoceanic Highway in the Southwestern Amazon, completed in 2011, connects the Atlantic ports of Brazil to the Pacific ports of Peru (Jensen et al., 2018). The highway has caused an increase in the extractive potential of forests in Madre de Dios. A growing economy based on accelerated illegal gold mining, agriculture, and timber extraction activities (Dablin, 2014) as well as the availability of natural resources such as rubber, brazil nuts and animal skins (Jensen et al., 2018) lead to a steady rise in migrants from Cusco and Puno to the region. The highway also connects the Western Amazon with the “arc of deforestation” in the Southern Amazon, providing access to intact forests to deforesters, whilst simultaneously increasing the risks of fires spreading alongside the roads.

3.2.2 Open pit gold mining

Illegal open-pit gold mining has continued to occur in Peru’s capital of biodiversity, Madre de Dios, despite intensive legal enforcement by the National Police of Peru and the Peruvian Army in 2012. Although mining activities were reduced after the enforcement, deforestation for illegal gold mining doubled the following year (Asner and Tupayachi, 2017). Vast swathes of forest are lost annually to predominately informal gold mining activities. A continuous cycle can be observed when evaluating the dynamics of deforestation due to illegal gold mining: as one area reduces the mining activities with legal enforcement, another area is in peril of the illegal activity and land use changes. Additionally, large scale gold mining causes the contamination of many tributaries with mercury, methylmercury, and other contaminants (Álvarez et al., 2011). Nicolau et al (2019) reported that almost half of deforestation between the years 2013 to 2018 was related to gold mining, with half of the mined areas occurring in buffer zones or national protected areas. The remaining deforestation was related to crop and pastureland expansion. Peru representatives for the COP25 in Madrid demonstrated a 17.7% reduction of deforestation in Madre de Dios (Delgado, 2020).

3.2.3 Coca cultivation

After the 1970's rubber industry crisis, coupled with an accelerated demand for cocaine in the USA and Europe, coca leaf production and the cocaine trade increased exponentially in the Amazon. It is an economic lifeline for many farming communities that depend on its cultivation. A low percentage of the yield is sold to coca tea producers, as it is estimated that over 90% is distributed to drug traffickers (Pastor, 2020). In Acre, a thriving illegal drug market is closely linked to police and business corruption, as well as the illegal use of violence by law enforcement agencies. Additionally, a symbiotic relationship has been evolving over the last four decades between the illegal drug trade and the world banking and financial system. The driver was the deregulation of the financial systems that buy and sell currency, credit, or commercial paper. Hence, politics in Brazil, and many countries across the Amazon, are often connected to relationships fostered in the criminal world (Araújo, 2002).

Peru has continuously upheld its reputation as the second dominant producer of coca leaves and cocaine over the last few decades (Grisaffi, 2021), even expanding coca leaf cultivation by about a quarter in the years 2016 to 2019 (Pastor, 2021). Recent upsurges in coca leaf production have also occurred in Madre de Dios and are linked to the implementation of Operation Mercury, an intensive police operation aimed at combating illegal gold mining via law enforcement. Large scale deforestation occurred near and within the Tambopata National Reserve and Bahuaja-Sonene National Park, with an estimation of 6,500 hectares of intact forest deforested for coca leaf production near the illegal gold mining epicenter of Madre de Dios called La Pampa (Romo, 2019). In 2021, prices of coffee fell, causing another upsurge in coca cultivation. However, due to a significant reduction in drug transportation linked to the COVID-19 pandemic, coca leaf prices dropped by half. Despite this reduction in prices, farmers are reported to favor coca leaf production due to the stable demand for the product (Grisaffi, 2021).

3.4 Impacts of deforestation in the Amazon

Accelerated deforestation leads to a reduction in biodiversity and water and carbon storage capacities, all of which are fundamental for human well-being (Marengo et al., 2011; Lovejoy & Nobre, 2019). Biodiversity is not only crucial for material, medicine, and food supply, but also for the provisioning of ecosystem services, such as nutrient cycling, water supply, pollination (Marengo et al., 2011), carbon storage, and climate regulation (Strand et al., 2018). Preserving the Amazon will maintain local, regional, and continental climate, as well as buffer the impacts of extreme climate events in the future and sustain the Amazon as a biodiversity hotspot. However, to obtain a marginal living, indigenous and migrant communities will participate in the destruction of the very ecosystems and ecosystem services that they depend on.

Deforestation decreases the forest's ability to buffer droughts due to reduced moisture recycling (evapotranspiration). This in turn affects the general resilience of ecosystems within the Amazon biome during drought episodes (Staal et al., 2018). Deforestation is therefore considered one of the main drivers of climate change in the Amazon (Aragão et al., 2018; Marengo et al., 2018; Covey et al., 2021). Smoke from fires can inhibit rainfall and further exacerbate drought conditions. Aerosol particles released due to biomass burning can also delay the start of the rainy season and alter regional climate (Marengo et al., 2018).

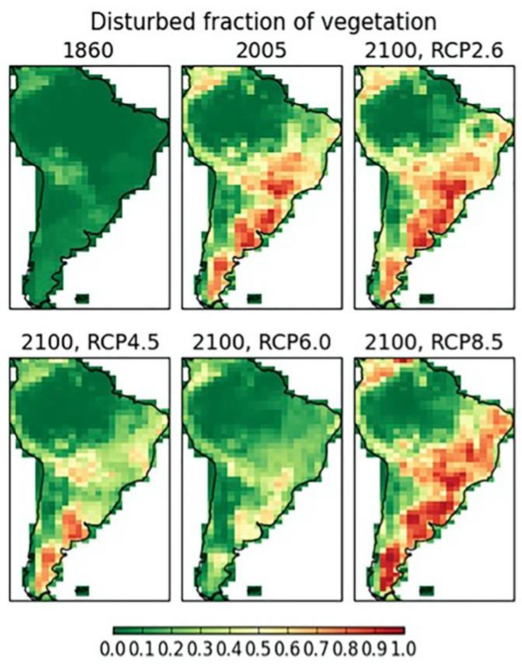

Figure 2. Habitat fragmentation predicted across South America simulated at HADGEM2-ES Earth system Model at 1860, 2005, and four future scenarios at 2100: RCP:6 (high mitigation), RCP4.5, RCP6.0, and RCP8.5 (high emissions). Source: Marengo et al., 2018

Although fires can occur naturally due to excessive drought experienced in a few drier regions of the Amazon, the frequency, extent, and duration are strongly increased by slash and burn activities in the long term (Aragão et al., 2018). The connectivity of the remaining inflammable forest edges promotes a wide spread of future fires (Marengo et al., 2018), causing fires to spread faster and burn longer. Smoke from fires has been affecting people's health across the Amazon and even more so for indigenous and migrant communities (Silva Junior et al., 2021). Additionally, the exposure to air pollution and smoke has already been linked to a higher probability of dying from an infection with COVID-19 (Thakur et al., 2020).

Droughts affect the functionality of hydropower dams. Electricity supply, which is highly dependent on hydropower, will be compromised (Mendes et al., 2017; Lapola et al., 2018), causing power supply insecurities and economic losses. Agriculture, industry, and hydroelectricity, which are important sectors for Latin American countries, will be affected (Marengo et al., 2011). The continuing negative interplay between climate change and deforestation could lower water levels in rivers, impairing health, food security and transportation and resulting in the migration of distressed residents to large Amazonian cities (Lapola et al., 2018). Accelerated deforestation rates, as observed in Brazil in 2020, coupled with a lack of legal enforcement in all nine Amazonian countries, endanger the conservation status of the Amazon rainforest and with it biodiversity and climate (Marengo et al., 2018).

As temperature increases are expected to occur in the Amazon, species may be inclined to migrate or expand territories to maintain their habitat in favorable environmental conditions. Primates will depend on the presence of trees for climate migration. Hence, deforestation will affect the climate-driven primate migration and act as barriers for primate dispersal. Based on models for primate dispersal and accelerated deforestation frequencies, conflict zones are mainly concentrated in the Central Brazilian Amazon and outside of protected areas (Sales et al., 2019). Similarly, for birds (Moraes et al, 2020) and bees (Giannini et al., 2020) the expected decline in forest cover is predicted to severely reduce suitable habitats by up to 70% in some cases. Nevertheless, studies that address flora and fauna predictions are almost all based in the Eastern Amazon, demonstrating the need for a wider geographic sampling.

Across the Amazon, wetlands and water bodies are often accompanied by peatlands (also known locally as aguajales, buritales or morichales). Although tropical peatlands represent a little over 10% of the global peatland area, they amount to almost a fifth of the total global peat carbon pool. Amazonian peatlands contain greenhouse gases, such as carbon dioxide, methane, and nitrous oxide (Griffis et al., 2020). This highlights their importance in the global carbon cycle, as well as for maintaining positive and negative feedback loops in Amazonian climatic systems (Householder et al., 2012; CIFOR, 2020). The aguaje palm (*Mauritia flexuosa*, also buriti or moriche palm), is the keystone peat-forming species dominant in Amazonian peatlands. The aguaje palm's fruit is harvested annually by native and migrant communities, who rely on its socio-economic benefits. Although it is illegal to fell aguaje palms, many individuals still selectively cut down palms to access their fruits to avoid the sustainable method of harvesting, which involves climbing up the palm with a harness. Cutting down the palms could lead to emissions of the greenhouse gases stored in the peat. This concern is based on the understanding that drained and deforested Amazonian peatlands are major sources of greenhouse gases (Murdiyarso et al., 2019; Ribeiro et al., 2020a). Peatlands therefore must be further protected for climate change mitigation. A recent study evaluated the impacts of increasing air temperature and reduced atmospheric moisture on an Amazonian peatland and reported that high values reduce CO_2 uptake and limit photosynthesis, despite sufficient water availability (Griffis et al., 2020).

Cox et al (2004) proposed the Amazon forest dieback hypothesis, which was the first thorough climate change simulation based on dynamic vegetation and interactive carbon cycle variables using the HadCM3 model. There are few doubts about whether forest dieback will occur in the Amazon, and some scientists even argue that the Amazon has already reached a tipping point (Lovejoy & Nobre, 2019). Atmospheric models from Lovejoy and Nobre (2019) project that when 25% of the Amazon is deforested, the Amazon will reach a tipping point. Today, over 20% of the Amazon is already deforested. When the effects of drought, deforestation and fire are combined, the potential of a nearing of these tipping points is even more likely (Cox et al., 2000; Nobre et al., 2016; Marengo et al., 2018). No studies were found concerning the impacts of rainforest dieback on Amazonian communities and their potential need for displacement within affected areas. The future health and well-being of Amazonian people will depend on the ability of each community to adapt to climate variability and the associated impacts, as well as the quantity and quality of support given by governmental health and social sectors during climate disasters or migrations.

The impacts of climate change that can already be observed will get stronger (Marengo et al., 2011; Gloor et al., 2015). It is projected that the increase in temperatures and the reduction in rain in the dry season are already the first sign of the Amazon approaching a tipping point. Simultaneously, changes in the environment and water cycle as a consequence of deforestation and climate change could already have impacts on a continental and global level (Marengo et al., 2018). When extending the scale, it becomes clear that the climate of the Amazon and the climate of the rest of the world are closely linked.

4. Excursus everything is interlinked: The Amazon and the Arctic

Just as the Amazon is an important driver of global climate, other biomes on Earth, such as the Arctic, also play an important role. The Amazon and the Arctic are two huge biomes and integral parts of the global climate system. Apart from their importance for our climate and that they both begin with A – what are other similarities these biomes share? Do we really have to worry about changes that happen in far-off parts of the world?

The Arctic is both an interesting and significant example of climate change impacts (Gillett et al., 2008), since warming there occurs two to three times faster than in the rest of the world (Cohen et al., 2014). Changes, therefore, happen so fast, that they are visible and easily understandable. When observing the Arctic, climate change and its extent can be visualized. And observations in the arctic are alarming: huge amounts of ice are disappearing (Screen & Simmonds, 2010). The extent of the Arctic sea ice has decreased drastically over just a few decades (Lenton, 2012), in extreme years to only half of its previous size (Overland & Wang, 2013). Sea ice decline for its part is linked to stronger warming of surface and atmosphere temperatures, affecting local and global climate (Bhatt et al., 2014).

To understand the link between melting ice in the Arctic and what happens in the MAP region, we have to again consider the global climate system. Greenhouse gases mix in the atmosphere across the planet. It then becomes evident that drastically reducing emissions and halting deforestation all over the world could help to prevent ice and permafrost thaw in polar regions. Loss of ice and snow cover in the Arctic in turn will increase temperatures in the Amazon. Acute and fundamental changes in one biome will affect another, as impacts spread across the world.

Irreversible, fundamental changes in the Arctic sea ice and the Greenland ice cap are considered to be the currently most critical tipping elements in the climate system (Lenton et al., 2008). But what are tipping points and why are they important for us?

5. Tipping points

Tipping points are defined as points where little differences lead to big and long-term system wide changes (Lenton, 2013; Milkoreit et al., 2018). By crossing a tipping point, a system switches into a qualitatively different state (Lenton et al., 2008). While crossing a tipping point can happen suddenly and as a result of a small change, reversing the tipping point is often much more difficult or not possible at all (Steffen et al., 2018). Tipping points are produced by strong positive (reinforcing) feedback inside a system (Milkoreit et al., 2018). It is a universally applicable concept that can be present in all kinds of domains.

While most tipping points that could occur in the global climate system pose a serious threat for us (Marengo et al., 2011), crossing potential tipping points in human socioeconomic systems could bring about sudden changes towards increased sustainability (Lenton et al., 2008).

5.1 Tipping elements on a global scale

Since the global climate system is under rapid anthropogenic forcing, several of its subsystems are at risk of exhibiting tipping points, for example, the Arctic summer sea-ice, the El Nino-Southern Oscillation and the Amazon rainforest (Lenton et al., 2008). Different environmental processes can result in the positive feedback that is associated with tipping points (Lenton, 2013). Examples of shifts in systems (e.g., rainforest to savannah, the collapse of the West Antarctic ice shield) are starting to be observed (Lenton et al., 2019). The coverage of both the Arctic winter and the Arctic summer sea-ice are declining, showing a strong non-linearity in thinning, and shrinking, and indicating that a tipping point towards complete summer ice-loss may be close (Lenton et al., 2008). Tipping elements of the Earth's climate system are assumed to shift in a response to different levels of warming (Lenton, 2013). Nevertheless, at a global warming of 2°C, interconnectedness could lead to a cascading of tipping elements which would produce further temperature increases (Lenton, 2013; Steffen et al., 2018). Even if warming is held within the range of the Paris Agreement, we cannot be sure that crossing tipping points in the climate system can be avoided (Marengo et al., 2011; Steffen et al., 2018).

One rare example of a tipping point that might have positive effects is the greening of the Sahara Desert and the Sahel in Africa (Lenton et al., 2008). A higher concentration of CO_2 in the atmosphere and increased water use efficiency could lead to increased vegetation.

5.2 Arctic tipping points

The greatest and clearest threat of a climate subsystem to reach a tipping point is the Arctic, where summer sea ice loss is already observed (Lenton, 2012). A strong positive ice-albedo feedback exists in the Arctic (Lenton et al., 2008): when the ice is melting, the bright ice surface is replaced by a dark ocean surface. The darker ocean reflects less and absorbs much more sunlight, leading to further warming of the atmosphere and water as a result of ice loss (Screen & Simmonds, 2010). Multiple stable states are possible in the Arctic: ice-free states as well as finite ice caps (Lenton et al., 2008). While some changes like the reduction in Arctic sea ice cover caused by increasing temperatures are assumed to be reversible on timeframes of less than a hundred years, most changes associated with feedbacks are irreversible on timespans that are relevant for today's societies and policy (Steffen et al., 2018). In the past, migration, societal changes, and collapses were often linked to climatic extreme events like strong droughts (Steffen et al., 2018).

5.3 Amazon tipping points

Feedback processes and dynamics inside a system (such as moisture recycling in the Amazon) play a role in pushing systems towards a tipping point (Lenton et al., 2008; Steffen et al., 2018). The recycling of rainfall in the Amazon (see section 5.4) is a reinforcing feedback and could under continuing drying conditions lead to a tipping towards degraded, seasonally dry forest or savannah (Lenton, 2013). During the process of "savannization", carbon is lost from soils and they become drier (Cox et al., 2000; Marengo et al., 2011; Marengo et al., 2018).

A sudden shift in the Amazon biome could either be triggered by drought as a result of global warming, or by deforestation exceeding a critical threshold (Pereira & Viola, 2020). Interactions between both drivers make crossing this tipping point more likely to happen (Marengo et al., 2011). The risk of the Amazon crossing a tipping point is increased by feedbacks between the vegetation state and fires, with human-made forest defragmentation causing more fires (Lenton et al., 2008; Marengo et al., 2011; Lenton, 2013; Marengo et al., 2018; Walker, 2021). Longer dry seasons, increasing summer temperatures and reduced rainfall challenge the forest and bring it closer to undergoing sudden and extreme changes (Lenton et al., 2008). Observed increases in drought frequency (years 2005, 2010, 2016) suggest that crossing a tipping point has become even more likely (Lovejoy & Nobre, 2019). Slowing down climate change can help biomes like the Amazon adapt to changing conditions, leading to a gradual transformation instead of abrupt changes (Steffen et al., 2018). To avoid crossing a tipping point in the Amazon, adequately managing and maintaining the water cycle in the rainforest is crucial (Marengo et al., 2018).

5.4 The Amazon climate system - Aerial rivers

The water cycle in the Amazon is highly dependent on moisture recycling by trees and moisture transport by aerial rivers. An aerial river is an analogy that describes plumes of water vapor and clouds that are transported by trade winds and low-level jets (Newell et al., 1992; Arraut et al., 2012; Satyamurty et al., 2013; Marengo et al., 2018). Low-level jets are wind channels of the lower atmosphere. Although the Atlantic Ocean supplies the main external inflow of water vapor to the Amazon rainforest (Sori et al., 2018), it has long been recognized that evapotranspiration plays a fundamental role in rainfall recycling (Salati et al., 1979, Moreira et al., 1997; Poveda et al., 2013). The moisture over the Amazon is brought inland by easterly trade winds from the Atlantic Ocean and South American Low-level Jets (SALLJs) (Marengo et al., 2004; Arraut et al., 2012; Marengo et al., 2018). The moist air is transported south along the eastern border of the Andes, across the Amazon and out towards the La Plata River Basin (Arraut et al., 2012; Poveda et al., 2013). There are three types of SALLJs that transport water vapor, clouds, and heat across South America: the Chaco Jet Event (Nicolini & Saulo, 2006), the No-Chaco Jet Event and the Argentinian Low-Level Jet. SALLJs continue to contribute to rainfall over the southern Amazon and La Plata region throughout the dry season. Therefore, anomalies in their moisture transport can lead to extreme droughts in the southern regions of the Amazon and excessive rainfall in other parts of South America (Marengo et al., 2008; Poveda et al., 2013).

Rainfall and temperature are also maintained and controlled by the process of moisture recycling, and it is considered that between 35%-80% of the rainfall in the Amazon is generated via evapotranspiration (Henderson-Sellers et al., 1993; Satyamurty et al., 2013). Based on calculations from numerous studies of evapotranspiration in the Amazon, Staal et al. (2018) suggest that approximately one-third of rainfall in the Amazon originates from within its own basin, of which at least two-thirds are transpired by vegetation.

The presence of Amazonian trees is therefore substantial for hydrologic and climate regulation at regional to global scales. This role emphasizes the vulnerability of the Amazon forest system in the face of excessive exploitation of resources and future climatic extremes (Moreira et al., 1997; Satyamurty et al., 2013; Nobre, 2014). An emergent Amazonian tree can transpire approximately 1000 litres of water per day, hence being fondly compared to silent forest geysers, or biological pumps (Nobre, 2014). It has also been estimated that 20 trillion litres of water are transpired daily from the Amazon rainforest, in comparison to 17 trillion litres of water discharged by the Amazon River into the Atlantic Ocean (Nobre, 2014; Staal et al., 2018). Emergent Amazonian tree species affiliated with terra firme ecosystems have significantly higher transpiration rates due to their root systems that access deep soil moisture (Kunert et al., 2017).

Despite the importance of trees for moisture recycling in the Amazon, forest-derived hydrological resources are inadequately incorporated into regional, national, and continental action plans for climate change mitigation and adaptation (Ellison et al., 2017). Large-scale deforestation, if continued at current rates, will cause a disequilibrium of the water cycle, and therefore have significant impacts on the people and wildlife of the Amazon (Salati & Vose, 1984; Marengo et al., 2018). Deforestation of the Amazon affects climate on a regional scale (Marengo et al., 2018; Sampaio et al., 2018). Scientists have attempted to model the potential climatic effects of deforestation in the Amazon since the 1980s and have projected a reduction in rainfall between 400-800 mm year-1 (Nobre & Nobre, 1991). Recent studies, covering more diverse land-cover changes, suggest that tropical deforestation reduces evapotranspiration and increases surface temperatures by 1-3 °C, causing boundary layer circulations. This would potentially increase rainfall in some regions and decrease it in others significantly (Marengo et al., 2018; Spracklen et al., 2018).

6. Climate and migration across the Amazon

According to the Intergovernmental Panel on Climate Change (IPCC), climate change has a great impact on human migration with displaced people due to flooding, agricultural disruption, desertification, and radioactive pollution. These displaced people are called “climate migrants” (Brown, 2008). Humans, like other animals, migrate to various regions due to climatic conditions. For climate migrants, migration is typically not the favored alternative and migration may play a negative role as response to environmental stress (Xu et al., 2020). For some individuals, moving is not considered an option due to cultural attachments. Those people are classified as "trapped migrants".

Climatic conditions, climate processes (sea-level rise, salinization of agricultural land, desertification, growing water scarcity), and climate events (flooding, storms, glacial lake outbursts) all contribute to migration. Beyond that, non-climate drivers such as government policy, population growth and war also cause migrations, and patterns of migrations are mainly dependent on an individual’s living conditions (Parry et al., 2007). Additional factors are age, gender, and current living status. Younger people have a higher tendency to migrate than older people while men typically migrate more than women. Less fortunate and poverty-stricken people are also more likely to migrate (Bergmann et al., 2021).

6.1 Climate migration in Bolivia

The most frequently reported causes of migration in Bolivia are environmental and climate issues such as for example glacier retreats (Boillat & Berkes, 2013), drought, and land degradation. These challenges and the subsequent migration reveal the vulnerability of agricultural outputs (Reuveny, 2007). The most intense migration in Bolivia occurred in 1983, when a two-year drought caused by El Niño devastated croplands and caused a mass migration for inhabitants of Northern Potosí towards La Paz, Cochabamba, and rural tropical zones. Men typically found work, but poverty-stricken women had to beg in the streets to survive on a marginal living. Many Andean families struggled to cope with conditions in the tropics and returned to Potasí after the drought to continue farming (Mariscal et al., 2011).

6.2 Climate migration in Brazil

Strict visa policies in France, the USA and Canada, coupled with employment opportunities, have contributed to the re-orientation of migration routes to the South. However, after the devastating 2010 earthquake in Haiti, it was reported that in 2014, the USA hosted 65% of the Haitian refugees, Canada 23%, and France 9% (Audebert, 2017). Unstable buildings and soft sedimentary plains, coupled with Haiti’s Caribbean plate-boundary location, meant that the infrastructure could not withstand an earthquake of that magnitude, causing the deaths of almost a quarter of a million people, the displacement of even more and the destruction of much of Haiti's capital city’s emerging infrastructure (Margesson & Taft-Morales, 2010). Migration towards South America, such as the Haitian migration (legal and asylum seekers) towards Acre in Brazil and Chile (Margesson & Taft-Morales, 2010; Dias et al., 2020), was due to the increased economic opportunities present in Brazil and the ease of entry into the country (Dias et al., 2020).

6.3 Climate migration in Peru

Extreme rainfall events and mega-floods have damaged thousands of homes and displaced people across many Amazonian countries. In the Peruvian Amazon, water-related threats have been a major factor in the destruction of urban and rural areas, displacing thousands of individuals per year. In some cases, entire communities were forced to migrate to safer areas with improved economic opportunities (Barichivich et al., 2018; Bergmann et al., 2021).

Extreme risks that could be faced in Peru in the subsequent years are a rise in sea-level, which may lead to loss of land, homes, and lives (Church et al., 2013) and droughts in the Peruvian Amazon with subsequent forest dieback. Additionally, an almost complete disappearance of Andean glaciers due to increased temperatures will cause negative impacts for hydropower and agricultural activities (Radić et al., 2014; Bergmann et al., 2021). Increased, intense and year-round heat stress that exceeds the ability of the human body to withstand surrounding temperatures could jeopardize the capacity of people to live in rainforests (Andrews et al., 2018). When facing such serious challenges, the hazard impacts can surpass the human capacity to adapt and catalyze migration (Bergmann et al., 2021).

When climate change influences livelihoods, people migrate from rural areas to cities in search of new opportunities, especially from the highlands to the coastal zones. An example near the MAP region is the severe glacial retreat in the Andes, reducing water availability and influencing Andean communities to migrate to the coast or rainforests (Adams, 2016; Bergmann et al., 2021).

There is a need to understand the complexity of migration processes. Climate change contributes significantly to the displacement of individuals (human beings or not), and currently people face both the impacts of climate change and the devastating effects of the COVID-19 pandemic. Although the interactions between climate change and pandemics are a new field of research, COVID-19 has revealed that some contagious diseases can be hampered by climatic impacts, such as heatwaves and water scarcity. Therefore, it is necessary to understand both to prevent and mitigate impacts.

7. Solutions for sustainable development in the Amazon

Climate change is predicted to have severe impacts for all forms of life across the Amazon biome, as well as for the rest of the world. The challenges posed by climate change come with responsibilities and opportunities. Actions that are taken (or not taken) and decisions that are made over the next decade, could have impacts for hundreds or thousands of years (Steffen et al., 2018). There are measures that are feasible and bring benefits, even if the modelled impacts do not occur. A paradigm shift towards an innovative green economy, with an interconnectedness of policy, is necessary for conserving the Amazon rainforest, whilst reinforcing sustainable development. The reconciliation of environmental, social, and economic aspects is necessary to foster socio-economic development in the Amazon, while preserving the forest as the biodiversity-rich biome that it currently still is (Perz et al., 2008; Marengo et al., 2018; Walker, 2021).

7.1 Resources and land use

Nature-based solutions such as restoration, sustainable harvesting of forest fruits, processing of NTFP for natural cosmetics and medicines, alley cropping in pasturelands, green credits/bonds, and protected areas in synergy offer decarbonized economic opportunities for communities in the Amazon. Simultaneously, they help safeguarding intact forests in protected and extractive areas. Solutions that cultivate social and economic regeneration must be prioritized and adequately managed by national and international institutions and governments. This progress is held back due to failures within markets linked to unjust pricing of NTFP and ecosystem services, as well as a lack of conscious consumerism by corporations. Investment in green economies by democratic, participatory, and sustainable initiatives is key to accelerating sustainable development within the Amazon (Burke, 2010). There is also a lack of subsidies and donations for producers to activate green economies, such as for accessing equipment to process, store and certify NTFPs. Certification of NTFPs by the Forest Stewardship Council and Organic and Fair-trade entities do empower producers' political voice. Nevertheless, reports from Madre de Dios regarding Brazil nut certification suggest that limited demand, monetary benefits, and economic viabilities reduce economic empowerment for producers and calls for the defragmentation of hierarchical economic structures (Quaedvlieg et al., 2014).

Soil management and climate change mitigation in crop and pasture lands can be improved by enforcing communities and agricultural associations to leave the cut vegetation to decompose in mounds instead of burning cleared forests for agriculture. Cut trees can also be shredded in woodchippers to produce mulch, but subsidies for machinery and fairly distributed use amongst farmers will need to be ensured. Implementing alley cropping techniques in pasturelands can generate an economically and technically feasible way to increase the productivity and value of the pasturelands without further forest clearance (Dablin, 2014). One way to reduce soil fertility losses and pest attacks is implementing agroforestry systems (Nobre & Nobre, 2019), funded by subsidies and green credits from governmental institutions or decarbonizing corporations. The allocation of a monthly or quarterly salary for fruit and cattle farmers can finance the transformation of monocultures to diverse and productive systems. Maintenance and periodical evaluation conducted by technicians who specialize in agronomy, forest engineering and biology, will reinforce transparency between corporations, stakeholders and farmers. "No-regrets" measures like environmentally rational agriculture will benefit people and the economy, as well as reduce acute shifts of rainforest to savannah (Lapola et al., 2018). Active reforestation and afforestation starting now as well as strengthening the resilience of the Amazon biome are necessary (Lovejoy & Nobre, 2019). Successful management of intact forest, reforested and afforested areas, will require careful consideration regarding the likelihood of multi-year droughts (Marengo et al., 2018).

7.2 Security of livelihoods and ecosystems

To improve risk and disaster assessments for communities in the region in anticipation of climatic disasters that could claim lives, climate change impact assessments can determine why, how and who will be affected. Mitigation strategies for climate change impacts, instead of compensation after a disaster, are economically more desirable both for citizens and for governance (Dolman et al., 2018). Academics, experts, stakeholders, native communities, migrant communities, and donors could unify under a shared set of goals to help create adaptive strategies to ensure disaster risk reduction and the security of livelihoods and ecosystems. A synergistic interdisciplinary approach which combines scientific field research, socio-economic surveys and geospatial analyses with indigenous knowledge can provide communities with updated information and adaptation strategies for extreme climatic conditions. Concurrently, sociologists and climate migrant social workers can explore and prepare ways to support individuals from Amazonian communities who decide to migrate from climate-insecure rural areas to urban areas. Field researchers can examine how individual demographic characteristics, such as age, education, ethnicity, gender, and physical ability affect the way people strategize and deal with hazards. Larger structural factors, such as power inequalities, along with family dynamics and the necessity for migration are of interest to understand people's behavior.

7.3 Governing and financing change

To mitigate the negative impacts of climate change and deforestation, there are two main goals: strengthening the forests' own resilience and reducing drivers of forest dieback (Lapola et al., 2018). Both goals can be achieved with a socially inclusive bioeconomy based on standing forests and flowing rivers, as described as the "Third Way" for development in the Amazon by Nobre and Nobre (Nobre & Nobre, 2019). Deforestation via slash and burn techniques can be decreased by law enforcement, policy, market forces, consumer demand for transparency, environmental monitoring, and the provisioning of human and financial resources (Silva Junior et al., 2021), as observed in Brazil before the recent upsurges of deforestation in 2020. Successful solutions should include actors from diverse social groups and demographics (Lapola et al., 2018). The focus needs to be on decoupling economic growth from deforestation (Nobre & Nobre, 2019), whilst unifying economic growth with green economies.

A start towards that is reinvesting a higher share of the wealth generated in the Amazon for local health and education improvements under a formal legal and ethical framework (Nobre & Nobre, 2019). Broadening the perspective on the Amazon (including all social groups and the forests' natural and economic assets) opens the road for a sustainable and profitable bioeconomy (Lovejoy & Nobre, 2019). Rainforest products such as brazil nuts, açai berries, aguaje palm fruit, cat's claw, fungi, edible weevil grubs and many others, all have a great potential to sustain a bioeconomy with minimized negative impacts (Horn et al., 2012; Manno et al., 2018; Lopes et al., 2019; Nobre & Nobre, 2019). Amazonia 4.0 describes development strategies that are possible with smarter, lighter, and customizable equipment due to the wide accessibility of the technologies of the fourth industrial revolution. Pursuing those ideas and prioritizing communities and marginalized individuals can help establish an intrinsic value across the Amazon biome. Needed for this paradigm shift is a broad imagination and an active will, upheld with transparency and equity, by stakeholders, external investors, local governance, and Amazonian communities (Lovejoy & Nobre, 2019).

7.4 Involving society

Encroachment in wild areas and the degradation of ecosystems create an environment in which pandemics can emerge and thrive. Climate change, viral pandemics and the loss of biodiversity are linked (IPBES, 2020), and reports of rabies, cutaneous leishmaniasis and malaria outbreaks have all been linked to upsurges in deforestation (Ellwanger et al., 2020). Fortunately, we can act to oppose such crises, and securing biodiversity will help securing human health. To preserve biodiversity, the entire environment in its integrity needs to be conserved (Woodwell, 2010), and that can only be achieved with collective human action (Steffen et al., 2018). Here we see that tipping points do not necessarily need to be negative: crossing a social tipping point, when it comes to collective decision-making, can help transform towards sustainability in the Amazon biome (Lenton, 2013). And policy has a crucial role in triggering such social tipping.

It was shown that Indigenous people are the best stewards for the Amazon (Garnett et al., 2018; Ribeiro et al., 2020b), but research indicates that they need empowerment and more financial support by governments and NGOs to address their health, wellbeing, and socio-economic needs (Nobre & Nobre, 2019). Ignoring the significance of local and indigenous knowledge must be evaded to preserve the forest and its inhabitants (Adade Williams et al., 2020). In addition to conservation being more effective with increased indigenous leadership, social improvements will be made (Butler, 2021). To secure mutual benefits and lasting engagement, regular consultation with indigenous and local communities about their needs and expectations is crucial (Ribeiro et al., 2020b). To strengthen the role of indigenous and local people in preserving the Amazon, besides national regulation, cross-national planning, international collaboration, and the support of international policies are needed.

A sharp reduction in active international field researchers in the Amazon has occurred in response to the COVID-19 pandemic. More national scientists should therefore be trained and paid to collect data for national and/or international research institutes. The urgency of climate change impacts across the Amazon calls for increased scientific field research to understand the dynamics of the impacts.

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