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Controls on deforestation in the Brazilian Amazon: Explaining past success actions, new challenges and recommendations

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ABSTRACT

This paper reviews important processes that drive deforestation and its control in the Brazilian Amazon. Governmental programs decreased the rate of deforestation in the Amazon by 70% from 2004 to 2015. This large reduction was the result of the Action Plan to Prevent and Control Deforestation in Legal Amazonia (PPCDAm) – a task force having the 'Arc of Deforestation' as target. During the PPCDAm's course, the creation of protected areas (PAs), punishment for illegal deforestation, and a soy moratorium were among the most important measures to reduce deforestation rates. Brazil's 2020 end goal, which was not reached, was to reduce the rate to 80% in relation to the 1996-2005 average. The current goal is to have no (0%) illegal deforestation through 2030. Our review shows both beneficial environmental policies that helped to reduce deforestation, e.g. soy and cattle moratoriums and creation of PAs, as well as threats to Brazil's Amazon Forest which came from anti-environmental policies between 2014-2022. Considering the main drivers of deforestation so far, we suggest that Brazil can reach the 2030 goal of zero illegal deforestation through (i) the creation and inspection of PAs to avoid illegal logging, (ii) maintenance and strengthening the soy moratorium, (iii) an improved law enforcement related to illegal deforestation, and (iv) a stronger forest concession system.

KEYWORDS: PPCDAm, illegal deforestation, protected areas, soy and cattle monitoring

Controles sobre o desmatamento na Amazônia brasileira: Explicando ações do sucesso no passado, novos desafios e recomendações

RESUMO

Este artigo revisa importantes processos que impulsionam o desmatamento na Amazônia brasileira. Programas governamentais reduziram a taxa de desmatamento na Amazônia em 70% entre 2004 e 2015. Essa grande redução foi resultado doPlano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm) – uma força-tarefa que tinha o 'Arco do Desmatamento' como alvo. Durante o curso do PPCDAm, a criação de áreas protegidas (APs), punições para o desmatamento ilegal e uma moratória da soja estiveram entre as medidas mais importantes para reduzir as taxas de desmatamento. A meta final do Brasil para 2020, que não foi atingida, era reduzir a taxa em 80% em relação à média de 1996-2005. A meta atual é alcançar 0% de desmatamento ilegal até 2030. Nossa revisão mostra tanto políticas ambientais benéficas que ajudaram a reduzir o desmatamento, como a moratória da soja e da pecuária e a criação de APs, quanto ameaças à Floresta Amazônica do Brasil provenientes de medidas antiambientais tomadas entre 2014-2022. Considerando os principais motores do desmatamento até agora, sugerimos que o Brasil pode alcançar a meta de 2030 de desmatamento ilegal zero por meio de (i) criação e fiscalização de APs para evitar a exploração ilegal de madeira, (ii) manutenção e fortalecimento da moratória da soja, (iii) uma melhor aplicação da lei relacionada ao desmatamento ilegal e (iv) um sistema mais forte de concessões florestais.

PALAVRAS-CHAVE: PPCDAm, desmatamento ilegal, áreas protegidas, moratória da soja e do gado

INTRODUCTION

Global warming has been one of the most important concerns in the modern world and the subject of government policies worldwide. The challenge is clear: reducing greenhouse gas (GHG) emissions to mitigate threats associated with global climate change. Deforestation and land-use change are among the main causes of GHG emissions (Delpierre *et al.* 2012, Domke *et al.* 2012, Fearnside 2012), so management of the world's forests is of critical importance to climate change.

Among the tropical regions, the Amazon basin's forests hold the largest amount of carbon (Nogueira *et al.* 2015). Brazil is the largest holder of forested land in the Amazon basin. Data

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from PRODES (INPE 2025) indicate that about 50 million hectares (Mha) of forest were cleared between 1988 and 2024 in the Brazilian Amazon, mostly across the 'Arc of Deforestation – AoD'. Estimates indicate that this clearance contributed to the loss of dozens of billion tons of CO_2-equivalents to the atmosphere in the Legal Amazonia region (Nogueira *et al.* 2015).

Brazil is not only a major global forest holder, but also one of the five biggest carbon dioxide emitters in the world. Studies reveal that deforestation in the Amazon may affect local, regional, and global climate (Leon *et al.* 2022, Fearnside 2016a, Lawrence and Vandecar 2015). In addition, research points out that new deforestation events tend to emit more carbon per unit area than deforestation of the Amazon in the past, because the previously cleared lands had lower biomass stocks than the remaining vegetation (Loarie *et al.* 2009, Nogueira *et al.* 2015). Researchers such as Shirai *et al.* (2024) and Nobre *et al.* (2016) warn that such depletion may provoke 'savannization' (conversion to a savanna-like landscape) in the Amazon under two possible "tipping points": temperature increase of 4 ºC, or deforestation exceeding 40% of the Amazon Forest.

The Brazilian Amazon forests have been cleared by many agents. Illegal logging has contributed substantially to forest loss, eliminating roughly 20% of the Brazilian Amazon over the past half century (Tollefson 2015b). Despite the lack of accurate estimates, Hummel (2014), who was Director-General of the Brazilian Forest Service (SFB), stated that Amazonia's rate of illegal wood harvesting is normally greater than 60%. Among various causes, he associates illegal logging mainly with a failed governance of public lands and logistical difficulties with inspecting hard-to-access lands, given the low-density road network in the Amazon. Deforestation for soy and cattle production was another major issue, related to favorable soy and beef prices (Soares-Filho *et al.* 2010).

This paper reviews measures taken by the Brazilian government for reducing the Amazon's rate of deforestation, as well as factors that contributed to increase this rate after a long period of success. First, the course and structure of the Action Plan to Prevent and Control Deforestation in Legal Amazonia (PPCDAm) is addressed, including factors that helped or hampered control of the deforestation rate. The current forest concession system is also discussed as a potential way of indirectly protecting native forests. Lastly, the paper highlights key issues which are crucial to understand the possible fate of the Amazon's forests depending on the extent to which deforestation is an unbridled or more tightly controlled process.

Creation of a plan for reducing deforestation in the Brazilian Amazon

In 2004, a Permanent Inter-Ministerial Working Group (GPTI) was created, aiming to coordinate actions to reduce deforestation in the Amazon (Fearnside 2016b), after Brazil having attained its second largest rate (2.78 Mha cleared) since 1988. In the same year, the GPTI created the PPCDAm, which consists of mutually reinforcing factors between policies, programs, and plans to prevent and combat deforestation in the Amazon. According to the Ministry of Environment - MMA (2013), the PPCDAm was structured following three strategic axes: 1) Land and Territorial Planning; 2) Environmental Monitoring and Control; and 3) Promotion of Sustainable Productive Activities (Figure 1).

Even though the strategic axes come from the Federal sphere, the State and Municipal ones have also played a key role in the PPCDAm progress (Figure 1). All these components (shown in Figure 1) work synergistically to promote integrated policies of agriculture, agrarian reform, biodiversity, industry, among others (MMA 2013).

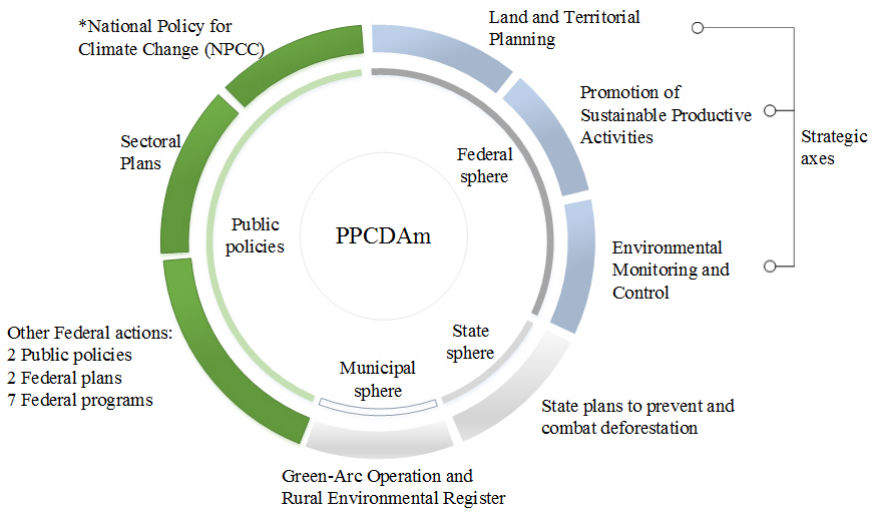

Figure 1. Action Plan to Prevent and Control Deforestation in Legal Amazonia (PPCDAm). *NPCC was enacted in 2009 (Law no: 12187/2009) to attempt the commitment assumed at COP-15 for reducing GHG by 36% - 39%.

The successful phases of the PPCDAm were carried out over the periods of 2004-2008 (1st phase), 2009-2011 (2nd phase), and 2012-2015 (3rd phase). The first and second phases were based mainly on the axis of Environmental Monitoring and Control (Figure 1). These two phases were associated with a project called Almost-Real Time Deforestation Detection (DETER), conducted by Brazil's Space Agency (INPE). However, the PPCDAm's third phase (2012-2015) required changes in the other axes, since the intensive deforestation made the forests more fragmented, so that large portions were below DETER's detection threshold. Thus, after the second phase, the PPCDAm's progress began to depend on instruments capable of detecting fragments smaller than 25 hectares (Diniz *et al.* 2015), increasing the importance of axes related to Land and Territorial Planning and Promotion of Sustainable Productive Activities (Figure 1). Consequently, this change ended up increasing costs of detection of deforestation (Godar *et al.* 2015), in addition to generating the need for a new deforestation model and the need for enhancing the effectiveness of those two underlying axes (MMA 2013).

The first three phases of the PPCDAm were responsible for decreasing the rate of deforestation in Legal Amazonia by almost 70% from 2004 to 2015, in relation to the 1996-2005 historical average. The sharpest reductions of deforestation since 1988 occurred during the first two phases of the PPCDAm, i.e., over the 2004-2011 period. The latest (2023) rate of deforestation is of 0.9 million ha (9,000 km², or 60% of the area of São Paulo City).

From the beginning of the PPCDAm, up to the end of its fourth phase, the 2020 goal was to decrease the rate of deforestation to 80% in relation to the 1996-2005 average (Figure 2). This 2020 goal came from an agreement forged at the International Panel of Climate Change (IPCC) meeting of 2004. The fourth phase (2016-2020) was implemented based on nine goals that should be achieved through 2020, which were developed in accordance with the following measures: 1) increasing Protected Areas (PAs) in 30% and ensuring that they have an effective management; 2) imposing heavier penalties for environmental crimes and infractions; 3) reviewing the criteria to list municipalities as priorities for monitoring and control, besides monitoring municipalities removed from a list for priority monitoring and control of deforestation and those never listed; and 4) slowing cattle ranching and the expansion of soybean production. A new axis was added to this phase, with the aim to address normative and economic issues around the combat and control of deforestation. This proposed axis was seen as necessary to increase the access of farmers to credit for sustainable forest management activities and environmental restoration. After being inactive in 2021 and 2022, the fifth phase of PPDCAm (2023-2027) has finally commenced. As it has only been in effect for a short period at the time of writing this article, its impact has not yet been addressed.

The most important measures that reduced the deforestation rate between 2004-2013

The large reduction of the Amazon's rate of deforestation attained during the PPCDAm was the result of several integrated efforts (Assunção *et al.* 2023), including creation of about 50 Mha of PAs, in addition to 10 Mha designated as Indigenous Lands (ILs). The study by Soares-Filho *et al.* (2010) reveals that the expansion of PAs in the Brazilian Amazon accounted for 37% of the total reduction in deforestation in the region between 2004 and 2006, without causing 'leakage' (i.e. deforestation induced outside of the boundaries of forests that became PAs).

From the late 1990s to 2004, the Brazilian Amazon experienced intensive deforestation due to agricultural

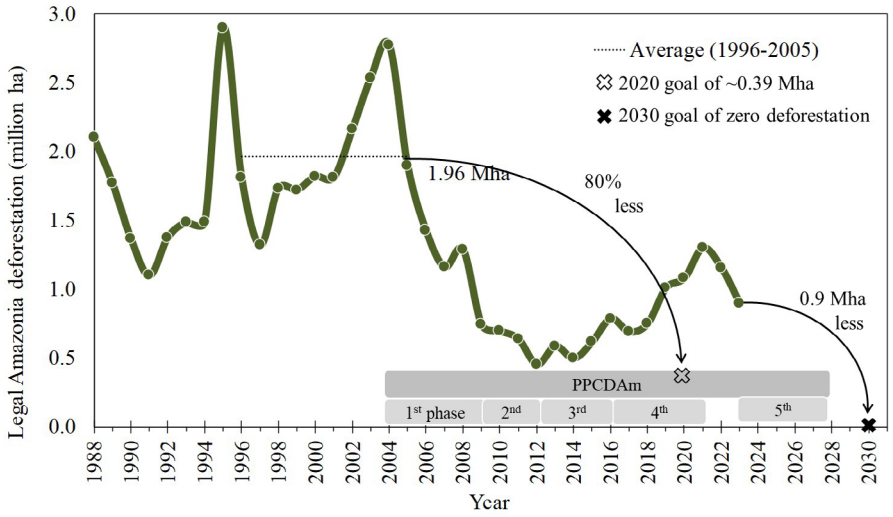

Figure 2. Annual deforestation rates in the Legal Amazonia and effects of the PPCDAm's phases. Mha = millions of hectares. Deforestation rates sourced from PRODES/INPE (2023).

expansion, strongly related with soy and cattle production (Nepstad *et al.* 2014). Before the onset of the PPCDAm in 2004, the extension of deforested areas increased as much as soy and beef prices rose. Soy and beef production were a driver of deforestation until 2006. In this year, non-governmental organizations and environmentalists pressured the major soybean companies and traders to sign an agreement known as Brazil's Soy Moratorium (SoyM). This agreement prohibits major buyers to purchase soy grown on lands deforested after 2006 in the Brazilian Amazon (Gibbs *et al.* 2015). Brazil's SoyM has been annually or biannually renewed since 2006, but its renewal was no longer necessary since 2016, because of a new pact that perpetuates the SoyM indefinitely (Heilmayr *et al.* 2020). The evolution of deforestation in the Amazon, alongside changes in soy and beef prices can be seen on Figure 3, highlighting the period of Brazil's SoyM, creation of PAs and ILs during the PPCDAm.

Under Brazil's SoyM, deforestation in the Amazon decreased even with a continued rise in soy (and beef) prices, meaning that farmers were effectively discouraged from clearing lands to grow soybeans. Researchers as Gibbs *et al.* (2015) and Nepstad *et al.* (2014) reported that the relation between soy production and areas deforested for this purpose took a different course, mainly after the beginning of the SoyM in 2006. Heilmayr *et al.* (2020) suggest a prevention of 1.8 ± 0.9 Mha of deforested area in the Amazon between 2006–2016. Official SoyM reports (GTS, 2023) also reveal that soybean cropland area in the Amazon biome increased from 1.64 Mha (2007/08) to 7.28 Mha (2022/23), from which only a small fraction (0.25 Mha) were not in sync with the SoyM, meaning that the recent soy expansion has been occurring in previously deforested areas.

Rudorff *et al.* (2011) studied the SoyM through the monitoring of areas belonging to 52 Amazonian municipalities that traditionally produced soy during 2009-2010, finding positive contributions of the SoyM as a driver for reducing deforestation in the Amazon. Less than 1% of the total deforested area in the region was shown to be cleared for growing soybeans from 2009-2010, based on remote sensing (Rudorff *et al.* 2011). Estimates from official SoyM reports (available in http://www.abiove.org.br) indicate a slightly larger number of 1.2%, when 97% of all areas of soybean croplands that existed between 2008 and 2016 were considered. These values are tiny compared to the rate of ~30% found two years before the moratorium (Gibbs *et al.* 2015).

In addition to the SoyM, Nepstad *et al.* (2014) revealed that changes in Brazil's public policies running until 2013 decreased deforestation riskier through improved law enforcement, fines and embargos associated with illegal deforestation. The Brazilian government repression of illegal activities of ranchers, farmers and land speculators also contributed to decrease the

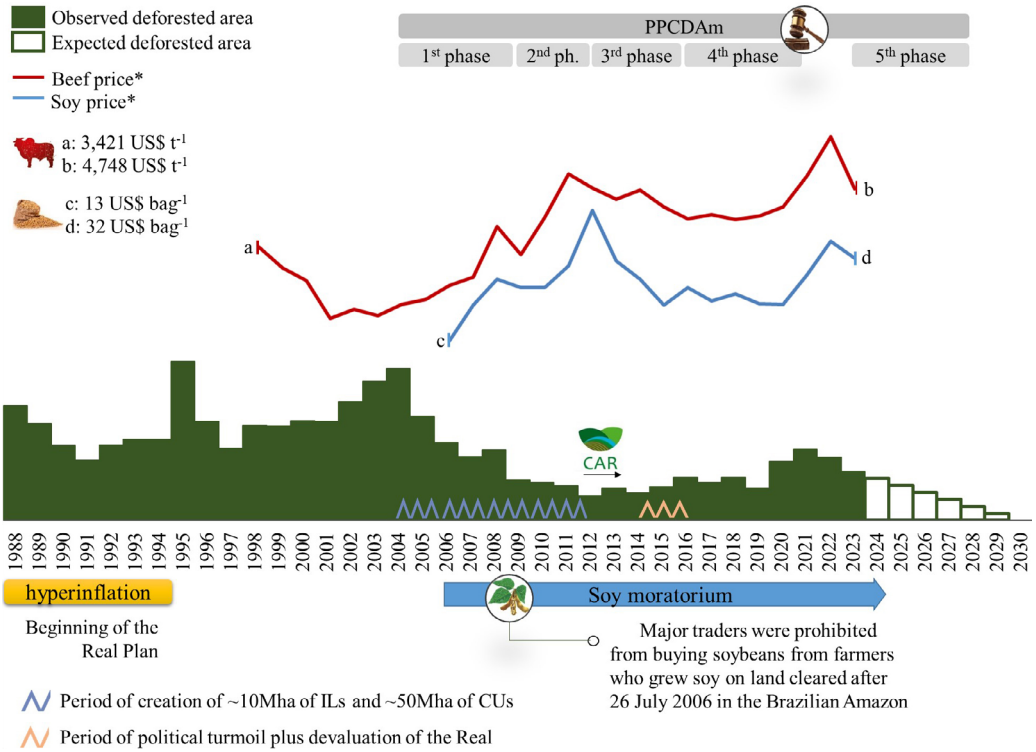

Figure 3. Historical evolution of Amazonian deforestation and its relationship with the PPCDAm, soy moratorium progress, and soy and beef prices. IL: Indigenous land. CU: Conservation Unit. Mha = millions of hectares. Deforestation rates sourced from PRODES/INPE (2023). Amounts of ILs and CUs sourced from MMA (2013). *Annual soy and beef prices sourced from 'www.farmnews.com.br'.

rate of deforestation (Tollefson 2015b). Such measures were mainly developed between 2009 and 2011, when the Ministry of the Environment (MMA) added 43 municipalities to a list for priority monitoring and control. The big difference in this strategy was that inspections, embargoes and fines due to illegal deforestation were no longer at the individual-farm level, but at the municipality level (Nepstad *et al*. 2014). There is strong evidence of a policy-enforcement effect on those Amazonia's listed municipalities, which ended up increasing the number of embargoed properties (Arima *et al*. 2014, Assunção *et al*. 2015). These listed municipalities are situated along the Arc of Deforestation (Figure 4), were most deforestation – 73% - was taking place, predominantly in Mato Grosso, Pará, and Rondônia, regions with historically high deforestation rates (Silva et al. 2022). That is the reason why the PPCDAm's fourth phase (2016-2020) remained focused on three areas with highest deforestation rates in the Arc of Deforestation: the frontiers between the States of Rondônia and Mato Grosso, as well as the State of Pará (Figure 4). Despite the noted success of embargoes as an auxiliary tool to slow down deforestation rates, after peaking in 2012 and 2013, the number of embargoes declined significantly from 2014 onwards, with minimal applications between 2017-2022 (Coelho-Junior *et al*. 2022).

Impacts of the economic crisis and political change on Amazonian deforestation between 2014-2022

After a successful period (2004 to 2014), PPCDAm's fourth phase began moving away from the 2020 goal of an 80% reduction in deforestation rates (see Figure 4). Despite the intent to halt deforestation and promote forest recovery, only 13.1% of embargoed areas complied with the legislation, as most embargoed areas remained in pasture and other agriculture uses. This low compliance rate has persisted over time, highlighting the limited effectiveness of embargoes in curbing illegal deforestation during this fourth period. Field inspections to evaluate the occurrence of environmental crimes suffered a 43% reduction from 2010 to 2019, from 1,311 to 743 inspectors acting in field (Silva et al. 2022).

Almost 800 thousand hectares were cleared in 2016, an increase of 28.7% in relation to the 2015 rate (Figure 4). This was the largest expansion of annual deforestation since 2009, corresponding to more than five times the area of São Paulo City. Research by Artaxo (2019), Fearnside (2015), and Tollefson (2015a) associated the growth of deforestation with Brazil's economic and political crisis between 2015 and 2016, culminating with the impeachment of the former President Dilma Rousseff in August 2016. In this period, the Brazilian currency (real) significantly devalued (~4 Brazilian Real to 1 US Dollar). The currency depreciation was an important driver for agricultural production, with exports becoming more profitable there was a stimulus to the agribusiness, and consequently the clearing of Amazon forests for agricultural land (Fearnside 2015).

Tollefson (2015a) and Fearnside (2015) also report that conservative lawmakers wanted to undermine the country's environmental regulations to clear the way for rapid development of energy facilities, mines and agriculture, creating new threats for forests in the Amazon region. According to Fearnside (2015), the Brazilian government reduced expenditures to enforce environmental laws by 72%, followed by discouraging the creation of new PAs. For example, ~1.6 Mha $year^{-1}$ were designated as PAs from 2011 to 2018 in Brazil, whereas the rate over 2003-2010 was more than double (~3.3 Mha $year^{-1}$). Additionally, in 2017, various institutes and environmental organizations formally expressed their discontent to Brazil's President, Ministers, and Parliamentarians regarding a provisional measure that reduced the size of Protected Areas (PAs) from over 2.5 Mha to approximately 1.5 Mha—a net loss of about 1 Mha (Greenpeace 2017). Another important change in law reported by Rajão and Soares-Filho (2015), is that farmers, since 2012, have benefited from a Brazilian policy related to the Legal Reserve (LR) –, which is a mandatory private conservation area created by the 2012 Forest Code. Under such a policy, all rural properties must maintain a portion (80% in Amazonian biome) of forested area. Recently, however, LRs may be compensated by purchasing titles to portions of forests from larger properties that have more than the required portion of LR. Such an offset market could reach 14 million ha of low-cost titles from private lands already inside PAs, and 38 million ha from LRs on small properties that already are protected, meaning that no additional forests would be saved (Rajão and Soares-Filho 2015). In addition, the 2012 Forest Code also granted amnesty to landowners who deforested beyond the allowed limits before July 2008, which encouraged farmers to clear lands until then, knowing that such precedent in law might benefit them in the future, as explained in Azevedo et al. (2017). The amnesty affected 32–41 million ha of native forest illegally cleared in Brazil (Freitas *et al*. 2018), thus decreasing the total area that would need to be reforested after clearing from 50 ± 6 million ha to 21 ± 1 million ha in the country (Soares-Filho *et al*. 2014).

The government of the former President Bolsonaro (2019–2022) undermined policies for combating deforestation, including the interruption of the PPCDAm and removal of important agenda from the Ministry of Environment, fragmenting the well-nested system that structured that program (Mathias 2022). Bolsonaro's government also extinguished the Secretary for Climate Change and Forests and removed Brazil from the United Nations Paris Agreement, what was considered by environmentalists (Artaxo 2019, Escobar 2019), as a threat to climate change-related efforts, since the country promised to reduce GHG emissions by 43% by 2030, in relation to 2005 emissions. His government also transferred the SFB from the Ministry of Environment to the Ministry of Agriculture, which loosened regulation of forest conservation and sustainability in favor of agricultural expansion. The SFB manages programs that could help to control or prevent Amazon deforestation,

such as the CAR (Environmental Rural Registry) and the forest concession system. The CAR has been in force since 2012 and consists of a mandatory registry nationally applied to landholders submitting information like boundaries and land-use of their rural properties. The CAR database contains information of lands that may or may not have been deforested, i.e., data to identify and possibly punish those engaged in illegal deforestation. The Ministry of Agriculture has conflicts of interest in such cases and only the Ministry of Environment has autonomy to punish illegal deforesters (Rajão 2019). The Ministry of Environment needs to remain a strong and separate political institution to enforce this policy correctly. There was a corresponding increase in deforestation in the Amazon during Bolsonaro's government of 34% in 2019 (in relation to 2018), 7% in 2020 (in relation to 2019), 20% in 2021 (in relation to 2020), and a fall came in 2022, his last year of government, which was 11% in relation to 2021 (see Figure 2).

Forest concession as a potential way of protecting the Brazilian's Amazon forest

Research suggests that forest concession systems are a good measure to reduce deforestation, especially for developing nations, if well-supervised, i.e., forests are not cleared while they are granted, but could be otherwise. From the point of view of Hummel (2014) and Karsenty *et al.* (2008), forest concessions can, for example, help promote sustainable forest management. The Brazilian forest concession system became law through the 2006 Public Forest Management Law, which enabled Federal, State, and Municipal governments to grant access to public forests for logging, harvesting of non-timber products, and tourism services. Both companies and communities were allowed to conduct long-term forest management plans under that system.

The SFB manages all federal concessions and is responsible for monitoring the commitments held in concession agreements. According to the SFB, until the date of this study, eight National Forests (NFs) in the Amazon were under concession to private companies (Figure 4): Jamari and Jacundá (both in the State of Rondônia); Saracá-Taquera, Crepori, Altamira and Caxiuanã (Pará state); Amapá (Amapá State); and Humaitá (Amazonas state). Only NFs have been devoted for concession, but other public forests may be devoted in the future.

Forest area of NFs under concession system until 2023 totals ~1.35 million ha. This area is a relatively small portion considering that public forests in Brazil comprise about 309.4 million ha (MMA 2023), including 32 NFs in the Brazilian Amazon that cover 14.3 million ha (Azevedo-Ramos *et al.* 2015). However, many of the NFs in the Brazilian Amazon are located across the 'AoD' and a large portion of them are located near or inside boundaries of the ten most deforested municipalities (Figure 4).

Although the forest concession system is a potential way for protecting public forests, some studies have pointed out concerns about such system. Azevedo-Ramos *et al.* (2015) report challenges in the Brazilian concession model, including

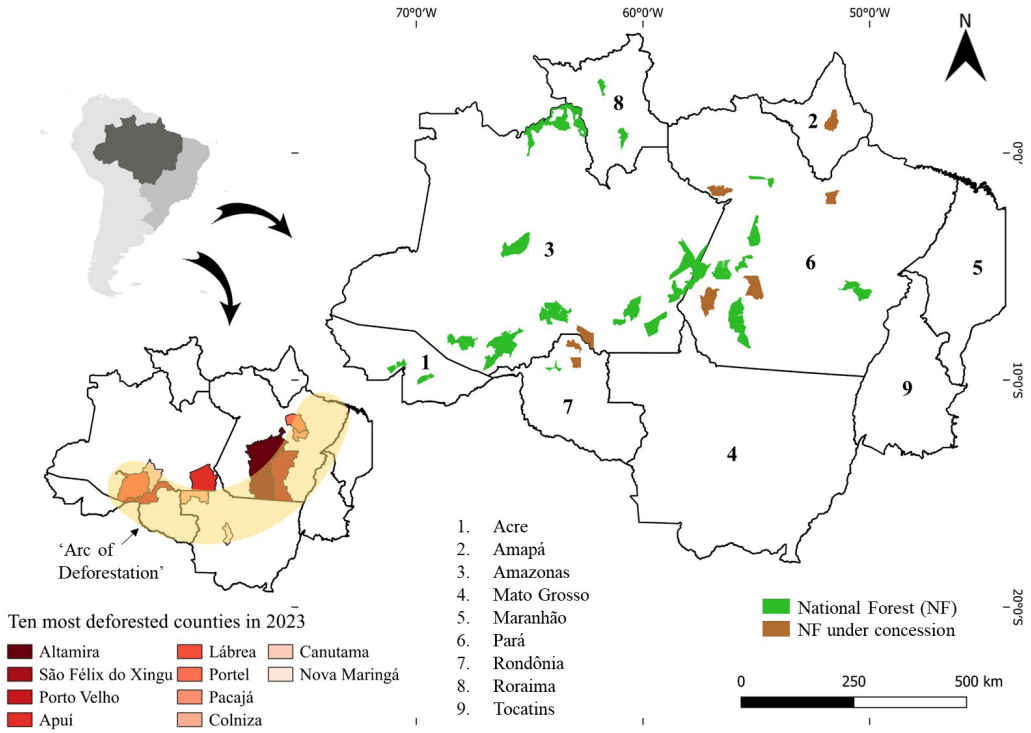

Figure 4. Location of Amazon's National Forests and the ten most deforested counties in 2023.

high cost transactions such as bidding, environmental assessments, forest inventory, infrastructure, and regulatory fees, which discourages investors; an industry unwilling to adapt to the stringent requirements set in the policy; and little success in inhibiting illegal logging that may occur in forest concessions. Macpherson *et al*. (2010) surveyed the effectiveness and performance of concessions and their compliance with reduced-impact logging and harvest volume requirements. They concluded that the auditing procedures are unlikely to induce full compliance with harvest regulations, due to the ease of maintaining low levels of illegal behavior hidden from the regulators, and an associated corrupt system.

Similar concerns are also reported in Peru and Bolivia. Both Amazonian countries have begun their forest concession systems a bit earlier than Brazil: Peru in 2000 and Bolivia in the 1990s (Sears and Pinedo-Vasquez 2011). In Peru, weak governance, corruption, and lack of monitoring and enforcement, were indicated as reasons for a failed forestry sector (Sears and Pinedo-Vasquez 2011). These authors also report that agencies responsible for enforcement and monitoring forest concessions do not have the resources necessary to operate in the remote and diverse environments of the Peruvian Amazon. Timber management in geographically remote and socially complex regions may be infeasible economically, especially due to the very high costs of logistics (Sears and Pinedo-Vasquez 2011). Thus, loggers tend to overexploit the forests in these areas, hoping to offset their high operational costs.

In Madre de Dios, Peru, Giudice *et al*. (2012) noted an undervaluation of forests granted for concession, so the government received lower fees than it could have. As a result, loggers may have had much higher profits than expected. These authors used simulation to estimate yields and economic timber rents over a 20-year period, concluding that annual forest revenues to the State could be increased from US$ 1 million to a maximum annual average of US$ 23.4 ±1.4 million in this period. In Brazil, modelling scenarios with and without concessions of forests in the Amazon basin were used to assess their impact on the economy and household welfare in the region, indicating that concessions contributed favorably if implemented with proper monitoring (Banerjee and Alavalapati 2010). On the other hand, negative effects on the economy and forestry sector were shown, when the government neglects concession monitoring. Brazil and Peru encompass more than 70% of the Amazonian region. Following these studies, there is a clear need for improvement of current concession systems in these countries. Also, Amazon's forests could be better managed, given their financial and social potential, but are hampered by an inefficient policy system (Banerjee and Alavalapati 2010, Karsenty *et al*. 2008).

Due to the large size of public forests in the Brazilian Amazon the forest concession system has both the potential to protect or debilitate millions of hectares of forests. So, it is crucial that the agency ruling the system (the SFB, in Brazil) efficiently supervises the concessioned forests to ensure the logging is conducted under sustainable yield principles. Given the tendency of illegal practices to increase profitability of logging in remote areas, granting concessions primarily in the most accessible forests would be an alternative, ensuring lower operational and inspection costs and conserving more forests in remote and wild places for non-timber benefits.

Despite the challenges reported about Brazil's forest concession system, it is important to consider that economic instabilities and the undermining of environmental laws of the country makes the concession system a viable alternative to avoid further deforestation. From a climate change point of view, the difference between forest concessions (overexploited or not) and clearing forests altogether is that the latter compounds to GHG emissions and climate change because it often is followed by fires (Aragão et al. 2018). On the other hand, tree carbon lost in sustainable logging can be recovered in the future, from 45 to 100 years in tropical forests (Blanc et al. 2009).

The fate of Brazil's Amazon Forest through 2030

The agreement reached at COP26 (Glasgow, 2021) known as the 'Forest Deal' established the goal of ending global illegal deforestation by 2030 (Oxford Analytica, 2021). Along with over 100 countries, Brazil signed that accord. To meet such commitment, Brazil needs to reduce the 2023 rate from 0.9 million ha $year^{-1}$ to zero (Figure 2). Such reduction has precedent, since even larger reductions were reached in the beginning of the PPCDAm. To conclude this review, we suggest three issues that may drive the fate of the Amazon Forest and allow Brazil to comply with the 2030 goal, or not.

First, surveys suggest that the protection of the Amazon Forest depends on the balance between forest protection and agricultural production, requiring agricultural development to occur in a more effective policy framework. In line with this, and considering the positive impact provided by the SoyM to halt deforestation in the Amazon (Paim 2021), another effective measure to better protect the forests would be to enact a beef production monitoring system, similar to the SoyM. A similar agreement had been conducted through a Greenpeace campaign aimed to exclude, from the supply chain of the largest beef companies, cattle from breeders who have deforested after 2009, but it was only in force for a short time (Greenpeace, 2009). Despite the unquestionable importance of moratoriums, they may only make farmers shift to agricultural products that are not covered by the moratorium. So, other measures are also needed.

Second, creating more PAs has shown to be an effective measure that helps to avoid deforestation, but an efficient monitoring is necessary to accompany them. The PAs and ILs created during the PPCDAm's progress notably helped to reduce deforestation (Barber *et al*. 2014, Nepstad *et al*. 2014, Walker *et al*. 2014, Yanai *et al*. 2016). However, studies

showed that in addition to creating them, it is necessary to protect them by means of surveillance. Fortunately, one of the aims of the PPCDAm' fifth phase is to enlarge and improve the management of PAs. Inspections and embargoes in rural properties are equally important actions. Field and remote surveillance relies on distribution of financial resource from the government, as occurred in the past success of the PPCDAm.

Third, the forest concession system is perhaps the best way to insert public forests into the economy, creating value to standing forests. On private lands, tax incentives to sustainable management of forest resources would be an important measure to discourage farmers from clearing their forests. Incentives and education programs to shift production towards shade-loving crops, that can thrive under tree cover (e.g., shade cacao), or to non-timber tree products that do not require open land (agroforestry), could be a valuable part of a comprehensive strategy.

Finally, there may be other remedies to Amazon deforestation not listed here, but, in any event, imminent solutions are needed to help protect and properly value this globally important forest region.

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