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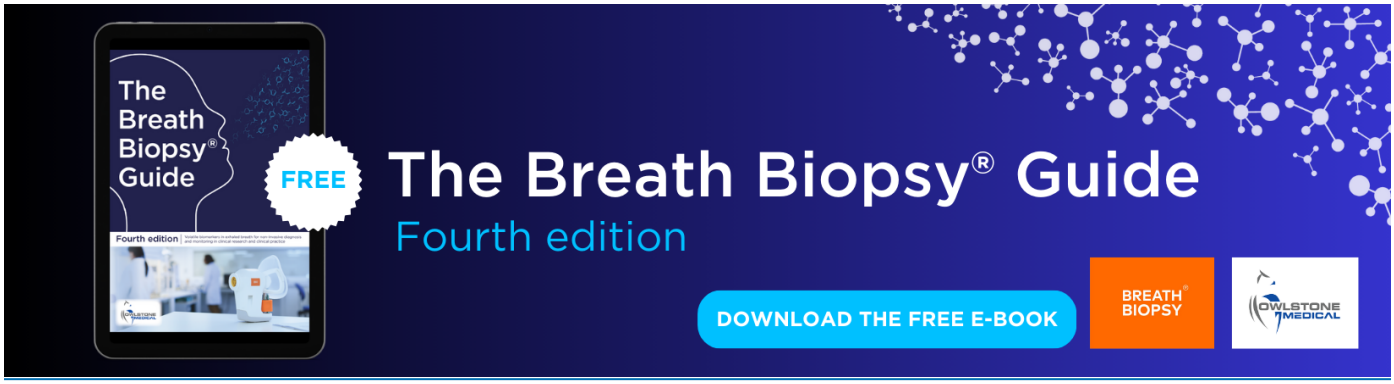

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Eroding resilience of deforestation interventions—evidence from Brazil's lost decade

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Abstract

Brazil once set the example for curtailing deforestation with command and control policies, but, in the last decade, these interventions have gone astray. Environmental research and policy today are largely informed by the earlier successes of deforestation interventions, but not their recent failures. Here, we investigate the *resilience* of deforestation interventions. We discuss how the recent trend reversal in Brazil came to be, and what its implications for the design of future policies are. We use newly compiled information on environmental fines in an econometric model to show that the enforcement of environmental policy has become ineffective in recent years. Our results add empirical evidence to earlier studies documenting the erosion of the institutions responsible for forest protection, and highlight the considerable deforestation impacts of this erosion. Future efforts for sustainable forest protection should be aimed at strengthening institutions, spreading responsibilities, and redistributing the common value of forests via incentive-based systems.

1. Deforestation and misaligned incentives

Economic theory suggests that deforestation occurs if its expected benefits exceed the expected costs. It is well known that the loss of forests and the ecosystem services that they provide, including their roles in sustaining biodiversity and stabilizing climate, largely outweighs the benefits of cleared land (Malhi *et al* 2008, Gibson *et al* 2011). The underlying incentives, however, are misaligned, and this calculation only tallies at aggregate levels, but not for individuals. Policies seek to bridge this alignment problem by redistributing the costs and benefits of forests and cleared land. A major challenge in this endeavor is the scope of the common value that forests provide. Their benefits may be immense, but they are borne locally, regionally, and globally—today and in the far future. In order to effectively preserve forests, interventions require foresight and multilayered collaboration.

To slow down the deforestation of the Amazon rainforest, Brazil implemented a number of interventions, including command and control measures that set a standard ('command') and sanction non-compliance ('control'). These interventions played an important role in reducing deforestation in the early 2000s, and continue to be an example for researchers and policymakers (Nepstad *et al* 2014, Tacconi *et al* 2019, Trancoso 2021). However, resurgences in deforestation rates highlight their lack of resilience, and the resulting lack of long-term efficacy. Recent years saw the gradual dismantlement of environmental legislation, the erosion of institutions responsible for enforcement and monitoring, and increases in anti-environmental rhetoric (Garrett *et al* 2021, Ruaro *et al* 2021, Moutinho and Escobar 2022, Oliveira *et al* 2023). The implications of such political, legislative, and informal changes for the design of deforestation interventions are profound, but not well understood.

In this paper, we investigate the resilience of deforestation interventions to recent changes in Brazil. We quantify the specific impacts on the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), the executive arm of the Ministry of the Environment, and its ability to enforce regulations. For this, we collect and process

data on environmental fines that were handed out over the past decades. In order to causally link this erosion of enforcement to deforestation, we use an econometric panel model to contrast the efficacy of environmental fines across policy regimes. We find that enforcement activity has reduced considerably in recent years, and sanctions have effectively become inconsequential. Additionally, we examine two large deforestation hotspots, in the frontier state of Pará, to illustrate the underlying deforestation patterns. These regions experience fast and accelerating forest loss that increasingly occurs in public, protected, and even indigenous lands. Our findings suggest that the lack of resilience in deforestation interventions to short-term changes and the resulting (real or perceived) lack of credibility have large impacts on deforestation, and need to be considered going forward.

1.1. Background and the case of Brazil

Deforestation[4] can be understood as the result of an alignment problem between common interests and the interests of specific local actors. The driving factors behind these interests can be summarized as ones impacting the perceived value of forests and of cleared land (as well as the costs of deforestation). Forests are a *common* good, since their value is largely realized at aggregate levels; this includes their role in mitigating climate change (Malhi *et al* 2008), harboring biodiversity (Gibson *et al* 2011), and providing various ecosystem services (Strand *et al* 2018). Meanwhile, the value of cleared land mostly manifests at the regional, local, and individual level. Agriculture, forestry, and mineral extraction drive economic growth, provide employment, and promise private profits. Local actors only bear a small fraction of the large common value of the forest, but most of the comparatively limited value of cleared land. This contrast leads to excessive deforestation, and is further complicated by the dimension of time and uncertainty—ecosystem services that are realized in the long-term oppose short-term monetary incentives.

This situation is mirrored in the Brazilian Amazon, where the most tangible benefit of forests concerns the livelihoods of indigenous peoples (Villén-Pérez *et al* 2022). Other local benefits of forests, such as its role in sustaining a climate that is suited to agriculture (Leite-Filho *et al* 2021), are less tangible, harder to quantify, and shrouded by more uncertainty. Meanwhile, the value of cleared land largely stems from resource extraction or the potential for it. The most prominent commodities produced in the Brazilian Amazon are beef and soy (Rajão *et al* 2020, zu Ermgassen *et al* 2020), but they are not the only ones affecting the expected value of land. Mineral resources, for instance, are not as prominent, since the direct land use for their (industrial) extraction is relatively limited (Giljum *et al* 2022). However, they impact the expected value of land via indirect effects (e.g. infrastructure or artisanal mining) and uncertainty (e.g. concerning the location of mineral deposits or environmental legislation that regulates extraction). In summary, the incentives for deforestation predominate at individual and regional levels, and—in the absence of effective interventions—threaten the continued existence of the Amazon and its ecosystem services.

The legislative cornerstone for ecosystem conservation in Brazil is the Forest Code (Soares-Filho *et al* 2014, Soterroni *et al* 2018, Brock *et al* 2021). It stipulates, inter alia, that proportions of *private* land must be maintained as native vegetation (80% in the Amazon biome), and designates environmental preservation areas. However, vast areas of the Brazilian Amazon are *public* lands, and not subject to the Forest Code. In these areas, land grabbing is prevalent, and forested lands are cleared, occupied illegally, and subsequently appropriated (Carrero *et al* 2022). Most interventions only take effect after appropriation, and the primary barrier to land grabbing is the registration of properties in the *Cadastro Ambiental Rural* (CAR) (Chiavari *et al* 2020), which can be misused for land appropriation without pending completion and validation of the system (Carrero *et al* 2022). Other measures for the protection of forests include environmental licensing (Ruaro *et al* 2021), conservation areas (Reydon *et al* 2020), indigenous areas (Baragwanath and Bayi 2020), and land tenure in general (Pacheco and Meyer 2022). Civil society and private-sector interventions also play a prominent, if limited, role in forest protection (Gibbs *et al* 2015, Alix-Garcia and Gibbs 2017, Villoria *et al* 2022). Examples are zero-deforestation commitments, such as the Soy Moratorium and the Cattle Agreements, which seek to eliminate deforestation-implicated commodities from the supply chains of participating companies.

This framework of deforestation interventions relies on compliance. Compliance to command and control interventions, which attempt to increase the cost of undesired acts, needs to be monitored and enforced under the threat of sanctions (see, e.g. Hargrave and Kis-Katos 2013, Assunção *et al* 2023). As executive authority for environmental policies, IBAMA plays a central role in exerting 'control' and is supported by, but also supports, a number of other institutions. On the one hand, the enforcement of compliance (in the vast Brazilian Amazon) is facilitated by innovative systems, such as CAR or remote sensing programs by the National Institute for Space Research (INPE). On the other hand, local landholders, communities, and particularly indigenous groups internalize (some of) the value of forests (Pacheco and Meyer 2022), incentivizing more sustainable use. These actors rely on sufficient property rights (and

[4] In the context of the Brazilian Amazon, we equate forest loss and deforestation, its predominant driver.

authorities to protect them) to effectively implement their preferred land use regimes (Baragwanath and Bayi 2020).

The Brazilian system for forest protection reduced deforestation in the past (Nepstad *et al* 2014), but arguably lacks the resilience needed to *sustainably* protect the Amazon. Recently, the political will that gave birth to many deforestation interventions has faded, and crucial measures for forest protection have seen systematic dismantlement (Abessa *et al* 2019). A 2012 revision to the Forest Code, for instance, lowered restrictions and gave amnesties for earlier offenses (Garrett *et al* 2021). In 2016, the Ministry of Environment (and therefore IBAMA) experienced a cut and freeze in its budget. There were also amnesties for land appropriation (Garrett *et al* 2021), and INPE's budget for satellite monitoring was decreased (Moutinho and Escobar 2022). More recently, political attacks against environmental policies and related authorities have accelerated, and frequently become more informal (Oliveira *et al* 2023). In addition to weakened environmental legislation (particularly during the early stages of the COVID-19 pandemic, see Vale *et al* 2021), the perceived threat of sanctions is muffled by public officials calling for the 'development' of the Amazon, attacks against the credibility of responsible institutions, and interference with their operations (for example, by blocking vacant positions or introducing mandatory reconciliation hearings for environmental offenses). As a result, the credibility of environmental policy is eroding, legal and illegal deforestation continue at unsustainable rates (Coelho-Junior *et al* 2022, Mataveli *et al* 2022), and land grabbing remains unrelenting (Carrero *et al* 2022).

2. Assessing comprehensive and specific impacts

We assess the impacts of formal and informal changes in the Brazilian system for protecting the Amazon rainforest in two ways. First, we analyze the activity and efficacy of enforcement by IBAMA. Second, we examine two deforestation hotspots in Pará to provide additional context and illustrate deforestation patterns in frontier regions.

2.1. Enforcement as a cornerstone

IBAMA is the primary executive organ enforcing compliance to environmental laws and regulations. To quantify impacts on its activity and efficacy, we collected, processed, and analyzed comprehensive data on fines handed out by IBAMA. We focused on fines for flora-related offenses within the Legal Amazon to assess their impacts on deforestation and its prevention. A number of data cleaning steps were necessary (inter alia, to avoid double-counting and to address entry mistakes), which are described in full in the supplementary material. The resulting dataset has information on individual fines, which includes relevant dates, as well as the location and last status of fines. This allows us to assess IBAMA's fining activity, capturing both the number and value of fines, as well as the practical impact of sanctions, that is, whether and to what extent fines are actually paid.

We relate this information on fines to forest loss, and are looking to quantify changes in the relationship between them. For this, we merge our dataset with information on relevant control variables that may confound the relation. This includes geospatial data on land use and land-use transitions (MapBiomas 2022), different types of protected areas (UNEP-WCMC and IUCN 2022), climatic conditions (Beguería *et al* 2010), as well as data on economic activity, population, soy prices, and cattle headcounts (IBGE 2022). The resulting dataset covers 807 municipalities in the Legal Amazon from 2003 to 2021. To statistically relate forest loss in municipality i at time t to earlier fines, we consider the following panel model:

$$\log \text{forest loss}_{i,t} = \boldsymbol{\beta}' \left(\log \text{fines}_{i,t-1} \times \text{period}_t\right) + \boldsymbol{\theta}' \mathbf{x}_{i,t-s} + \mu_i + \lambda_t + \varepsilon_{i,t},$$

where the coefficient $\boldsymbol{\beta}$ quantifies the *elasticity* between forest loss and fining activity in the previous year for certain periods. This means that an estimate of negative two would imply that a one-percent increase in fines correlates with a two-percent decrease in forest loss. The vector $\mathbf{x}_{i,t-s}$ holds (suitably lagged) control variables, μ_i and λ_t capture unobserved municipality- and time-specific effects. The error term $\varepsilon_{i,t}$ is assumed to be Gaussian, with mean zero and variance σ^2; standard errors are clustered at the municipal level.

We are interested in contrasting the coefficients associated with fining activity for the period 2003–2015 against the period 2016–2021. We focus on these two periods for their contrasting political approaches to environmental issues. The first period falls under the presidencies of Luiz Inácio Lula da Silva and Dilma Rousseff, and the second period under the governments of Michel Temer and Jair Bolsonaro—note, however, that environmental governance is not unilateral and is not changed steadily over time.

When interpreting our estimates, two things must be considered. First, we assert that political circumstances are the main cause of changes in the activity and efficacy of enforcement by IBAMA that we observe in the data. Second, the causal interpretation of the effect of interest is subject to two main caveats—confounding and reverse causality. To address confounding, we consider a range of controls and exploit the panel structure to control for observed and unobserved effects that are specific to municipalities i or years t. To alleviate reverse causality, we consider lagged fine values, and focus on the difference between periods, rather than the effect of fines

in each period. We can interpret this difference if the reverse effect (the impact of forest loss on fines) does not change from period to period (or, to an extent, if it decreases). The supplementary material contains more details on interpretation, as well as robustness checks and more fine-grained results.

2.2. Two windows into the process

To illustrate recent patterns of deforestation, we analyze two square extracts representing an area equivalent to the size of Croatia (or Togo or Costa Rica), during the period 2011–2021. The first region is located along the Xingu river, with the town of São Félix do Xingu located in the east of the extract. The eponymous municipality covers most of the area, with the municipality of Altamira covering the far west. The region is home to many indigenous peoples, and (partially) contains large indigenous areas with full property rights (Baragwanath and Bayi 2020), including the lands of the Kayapó and Apyterewa. The second region is located along the BR-163 highway, and is covered by the municipality of Altamira in the east, and Novo Progresso in the west. It is exemplary for newly accessible frontier regions, which see rampant land grabbing, logging, and environmental degradation (Ferrante *et al* 2021). Both extracts contain large expanses of protected areas, including Triunfo do Xingu and the Jamanxim National Forest.

Both regions are, historically and currently, deforestation hotspots and focal points for the enforcement of environmental law, as evidenced by yearly forest loss and fining activity statistics (maps are provided in the supplementary material). The region in and around the first extract is a notable example of effective, multifaceted deforestation interventions in the late 2000s and early 2010s (Schmink *et al* 2019). More recently, however, deforestation rates have been drastically picking up again. Considering the scope of these two extracts—965 873 hectares of forest were lost over the ten years considered[5]—insights from these regions are important on their own, and may be useful for understanding deforestation patterns in frontier regions.

3. Eroding deforestation interventions

Forest loss in the Legal Amazon peaks in 2021, at a loss of over 3.5 million hectares. As we can see in figure 1, this number represents a sharp spike in annual forest loss, following a steady decline from 2003 to 2011, and stagnant forest loss until 2019. When examining the development of environmental fines, we find that the number of fines levels off after a peak in 2005, with initially declining forest loss. However, a low point in fine levels in 2020 contrasts with a stark increase in forest loss. While this is partially due to the COVID-19 pandemic, figures for the intensity of fines (per forest lost) show a similar, steady decline, and do not recover either in 2021. This development of fines and fine intensities is mirrored when considering the value of fines (as can be seen in the supplementary material). The data indicates a pronounced relationship between forest loss and fines, and a possible change in this relationship. However, as we find below, it only begins to show how deforestation interventions are undermined.

Closer inspection of environmental fines suggests that fines handed out today have little effect. We find that, since the beginning of 2019, only around 2.5% of fines have been approved for payment. Moreover, less than 0.1% of the total amount fined has actually been paid since 2019. Further information on the status of fines is provided in the supplementary material. These figures are driven by amnesties, other cancelations of fines, and overwhelming bureaucratic burdens that undermine the impact of enforcement by IBAMA. Their impact on deforestation is likely to be considerable, as they directly affect the perceived threat of sanctions, and thus the perceived costs of deforestation.

This is confirmed by our econometric analysis—in recent years, IBAMA appears to chase after deforestation instead of preventing it. The efficacy of fines in preventing forest loss fell considerably. In the 2016–2021 period, the negative elasticity between forest loss and fines fell by 0.101 percentage points ($p < 0.01$). This means that a one percent increase in fines during the presidencies of Temer and Bolsonaro would result in a reduction in forest loss that would be 0.101 percentage points lower than during those of Lula and Rousseff[6]. This efficacy reduction is considerable and highly relevant in practice. Consider a hypothetical policy that doubled fines in 2020 (from 1896 to 3792). This intervention would lose out on 251 781 hectares of prevented forest loss in 2021, just from reduced efficacy.

To provide context to the rapid acceleration of forest loss, and the related inefficacy of environmental fines, we analyze two notable hotspots of deforestation. On the right of figure 2, we can see the locations of the two extracts in Pará and Brazil. On the left, we can see the cumulative forest loss over seven years from 2011 to 2018 and three years from 2018 to 2021. In both regions, forest loss accelerated

[5] For comparison, Colombia is around ten times the size of both areas, and lost 1187 205 hectares of primary forest over this period (UoM and WRI 2023).

[6] The conditional correlation between forest loss and fines is negative (a one percent increase in fines is associated with a 0.036 percent decrease) in the earlier period, and positive in the later period (associated with a 0.065 percent increase), implying that reverse effects predominate. This result also holds for fine values, and is robust to a number of sensitivity checks, as can be seen in the supplementary material.

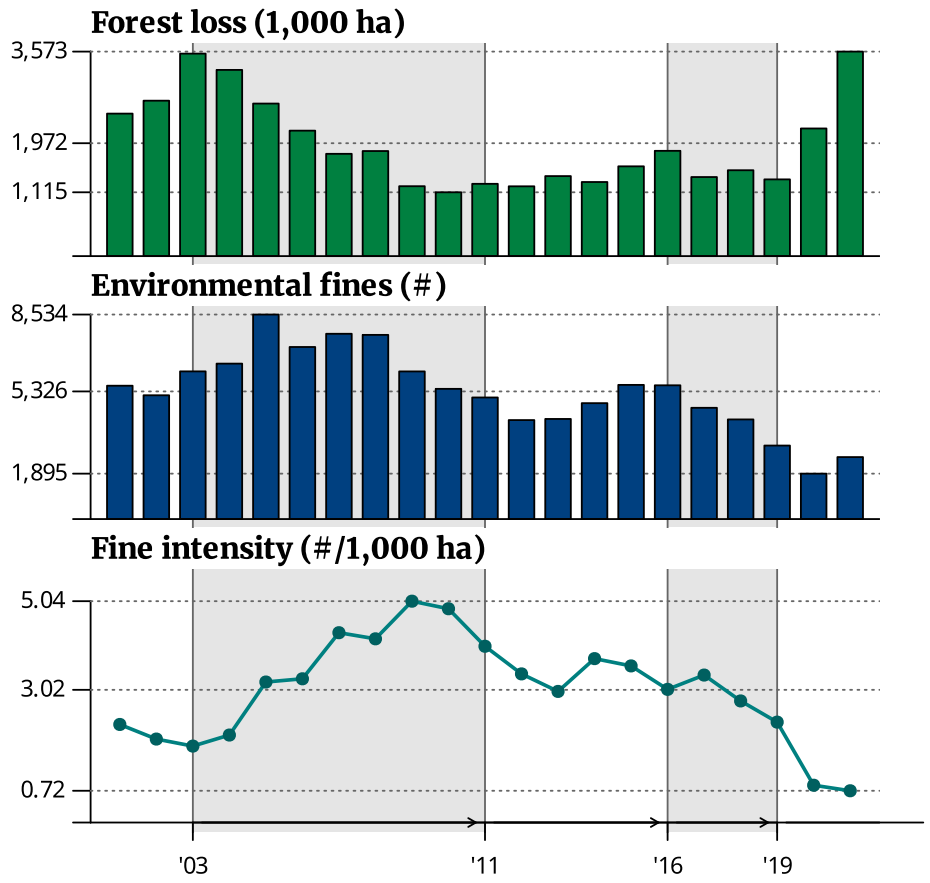

Figure 1. Forest loss and environmental fines in the Legal Amazon.
Note: Shaded areas indicate different administrations; ticks and lines on the vertical axis indicate the maximum, mean, and minimum values.

drastically in the last three years—yearly rates climb 3.8-fold around São Félix do Xingu, and threefold around the BR-163 highway. *Where* forest is lost in these extracts is especially notable. From 2011 to 2018, a total of 9377 and 3903 hectares of forest loss occurs in indigenous areas; from 2018 to 2021 this figure increases to 35 434 and 15 205 hectares. This rapid acceleration also occurs across the entire lands of the Apyterewa and Kayapó, which experience a sevenfold increase in yearly rates of forest loss (see the supplementary material for more details). Even larger amounts of forests are lost in protected areas, often in demonstrably public lands[7]. In Triunfo do Xingu, for instance, we find that 12.9% of the total area—an area around the size of Bali—is cleared from 2018 to 2021.

4. Discussion and ways forward

Our results paint a clear picture of the impact of eroding deforestation interventions in Brazil, best reflected by the severely reduced efficacy of environmental fines. IBAMA, the responsible institution, plays a pivotal role in Brazil's control-heavy system of interventions, and as it loses its ability to exert this control, the real and perceived threat of sanctions declines. The erosion of IBAMA directly affects the efficacy of most existing deforestation interventions, but also reverberates beyond the institution's mandate. Without capable authorities to protect them, property rights and the rule of law are under threat. Frontier regions are particularly susceptible, as highlighted by two illustrative examples that feature striking and rapidly accelerating rates of forest loss. Even in protected and indigenous areas with full property rights, thousands of hectares of forest are lost, complementing earlier evidence that the rights, livelihoods, and lives of indigenous peoples are threatened (Ferrante and Fearnside 2019, Ferrante *et al* 2021).

The reduced role played by IBAMA in combatting deforestation is not an isolated case. Another example of the erosion of Brazilian deforestation interventions is the 'falling star' INPE (Moutinho and Escobar 2022). Its satellite-based monitoring and early warning systems enable private and public deforestation interventions, allowing them to cover the vast Amazon in the first place. Budget and staff cuts as well as public attacks by government officials jeopardize the continued operation and

[7] An overlay of CAR registrations, which approximate privately-held properties, is provided in the supplementary material.

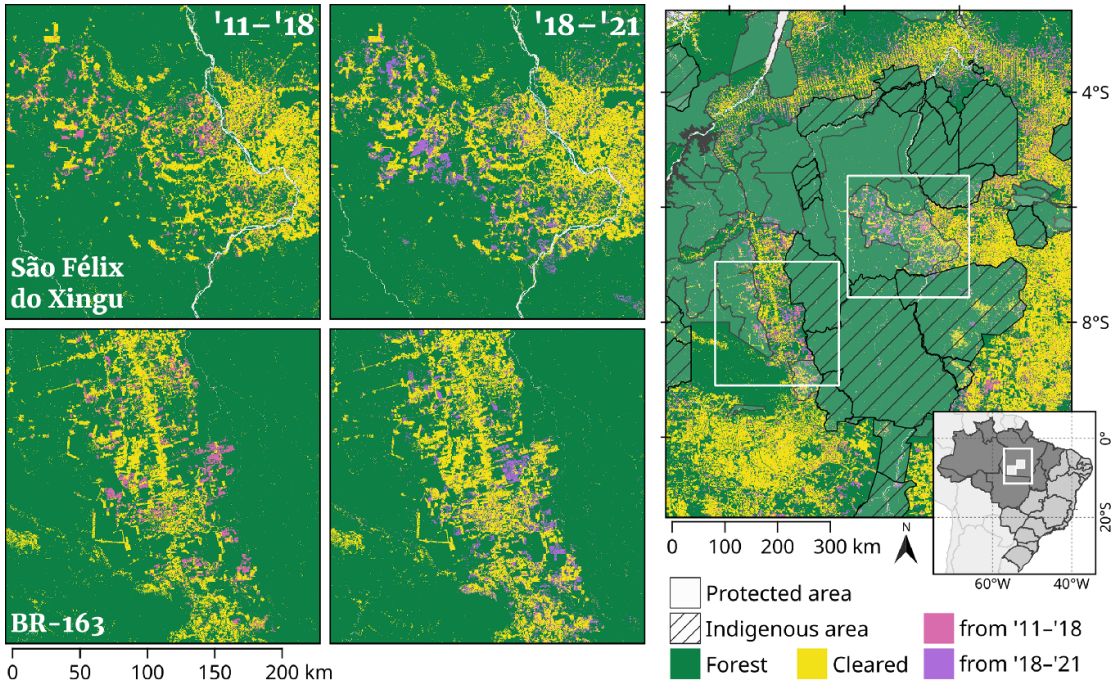

Figure 2. Forests and forest loss around São Félix do Xingu and the BR-163 highway.
Note: Extracts around São Félix do Xingu (top), and the BR-163 highway (bottom), show the forest loss from 2011 to 2018 (seven years) to 2021 (three years) in greater detail. The locations and surroundings, including indigenous and other protected areas, of these extracts are visualized to the right. Notable protected areas are the Kayapó and Apyterewa indigenous areas to the bottom- and top-right of the first extract, the Triunfo do Xingu protected area at the center of the first extract, and the Jamanxim National Forest towards the left of the second extract, i.e. to the west of the BR-163 highway.

credibility of these systems. This limits the availability of critical information for designing, implementing, and monitoring environmental policies and interventions.

This situation is brought about by a political shift and a severe lack of long-term resilience in the Brazilian system for forest protection. Formal legislative changes play an important role, but they do not fully do justice to the situation. A major issue lies with informal, short-term changes affecting vital institutions and stakeholders to the Amazon. Mandatory reconciliation hearings, staffing interventions, amnesties, and public attacks by elected officials are, in no small part, responsible for incessant deforestation (Garrett *et al* 2021, Vale *et al* 2021, Oliveira *et al* 2023). Without a major shift, these thousand cuts permanently damage the credibility of deforestation interventions and the institutions responsible. When non-compliance is expected to go unsanctioned or be forgiven down the road—i.e. when the underlying incentives are not changed in a resilient manner—then the real-world impacts of any intervention will be severely limited.

How to understand and address this lack of resilience in deforestation interventions? The Brazilian system heavily relies on command and control policies, punishing undesirable actions, instead of incentivizing desirable ones (Nepstad *et al* 2014). The enforcement of such policies is complicated and costly—only few actors have a vested interest in upholding them, and the power to enforce them is concentrated. This concentration of power requires oversight, but also invites political meddling. A resilient command and control system presents a conflict of interest for political decision-makers, who must give up control to allow for sufficient agency of the responsible institutions. Although political will is essential for implementing deforestation interventions, operations need to be decoupled from politics in the short- and medium-term.

The foundations of effective deforestation interventions are strong institutions with a clear mission and sufficient agency to pursue it. Their operational integrity is vital, and independence from political interests in the medium-term arguably desirable. The satellite monitoring programs of INPE are one example to address. They fulfill an indispensable role in preventing deforestation, and have already benefited from international funds in the past. Maintaining their role is crucial, and improved operational integrity and stable funding could help to build resilience in face of political upheaval. IBAMA would also undoubtedly benefit from a higher degree of operational integrity. However, the monolithic nature of executive authorities can be problematic, and new interventions that reduce and shift the burden on enforcement (e.g. by getting local actors invested in the Amazon) should be a priority.

For this purpose, incentive-based interventions are a promising option. In the past, they have mainly been considered for their efficiency, which stems from tackling the alignment problem at its root. However, their resilience, from creating broad incentive structures in which stakeholders have a vested interest (that are, ideally, independently backed), may prove to be their decisive benefit. One example are steering taxes, which increase the costs of undesirable behavior without relying on the threat of sanctions. A land use (or carbon) tax, for instance, can disincentivize the use of unproductive land, effectively limiting deforestation (Souza-Rodrigues 2019). Furthermore, it could present a barrier against land grabbing that does not rely as heavily on monitoring and enforcing compliance in large swaths of public land. Such taxes can be effective and offer some resilience (by generating revenue for the government), but are best augmented by positive incentives.

Positive incentives can get local actors committed to protecting (and even restoring) the Amazon and upholding the incentive system itself, making them particularly resilient. Agricultural credits are one such incentive that has been successful in the past. A 2008 policy, for instance, that tied the provision of credit to proof of compliance with environmental legislation reduced deforestation substantially (Assunção *et al* 2020). This type of incentive facilitates agricultural intensification, which can be an important deforestation intervention itself (Marin *et al* 2022), and reduces the burden on enforcement. Positive incentives are not a panacea and must be designed carefully, but they can help create a more resilient and effective system of forest protection. One example of the importance of their exact design is a mechanism for compensating landholders for forested areas (Stabile *et al* 2022). On its own, such a mechanism may even increase deforestation by incentivizing land grabbing. A resilient system that can sustainably protect the Amazon must accommodate and shape the interests of decision-makers—whether they are indigenous groups, farmers, or local and national politicians—to better reflect the common value of the Amazon.

5. Concluding remarks

In this paper, we showed that enforcement of deforestation interventions by IBAMA deteriorated significantly in efficacy, and showcased the impacts in the context of two frontier regions. We argued that earlier deforestation interventions must be viewed critically, as they are not resilient to political turmoil and cannot sustainably protect the Amazon. Two possible solutions for this lack of resilience are strengthened institutions and incentive-based interventions, which commit locals to forest protection.

The new Brazilian administration is expected to be comparatively pro-environmental, but a number of challenges must be overcome and a lost decade for environmental protection must be addressed (Fearnside 2023). Going forward, the lessons of this lost decade must inform policies, such as the ongoing fifth phase of the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm), in order to build a resilient and sustainable system for forest protection.

Data availability statement

Data and scripts used for this paper are openly available at https://github.com/nk027/deforestation_resilience.

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