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POLICY ARTICLE

Governance and policy constraints of natural forest regeneration in the Brazilian Amazon

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Environmental legislation requires well-defined concepts, criteria, and indicators to support its effective implementation and provide legal security to the diverse stakeholders involved. The Native Vegetation Protection Law (NVPL) establishes the obligation to restore native vegetation in protected areas within rural properties. This federal law is regulated and implemented by each state through its own Environmental Compliance Program (Programa de Regularização Ambiental [PRA], in Portuguese). Landowners must register their land, indicate whether native vegetation needs to be restored (i.e. if there is an environmental debt), and submit a restoration plan to the state government for analysis, validation, and approval. Due to the high cost of forest restoration, natural regeneration has most likely become a viable strategy for Amazonian landowners to meet their environmental debts. However, according to disturbance intensity, frequency, and duration, natural regeneration will not always succeed. In this context, we analyzed the PRAs of the seven main Amazonian states to assess the status of their implementation, identify how natural regeneration is defined and approached in the law, and evaluate whether improvements in the law are needed to ensure effective restoration to accomplish the NVPL.

Key words: Amazon region, forest act, native vegetation, restoration, secondary forests

Implications for Practice

- To effectively encourage environmental compliance in the Amazon, policy efforts should focus on preventing delays in the rural environmental registry (Cadastro Ambiental Rural) deadlines and expediting the analysis of this registry to accelerate enrolment in the environmental compliance program (Programa de Regularização Ambiental) and promptly start the restoration phase.
- Clear definitions regarding natural regeneration are essential for monitoring vegetation recovery progress and effective restoration strategies.
- Collaborative initiatives among states should be designed and implemented to establish standardized indicators and reference values for monitoring ecosystem restoration, capitalizing on the recent interest of states in the restoration agenda.
- Amazonian states can jointly discuss and revise existing technical protocols and regulations to provide stakeholders with standardized concepts, criteria, monitoring protocols, and indicators for ecological restoration across the biome.

Introduction

Ecosystem restoration is expected to help halt and mitigate the global biodiversity and climate crises. It is estimated that a significant contribution of restoration depends on its urgent implementation and over large areas (Girardin et al. 2021). A promising strategy to facilitate and upscale restoration is through forest natural regeneration (Chazdon & Guariguata 2016), given its low economic costs (Crouzeilles et al. 2020) and high potential for biodiversity recovery (Rozendaal et al. 2019) and carbon

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sequestration (Poorter et al. 2016). Implementation and persistence of natural regeneration, though, requires incentive and governance mechanisms (Tedesco et al. 2022).

In Latin America, the effectiveness of restoration through natural regeneration varies across countries because of socioeconomic, political, and ecological contexts that drive the abandonment of agricultural areas and the protection of regenerating forests (Schwartz et al. 2020). Costa Rica's collapse of cattle ranching in some regions led to a 40% increase in forest cover in the last 30 years, which protection was guaranteed by protective public policies put forward by the country's tourism sector (Chazdon & Guariguata 2016). In Colombia and Venezuela, high rates of loss of regenerating forests result from their political instability and weak law enforcement (Schwartz et al. 2020; Blum et al. 2022). In the Brazilian Amazon, regenerating forests cover 17 million ha but half of it is recleared within 8 years (Nunes et al. 2020), partially due to conflicting agricultural and environmental policies (Chazdon et al. 2020; Hänggli et al. 2023). These examples illustrate how effective policies and governance are necessary for natural regeneration to realize its potential as a restoration strategy.

In Brazil, the Native Vegetation Protection Law (NVPL), created 12 years ago, established the country's regulatory framework for environmental protection, demanding the restoration of native vegetation over at least 16 million ha within private rural properties (Brasil 2012*a*). The NVPL requires preservation in sensitive areas like riparian vegetation and steep slopes (called APP—*Áreas de Preservação Permanente* in Portuguese) and in a percentage of the property (called Legal Reserves; RL—*Reserva Legal* in Portuguese), which vary across biomes (80% in the Amazon). If deforestation has occurred in the areas, properties face an "environmental debt" needing to be settled through the vegetation recovery. The law encourages compliance by associating access to government subsidies with environmental adherence.

Such environmental regulations can aid nations in achieving international targets such as the Bonn Challenge's goal of restoring 350 million ha by 2030. Brazil's NVPL mandates restoration of 20 million ha, nearly the size of the United Kingdom. More than a decade after the NVPL creation, however, restoration has not yet expanded as expected and regenerating forests continue to be recleared (Nunes et al. 2020). Understanding the obstacles for the implementation of such legislation in Brazil can help other countries tailor their environmental regulations. The inefficiency of the NVPL to promote ecosystem restoration can be a result from failures along the law's implementation path or from the lack of necessary definitions and guidelines, among other socio-economic constraints.

The NVPL, while federal, is enforced by state governments through a governance instrument called the Environmental Compliance Program (*Programa de Regularização Ambiental*—PRA in Portuguese). While the NVPL provides broad definitions and rules, the PRAs of each state must establish criteria and guidelines for the assessment of the properties' environmental situation, the restoration of its environmental deficit, and the evaluation of restoration success. The PRA's implementation involves: (1) issuing the PRA and regulatory instruments; (2) analyzing self-declared landowner information in the Rural Environmental Registry (Cadastro Ambiental Rural [CAR] in Portuguese); (3) enrolling properties with environmental deficits in the PRA; and (4) approving the Plan for Recovery of Degraded and Altered Areas (PRADA in Portuguese and hereafter native vegetation recovery plan) submitted by enrolled properties where the restoration strategy (passive or active) must be proposed (Art. 9, December 7830/12; Federal Decrees No. 7830/12 and No. 8235/14; Fig. 1; Brasil 2012*b*, 2014). After PRADA approval, landowners must implement and monitor the restoration, providing technical reports to the state environmental agencies.

Approximately 60% of Brazil's legal restoration demand (9.4 million ha) is in seven Amazonian states: Acre, Amazonas, Amapá, Mato Grosso, Pará, Rondônia, and Roraima. We analyze these state's PRAs to identify limitations in NVPL implementation and how natural regeneration is addressed as an option for settling the environmental debts. We compiled relevant policy instruments related to the NVPL implementation, analyzed the environmental compliance process in each state, and examined how state legislation defines and establishes mechanisms to promote and monitor forest restoration through natural regeneration in rural landholdings.

Status of the Implementation of the Environmental Compliance Program (PRA) in the Amazonian States

Our analysis of the PRAs and related state laws shows that the legal implementation and compliance status of the PRAs varies among the analyzed Amazonian states (Table 1), partly due to the asynchrony in publishing legal instruments (Table S1). The seven states published their PRAs between 2015 and 2021 (Table S1). After PRA documentation publication, all states, except Amapá, issued legal decrees to regulate it and establish technical restoration criteria (Table 2). However, the regulatory decrees were published at different times (Table S1). For instance, Pará issued no normative instruction on enrolment procedures until 2020, leaving landowners without legal means to settle their environmental debt. Amapá published its PRA in 2021 but lacks any regulatory instruments. In the seven states of the Amazon region, law compliance has been constrained by the lack of governance mechanisms (such as the PRA and SISCAR), which were only available to landholders at least 5 years after the NVPL was issued (Tables S1 & 1).

Delays in PRA implementation by the states probably resulted from political disinterest in getting private properties checked on their environmental status lack of resources to execute the CAR process effectively. The Brazilian Congress, influenced by agribusiness, frequently requested NVPL revisions and postponed deadlines for CAR registration multiple times. Furthermore, the states apparently focused on first starting up the CAR registration and validation processes, with limited resources and personnel, which are steps needed before enrolment in the PRA (Fig. 1).

In addition to the delays in the legal implementations, the postponement in the availability of digital platforms for registration and control of the NVPL has compound delays in

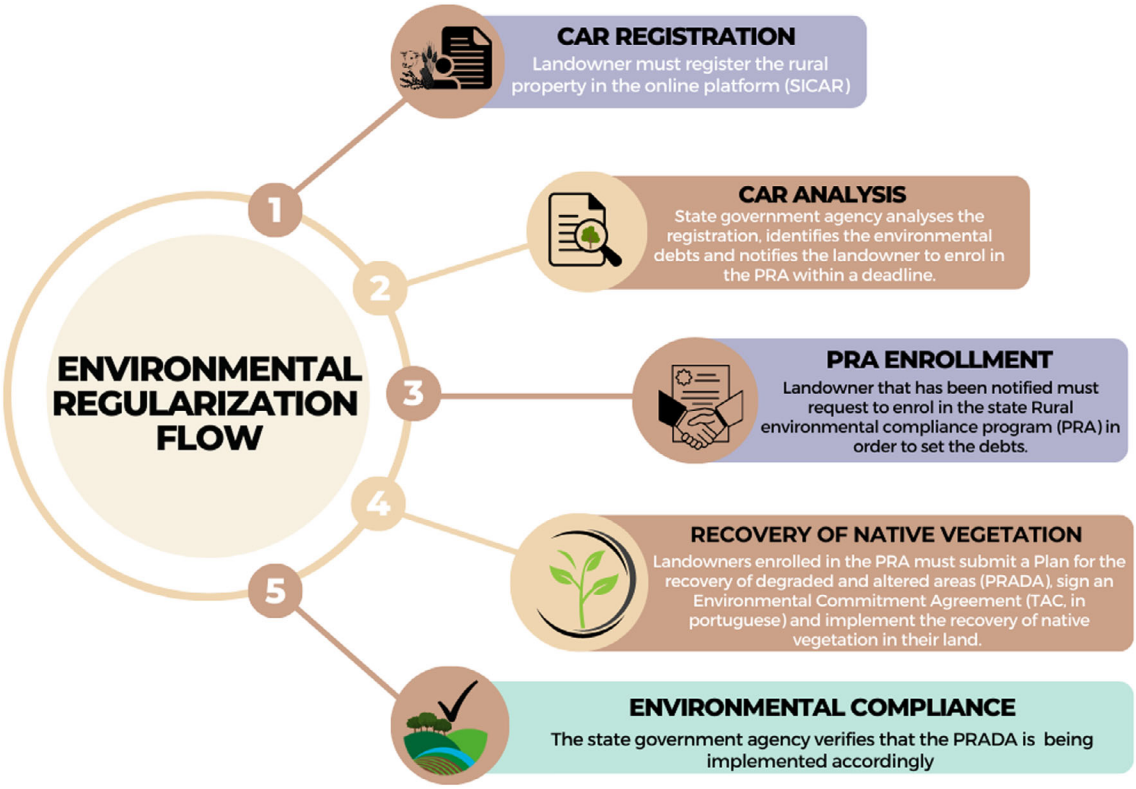

Figure 1. Environmental compliance flow of rural properties in Brazil according to the Native Vegetation Protection Law (NVPL). The figure summarizes the five main steps for landowners to conclude the environmental compliance of their rural properties. The NVPL is a federal law, but all compliance steps are overseen by each state government.

Table 1. Status of the rural environmental registration system in each analyzed state until September 2022. For each state, we present the status of the implementation and regulation of the PRA. The number of properties currently registered in the rural environmental registry (CAR registered), the percentage of registered properties that have environmental debts and have been requested to adhere to PRA (enrollment requested), and the percentage of properties whose registered information has been analyzed by the state agencies (CAR analyzed). States are sorted in alphabetical order. *Source*: SFB (2022).

		Properties		
State	*PRA legal implementation*	*Registered in CAR*	*Requested to enroll in the PRA*	*CAR analyzed by the state*
Acre	Complete	44.385	58%	1.2%
Amapá	Incomplete	9.846	40%	0.1%
Amazonas	Complete	72.649	70%	0.3%
Mato Grosso	Complete	168.237	74%	3.5%
Pará	Complete	274.878	38%	2.1%
Rondônia	Complete	145.865	60%	2.8%
Roraima	Incomplete	22.279	39%	0.0%

implementing the native vegetation recovery plan (PRADA) within private properties. The online platform for the environmental registration of rural properties Sistema Nacional de Cadastro Ambiental Rural (SICAR) was launched in 2014, but submission functionalities became available in 2021, well after the NVPL's inception. The registration deadline has been postponed eight times since 2014, largely due to the interests and strong political ties of the agribusiness sector. The new deadline is December 2024. Such postponements reduce the strength of mandatory registration as a law enforcement instrument.

More than 700,000 properties in the analyzed states registered in the CAR, with only 55% requested to enroll in the PRA in order to settle their environmental debts (Table 1). Most registered rural properties in the Amazon contain deforested APPs or RLs that need to be restored through either passive or active strategies (or compensated). However, the restoration of these areas can only occur after the state agencies have analyzed the information provided in the CAR, which has so far occurred for only 2% of registered properties in the Amazon (Table 1). These small numbers likely indicate limited processing capacity

Table 2. Requirements and monitoring indicators defined by the states of Acre (AC), Mato Grosso (MT), Pará (PA), and Rondônia (RO) and recommended by the Alliance for Restoration in the Amazon (ARA) to assess the forest restoration. *Note*: "×" means the indicator is included in the state and ARA 2022 protocols. "—" means the indicator is absent.

Indicator	*AC*	*MT*	*PA*	*RO*	*ARA 2022*
Protection against disturbance	×	×	×	×	—
Percent tree cover	×	× (by native and non-native species)	×	×	×
Morpho-species richness	× (shrubs and trees)	× (naturally regenerating saplings)	×	×	× (total and of naturally regenerating trees)
Plant density	× (naturally regenerating all life forms)	× (naturally regenerating shrubs and trees)	—	× (naturally regenerating all life forms)	× (native trees)
Dominant life form	×	—	—	×	
Proportion of invasive exotic species	× (woody species)	× (woody species)	× (of woody species)	× (all life forms)	× (all life forms)
Biomass	—	—	—	—	×
Structural heterogeneity	—	—	—	—	×
Monitoring frequency	6th, 10th, 15th, 20th year	Bianual	4th-, 7th-, 9th- year-APP 4th-, 7th-, 13th-, 19th-, 20th-year RL	3rd, 6th, 10th, 15th, 20th year	—

of the state agencies and highlight the need for larger task forces to automate the CAR system, as recently done in Pará (Agência Pará 2023). Hence, most of the rural properties in the Amazon are not yet officially committed to a formal native vegetation recovery plan (PRADA).

Overall, the PRA and the CAR are powerful instruments for promoting ecosystem restoration in the Amazon, but the number of registered properties and validated information are insufficient. Twelve years post-NVPL creation, most Amazonian landholdings remain non-compliant. As we saw, delays in the legal implementation of PRAs, in analyzing and validating the CAR information, and in launching online platforms, together with the continuous postponements in the registration deadlines, are major obstacles to effectively restoring legally protected areas within rural properties in the Amazonian states.

Natural Regeneration as a Restoration Strategy in the NVPL

The NVPL allows multiple strategies for recovering native vegetation in APP and RL, but definitions are lacking in the main text and in many states´ legislation. The definitions found in the state's PRAs mostly follow the NVPL, but lack clarity on: (1) what characterizes natural regeneration (can any regenerating vegetation be considered as part of a restoration process?), (2) where natural regeneration is an appropriate strategy (can forest regeneration proceed everywhere without human intervention?), and (3) when an area can be considered restored—at least legally. Further, the NVPL requires monitoring the vegetation recovery every 2 years for 10 years in APPs and 20 years in RLs (Brasil 2012*a*, 2012*b*). Yet, no indicators and reference values are defined. Here we discuss how these aspects are considered in the NVPL and state legislation.

Natural regeneration is a key concept included in the federal and state legislation that has dubious or conflicting definitions. The NVPL and the PRAs of all Amazonian states consider assisted natural regeneration as a valid method for native vegetation recovery, but a definition is only presented elsewhere, in the Brazilian National Plan for Native Vegetation Recovery-PLANAVEG. The PLANAVEG defines natural regeneration as "a set of processes by which native species colonize an altered or degraded area without being intentionally introduced by human intervention" and defines assisted natural regeneration (*condução da regeneração natural* in Portuguese) as "a set of planned interventions aimed to boost the natural regeneration of an area under restoration such as the introduction of bird perches, control of herbivores and invasive plant species, and creation of enabling environmental conditions for the establishment of native species."

The definition of natural regeneration is repeated in Mato Grosso's legislation (Decree 1491/2018) and in technical protocols of Pará and Rondônia, but is absent in the remaining states (Table S1). This definition has two main problems: (1) it conflicts with the NVPL (as discussed next) and (2) the term is used with different meanings in the federal and state legislation. The conflict with the NVPL regards the use of the words "degraded" and "altered." Following the Decree 7.830/2012 that regulates

the NVPL, the PRAs of Pará, Rondônia, and Amapá classify lands as altered or degraded based on their natural regeneration capacity, and provide definitions as follows: "*altered* areas are the capacity for native vegetation to regenerate naturally" and "*degraded* areas have no regeneration capacity." Therefore, to solve this conflict, either the PLANAVEG should remove the word "degraded" from its definition of natural regeneration or the other legal instruments should refrain from distinguishing altered and degraded areas.

This distinction, though, can be useful for guiding restoration plans, but only if criteria for classifying altered and degraded areas are defined (currently they are not). Public policies could use the accumulated scientific knowledge to define criteria for classifying the areas into levels of natural regeneration potential, which is the feasibility of altered areas to allow the regeneration of native vegetation without the need of human interventions. The potential for natural regeneration could be estimated according to the main factors that affect forest recovery: soil conditions, topography, seed availability, land use history, and amount of forest cover in the landscape (Arroyo-Rodríguez et al. 2017; Crouzeilles et al. 2020; Jakovac et al. 2021). Through these main factors, it is possible to infer if an area has low, medium, or high potential for natural regeneration (Vieira et al. 2017).

Given challenges in determining natural regeneration potential in human-altered lands, some states' legislations require that the technical viability of using natural regeneration as a restoration strategy must be confirmed by the actual presence of regenerating native vegetation, named expression of natural regeneration in the PRAs (see Table 3). How to identify the expression of natural regeneration depends on the state. Mato Grosso defines an "area under regeneration" as "an area previously subjected to anthropogenic activities that has undergone uninterrupted regeneration of native vegetation without land use for at least 5 years" (Decree 1.199/2021). Pará and Amazonas legislation and Rondônia technical protocols require the landowner to inform the environmental agency when natural regeneration is being inefficient in order to reformulate the restoration plan (PRADA). Identifying the expression of natural regeneration is indeed important and most practical to validate the effectiveness of adopting natural regeneration as a restoration strategy in the PRADAs. However, states must define clear criteria for assessing such an expression to ensure the natural regeneration strategy can unfold over time toward effectively restoring the ecosystem's structural, functional, and ecological conditions (Chaves et al. 2015).

Finally, states could also define criteria and guidelines for the use of assisted natural regeneration, which is defined in the PLANAVEG (see above) but not mentioned in the states' legislations. The scientific and practitioner communities agree that in most altered areas it will be needed to assist natural regeneration through management practices to achieve actual ecosystem restoration (Alves et al. 2022; Wilson et al. 2022). Given varied practices for assisting natural regeneration and their feasibility might be context-dependent, it is crucial to develop operational definitions, guidelines, and protocols for implementing and monitoring them.

Monitoring Restoration under the NVPL

According to the NVPL, vegetation recovery must be monitored every 2 years, until the 10th year after restoration implementation in APPs and until the 20th year in RL (Brasil 2012*a*, 2012*b*). Landowners are responsible for monitoring and delivering a technical report to the state environmental agencies, which will validate the reported information through remote sensing (preferably) or field visits (in exceptional cases). In Mato Grosso, landowners are obligated to provide a technical report containing field measurements of ecological indicators of restoration success, such as canopy cover, the richness and density of under-canopy trees. Additionally, they must include photos taken within the restoration site in their submissions. State officials combine these site monitoring data from the area submitted by landowners with remote sensing information (e.g. satellite imagery) to assess the progress and efficacy of restoration efforts in the region. Furthermore, a technical note has been produced to guide producers in their restoration choices, based on various remote sensing products that have been tested using both visual and automatic interpretation methods (Dias et al. 2023). Following this example, to effectively validate restoration success or vegetation recovery, states must define indicators for monitoring and reference values for setting standards for the desirable vegetation condition at different moments in time.

Indicators and reference values for monitoring are only legally defined by Mato Grosso and provided in technical guidelines by Acre, Pará, and Rondônia. These states define indicators (Table 2) that are relatively easy to measure in the field, are coherent with the vegetation structure at early restoration stages (Ota et al. 2021), and provide good information on the restoration process (Campos-Filho et al. 2022; Regenera-Amazônia 2023; Rosenfield et al. 2023). Rondônia and Pará define reference values based on the time passed under restoration, whereas Mato Grosso reference values differ depending on the property size. Despite some disparities, the thresholds reference (Table 2) is consistent across these states. Reference values, however, remain to be validated on the ground.

Finally, only three states provide criteria for defining whether the vegetation has recovered, and the environmental debt can be considered settled. Acre and Mato Grosso define "regenerated areas" as those under an uninterrupted process of natural regeneration for at least 10 years (Acre Decree 9.025/2018; MT Decree 245/2019). A criterion based solely on the time elapsed and not on ecological indicators does not guarantee effective ecological restoration. Therefore, for an area to be considered recovered under the law, it is important that all states legally define unified indicators with reference values that vary according to their ecological and social contexts. States could use the existing monitoring indicators (Table 2) and reference values and their rate of increase over time to guide this settling up process. From the landowner perspectives, it is desirable that the environmental debt is settled early on, and from the state and society perspectives, it is important to assure that restoration is sustainable and will not regress. Therefore, it would be useful

Table 3. Glossary of key terms and concepts used in the text, with their Portuguese translation. The concepts are listed in alphabetical order.

Concept (acronym)	*Concept in Portuguese*	*Definition*
Environmental compliance	Regularização Ambiental	The process of adjusting the rural properties´ activities and land use to comply with the federal NPVL. It involves protecting and recovering native vegetation in APP and RL.
Environmental Compliance Program (PRA)	Programa de Regularização Ambiental	A state government program setting the conditions and criteria for rural properties in Brazil to meet environmental conformity with the NVPL. It includes instruments to geocode and register rural properties and existing environmental debts and to guide the design and development of the Plan for Recovery of Degraded and Altered Areas (PRADA, in Portuguese). This is a governance instrument established by the NVPL and implemented at the state level.
Expression of natural regeneration	Expressão da regeneração natural	Refers to the visible evidence of the regeneration process, such as the growth of seedlings, saplings, and other vegetation without human intervention. It confirms the natural regeneration potential of the area. The concept is used by practitioners and proposed by this study but is not defined in regulatory instruments.
Legal Reserves (RL)	Reserva Legal	A proportion of rural properties that must be set aside to conserve native vegetation in different biomes. Defined by the NPVL.
National plan for the recovery of native vegetation (PLANAVEG)	Plano nacional de recuperação da vegetação nativa (PLANAVEG)	A governance instrument for supporting the recovery of native vegetation in the scope of the NVPL. It was produced by the federal government and is now being revised and updated. State governments followed the PLANAVEG to produce their PRAs.
Native Vegetation Protection Law (NVPL)	Lei de Proteção a vegetação nativa	Brazilian environmental legislation aimed at conserving and regulating the use of native vegetation. Federal level of jurisdiction.
Permanent Preservation Areas (APP)	Áreas de Preservação Permanente	Legally protected native vegetation in areas within rural and urban environments designated to protect environmentally fragile areas and natural resources. Defined by the NPVL.
Plan for Recovery of Degraded and Altered Areas (PRADA)	Projeto de recuperação de áreas degradadas e alteradas	A plan for the recovery of degraded areas in APP and RL, as defined by the NVPL. It must be presented to state governments by landowners. It must describe the strategy chosen for the recovery of native vegetation. It is defined in the NVPL and implemented, monitored, and enforced by state governments.
Potential for natural regeneration	Potencial da regeneração natural	Refers to the capacity of an area to undergo natural regeneration, considering various factors such as soil conditions, climate, presence of seed sources, and absence of disturbances. It indicates the inherent ability of an ecosystem to recover its native vegetation through natural processes. The concept is mentioned in the PLANAVEG but not defined.
Rural Environmental Registry (CAR)	Cadastro Ambiental Rural	A governance instrument to registry rural properties nationwide, facilitating environmental law monitoring and enforcement. This is a governance instrument established by the NVPL and implemented at the state level.

to identify metrics that indicate early on in the first decade or so that the restoration will be sustainable without further interventions in the area (Chaves et al. 2015).

To validate the information provided by landowners, state agencies rely preferably on remote sensing methods, as indicated in the PRA of Acre, Amapá, Mato Grosso, Pará, and Rondônia, in order to be able to cover the large extents of illegally deforested land (Chiavari et al. 2021). The only indicator currently used in these remote sensing assessments is the percentage of forest cover, which measures vegetation growth but not biodiversity recovery or the presence of invasive species, which are indicators required to be monitored in the field by the landowner. Therefore, there is an urgent need to develop reliable remote sensing indicators (proxies) of biodiversity and biomass recovery that can include them in the monitoring protocols of state agencies. Besides, it would be cheap for farmers to photograph with mobile phones the forests for acquiring basal area, diameter distribution, and morpho-species through automatized software and applications (Sandim et al. 2023). Such ecological indicators cannot be provided by satellites to date at a fine scale. This will allow assessing and monitoring restoration with greater efficiency and quality.

Existing technical protocols prepared by Amazonian states are useful to guide restoration strategies, but they vary in the concept definitions, monitoring protocols, and metrics of indicators across the diverse vegetation types existing in the Amazon. Also, these protocols are not always complete or easily available to the public. The Amazonian region would benefit from a joint revision of technical protocols by the states in order to assist delayed states and to propose standardized criteria for the various vegetation types in the Amazon.

Conclusions and Recommendations

Here we analyzed the implementation of the Brazilian federal legislation that requires native vegetation to be preserved or restored within private properties and creates governance mechanisms. Our analyses suggest that efficient implementation of such law requires a prompt investment in a robust digital system for properties registration, an expansion of personnel for validating the information, as well as the standardization of definitions and protocols across federative units. Moreover, this study shows that conflicting political and economic interests have hampered the effective implementation of the environmental law.

Specifically, the implementation of PRAs by the states presents challenges due to their lack of clear criteria and guidelines for restoration, exacerbated by delays in legal processes and limited digital infrastructure. To overcome these obstacles, state governments must prioritize providing tools for landholders to facilitate property registration in the CAR system and enable state agencies to expedite the analysis of registered information, thereby advancing toward the restoration implementation phase. Moreover, the ambiguity surrounding concepts linked to natural regeneration in state legislation needs to be better addressed to ensure its effective utilization. Monitoring restoration progress remains imperative, yet the current lack of defined indicators and reference values, particularly concerning biodiversity and biomass recovery, poses a significant obstacle. Therefore, to address these issues, unified indicators and protocols for monitoring restoration should be established, incorporating ecological and social contexts and revising technical protocols collaboratively to ensure comprehensiveness and accessibility.

The creation of a Pan-Amazonia forum, including representatives of the Amazonian states´ governments as well as research and practitioners' institutions, could help fill up the conceptual and operational gaps required for the full implementation of legal forest restoration in the Amazon.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Laws, Decrees, and Normative Acts in force regarding the implementation and regulation of the Rural Environmental Registry (PRA) in the Brazilian Amazonian states.

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