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Changes to the Forest Code and forest cover loss in the Western Amazon, Brazil

Mudanças no Código Florestal e a perda da cobertura florestal na Amazônia Ocidental, Brasil

José das Dores de Sá ROCHA[1]*, Jhony VENDRUSCOLO[1]**, Nilson Reinaldo Fernandes SANTOS JÚNIOR[1]

1 Federal University of Rondônia (UNIR), Ji-Paraná, RO, Brazil.

* Contact e-mail: josedesa@unir.br

** Contact e-mail: jhony@unir.br

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Abstract: The clearing of native vegetation for alternative land uses is a major driver of climate change. Since the early 1980s, deforestation has remained a major driver of environmental degradation in the Brazilian Amazon, prompting several legislative revisions aimed at protecting native vegetation. Against this backdrop, this study aimed to evaluate Legal Reserve (LR) protection standards in the context of changes in forest legislation. We analyzed the dynamics of native vegetation loss on private rural properties located in the Alto Rio Branco micro-basin in the Western Amazon, considering both previous and current Brazilian legislation. Using remote sensing imagery and property-boundary databases, we analyzed the micro-basin landscape in 1984, 1996, 2012, and 2020 to assess the impact of legislation on Legal Reserve protection. The data show that legislative changes have not improved the effectiveness of anti-deforestation efforts. They also indicate limited government interest in structuring enforcement agencies, as well as the failure of the legal system to enforce laws protecting native vegetation.

Keywords: deforestation; forest legislation; Legal Reserve.

Resumo: A devastação da vegetação nativa para uso alternativo do solo é um dos fatores que contribuem para o agravamento das mudanças climáticas. Desde o início da década de 1980 até os dias atuais, o desmatamento tem sido um dos principais problemas de degradação ambiental na Amazônia brasileira, o que motivou várias mudanças na legislação de proteção da vegetação nativa. Nesse contexto, este estudo teve como objetivo evidenciar o padrão de proteção da Reserva Legal a partir das mudanças da legislação de proteção da floresta, por meio da análise de dinâmica da perda da vegetação nativa em propriedades rurais privadas, localizadas na bacia do rio Alto Rio Branco, na Amazônia Ocidental. Com o uso imagens de sensoriamento remoto e o banco de dados de delimitação da propriedade, foi possível realizar uma análise da paisagem da microbacia nos anos de 1984, 1996, 2012 e 2020, a fim de verificar os impactos da legislação na proteção da Reserva Legal. Os dados evidenciam que as mudanças na legislação não resultaram em eficácia no combate ao desmatamento, além de indicarem a falta de interesse dos governos em estruturar órgãos de fiscalização para fazer cumprir o arcabouço legal, bem como a insuficiente atuação do sistema de justiça na aplicação das normas de proteção à vegetação nativa.

Palavras-chave: desmatamento; legislação florestal; reserva legal.

1. Introduction

Extreme weather events are becoming increasingly frequent, and all regions worldwide are experiencing their consequences, particularly rising temperatures, drought, aridity, and more frequent wildfires. Deforestation and

alternative land uses are among the main drivers of this process (Nepstad et al., 2014; Intergovernmental Panel on Climate Change [IPCC], 2022).

In this context, forests protected as Legal Reserves (LR) in Brazil – the portion of a rural property where native vegetation must be conserved, especially in the Amazon – play essential roles in biodiversity conservation, food security, water and climate stability, the economy, and all dimensions required to sustain life (Metzger et al., 2019; Przybyszewski et al., 2022; Machado et al., 2024).

Since the earliest human societies, forests have been exploited as an essential resource and incorporated into both the economy and private property. The legal framework governing forest use dates back to the 9th century, beginning with decrees that prohibited timber extraction during certain periods to facilitate hunting by the landowning nobility, followed by timber-control regulations established in the 13th century (Killian, 2000). Immediately after the European occupation of Brazilian territory, regulations on the use of forest resources were extended to the colony. These began with the Manueline Ordinances of 1514 and 1603 and the Brazilwood Regulation of 1605, among other instruments, culminating in the promulgation of the first Forest Code of the Brazilian Republic in 1935 (Magalhães, 2001).

Today, forest law encompasses the legal and regulatory framework governing the protection and use of forests, as well as provisions aimed at preserving flora and its associated natural resources (Benjamin, 2000; Benjamin, 2014; Rocha & Silva, 2009; Rocha et al., 2020). In Brazil, all activities on private and public forest lands are subject to legal standards for use and conservation. Consequently, individual discretion in the use of forest lands is constrained by this legislation (Benjamin, 2000; Rocha & Silva, 2009). This forest legal framework is implemented by forestry institutions or equivalent bodies responsible for enforcing these legal mandates, which are ultimately intended to safeguard forest functions across all temporal scales. However, Poteete and Ostrom (2002) have noted that many societies have exhausted their forest resources even under the aegis of legal protection.

In this regard, the loss of approximately 330,000 hectares of forest cover in the Brazilian Amazon, accumulated by 2023, occurred primarily after the enactment of the 1965 Forest Code, driven by policies promoting colonization, agriculture, livestock, infrastructure, and credit, along with the actions of regulatory agencies, among other factors (Becker, 2001; Swann et al., 2015; Fearnside, 2017; MapBiomas, 2023).

Since monitoring of deforestation in the Amazon began, the highest rate was recorded in 1995, when approximately 29,000 km^2 of forest were cleared and burned. The second-highest rate occurred in 2004, when more than 24,000 km^2 of forest were destroyed. After 2004, deforestation rates fell sharply, declining by as much as 70% compared with 2004

levels. However, rates began to rise again in 2014, with an even sharper increase after 2018 (Instituto Nacional de Pesquisas Espaciais [INPE], 2024). Between 2019 and 2021, the deforestation rate exceeded 10,000 km^2 per year. Consequently, this deforestation rate was 56.6% higher than the annual average for the 2016 to 2018 period (Alencar et al., 2022).

This extensive loss of Amazonian forest cover did not occur in a legal vacuum. The highest deforestation rates occurred under the 1965 Forest Code, which required a 50% Legal Reserve on properties in forested areas. This requirement was later raised to 80% by Provisional Measure No. 1.511 of July 25, 1996, which amended the 1965 Code.

However, increasing the Legal Reserve requirement from 50% to 80% failed to curb forest cover loss in the Amazon biome. In fact, the new regulatory framework, the Native Vegetation Protection Law (NVPL, Law No. 12,651/2012), emerged as a mechanism for accommodating this forest loss, thereby granting amnesty to a large proportion of rural producers who had previously been operating illegally (Sparovek et al., 2011; Miguel, 2014; Camargo & Rodrigues, 2018; Rocha & Silva, 2019).

In this context, protecting tropical forest remnants has become a global challenge, requiring greater effectiveness in resource management given the critical role of these forests in mitigating climate change (Dwyer et al., 2016; Fisher et al., 2017; Fanta & Petřík, 2018; Ahmed & Atiqul Haq, 2019). Against this backdrop, questions arise about the effective enforcement of legislation designed to protect the Legal Reserve (LR) in the Western Amazon. Therefore, this study aimed to clarify the level of LR protection in response to legislative changes, covering both the period of the 1965 Forest Code and the current NVPL. To this end, we analyzed the dynamics of LR loss on private rural properties in the Alto Rio Branco basin in the Western Amazon.

2. Materials and methods

2.1. Location and characterization of the study area

This study focused on the Rio Branco micro-basin in the state of Rondônia (Figure 1), which is part of the Guaporé River basin, a tributary of the Madeira River within the Legal Amazon biome. The regional climate is tropical monsoon (Am), with an average annual temperature above 25ºC and precipitation ranging from 1,564.5 to 1,843.5 mm, distributed over 6 to 8 months of the year (Alvares et al., 2013; Franca, 2015). The soils in the study area are classified as Quartzarenic Neosols (59.30%), Red Latosols (30.91%), and Red-Yellow Latosols (9.79%) (Secretaria de Estado do Desenvolvimento Ambiental [SEDAM], 2002). The vegetation in the micro-basin consists predominantly of Open Ombrophilous Forest (Instituto Brasileiro de Geografia e Estatística, 2012).

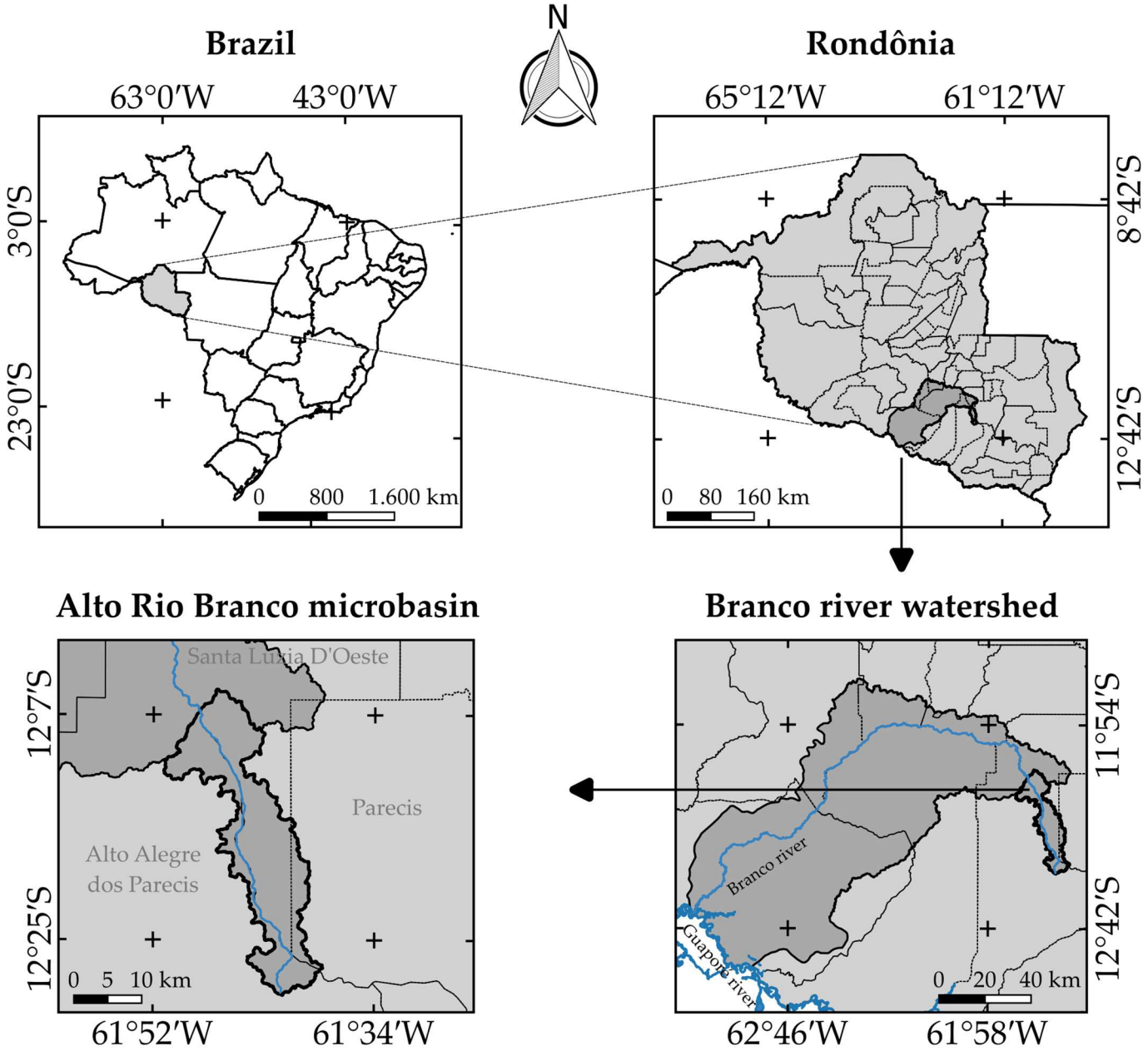


Figure 1

Location of the Rio Branco micro-basin in the state of Rondônia, Brazil.

Source: Vendruscolo et al. (2021).

The main economic activities in this region are beef cattle ranching, coffee and bean cultivation, and energy generation from eight Small Hydropower Plants (SHPs); the area is characterized primarily by small and medium-sized rural properties (IBGE, 2022, 2024). The micro-basin also encompasses two Indigenous Territories (Massaco and Rio Branco) (Instituto Socioambiental [ISA], 2024), the Guaporé Biological Reserve, and the Pedras Negras Extractive Reserve (Ministério do Meio Ambiente e Mudança do Clima [MMA], 2024), forming a landscape of substantial ecological and cultural importance for the state of Rondônia and the Amazon biome. Indigenous populations and traditional communities, although a demographic minority, are concentrated in forest remnants legally designated for their use. Conversely, the largest population segment, commonly

referred to as settlers (*colonos*), occupies landscapes that have largely been stripped of native forest (Teixeira & Xavier, 2018; Mezacasa, 2021).

The micro-basin was selected as the territorial unit of analysis because it represents the smallest unit for landscape and territorial planning. This choice is consistent with Article 14 of the NVPL, which states that LR allocation must consider the river basin plan, as well as the National Water Resources Policy (Law No. 9.433 of January 8, 1997). The micro-basin was chosen because of its multiple water uses across rural properties, urban areas, Indigenous Territories, and Conservation Units; its predominantly water-erosion-susceptible soils; the high intensity of anthropogenic activities; and its role as a natural nursery for the Rio Branco ichthyofauna. The temporal scale was defined on the basis of key legislative changes concerning forest protection and use, together with the region's colonization history.

The dynamics of native vegetation loss were assessed using the database of the National Institute for Colonization and Agrarian Reform (INCRA), specifically the boundaries of private agricultural establishments. We evaluated all 158 private agricultural establishments located entirely within the Alto Rio Branco micro-basin.

2.2. Legislation governing the Legal Reserve

For the purposes of this study, we established a baseline using the legal instruments that created the Legal Reserve (LR): the 1965 Forest Code (FC, Law No. 4.771 of September 15, 1965); subsequent laws amending the 1965 FC; Provisional Measures (MP) No. 1.511 (July 25, 1996) and No. 2.166-67 (August 25, 2001), which introduced changes to the FC; and the current Native Vegetation Protection Law (NVPL, Law No. 12,651 of May 25, 2012), which repealed the 1965 FC.

Using these legal provisions as a baseline, we analyzed remote-sensing images of the Rio Branco micro-basin to assess vegetation cover dynamics within the Legal Reserve (LR) over the following time intervals:

- 1984-1996, to investigate the dynamics of LR loss during the period when the required LR area in the Amazon region was 50% of the property;
- 1996-2012, to characterize forest cover loss between implementation of the 80% LR requirement and the end of the 1965 FC's period in force. This period was evaluated in two stages: before and after the July 22, 2008 milestone, which introduced the concept of the 'consolidated rural area' under the NVPL;
- 2012-2020, to demonstrate the dynamics of LR area gains or losses under the new legal framework (NVPL).

To evaluate the dynamics of LR area loss and gain in the study area, we developed a forest-cover percentage classification system to quantify the number of properties in each LR percentage class. The forest-cover percentage

classes were: < 20, > 20 < 40, > 40 < 60, > 60 < 80, and > 80, thereby providing better visualization of and sensitivity to landscape alterations.

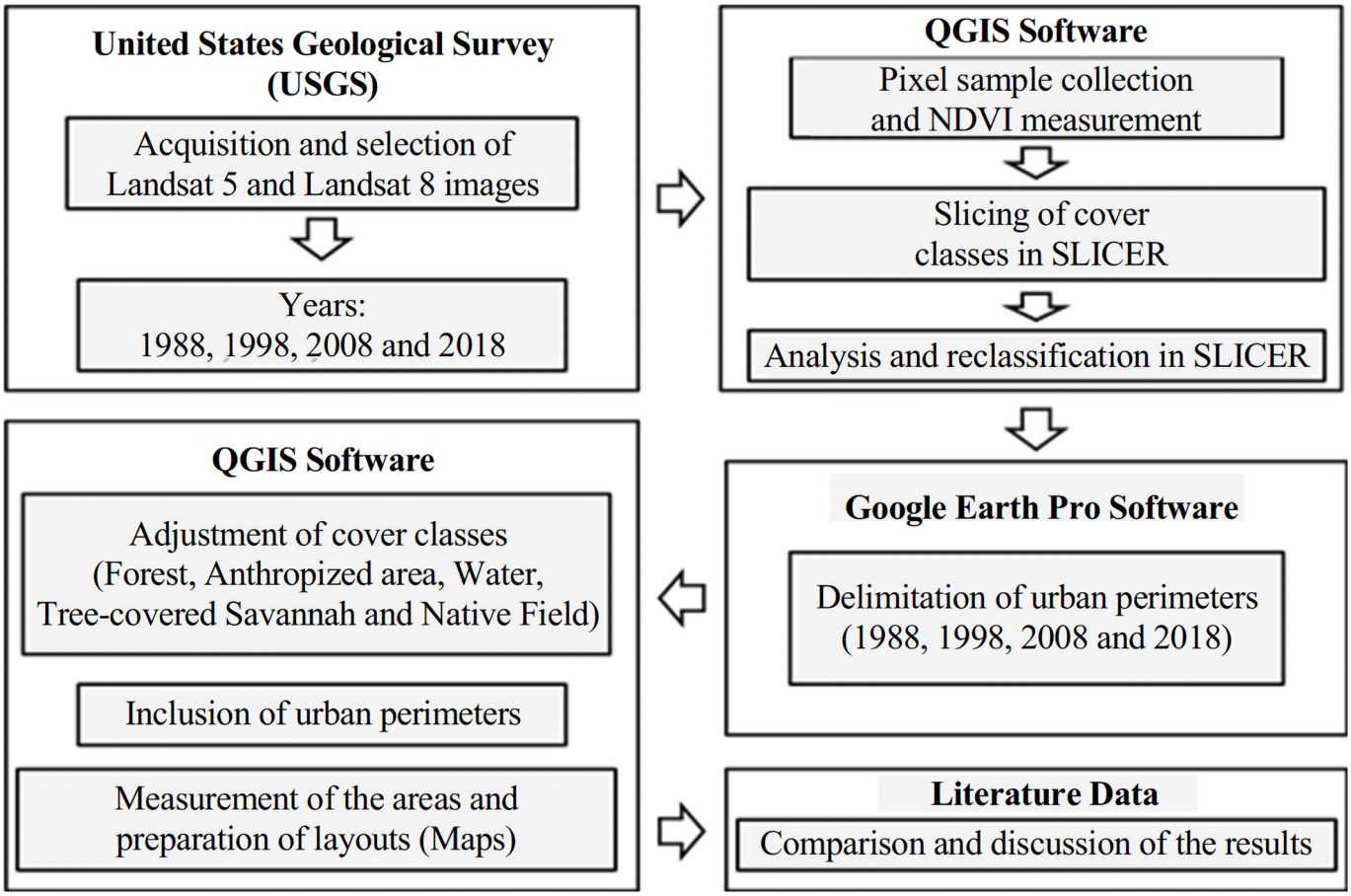
2.3. Land-cover analysis

Land-cover characterization in the Rio Branco micro-basin was performed using indirect landscape analysis methods based on orbital remote-sensing imagery. We selected the main land-cover classes in the micro-basin over the past 30 years, identifying and classifying them as Forest, Anthropized Area, Water, Wooded Savanna, and Native Grassland. To this end, we used Digital Image Processing (DIP) within a Geographic Information System (GIS) environment, using QGIS *software* version 2.10.1 (Pisa) (QGIS Development Team, 2024).

The methodology followed the protocol proposed by Gonzalez and Woods (2008), adapted for this study, with a focus on image acquisition, processing, and qualitative-quantitative analysis. The image-processing and data-acquisition phases are outlined in Figure 2 and detailed below.

For the land-cover analysis, we used satellite imagery from *Landsat* 5 (1988, 1996, and 2008), *Landsat* 8 (2012), and *Sentinel* 2 (2020). Images from July to August were selected because they were of higher quality owing to lower cloud cover. The images were obtained from the *United States Geological Survey* website (U.S. Geological Survey [USGS], 2020).

Figure 2
Flowchart of the processing phases for data acquisition and results discussion for the Rio Branco sub-basin, Rondônia.



The classes were derived in six steps:

1st: We calculated the Normalized Difference Vegetation Index (NDVI) (Equation 1) (Rouse et al., 1973), which indicates vegetation cover density, using the "*raster* calculator" tool in QGIS 2.10 *software*;

$$NDVI = \frac{IP - V}{IP + V} \quad (1)$$

Where: NIR: Near Infrared (B4 = Landsat 5; B5 = Landsat 8, and B8 = Sentinel 2) and R: Red (B3 = Landsat 5; B4 = Landsat 8, and B4 = Sentinel 2).

2nd: We collected 60 pixel-value samples for each land-cover class, using the NDVI images as a reference;

3rd: We divided the NDVI images into classes using the "SLICER" tool;

4th: We converted the SLICER outputs from raster to vector format using the "polygonize" tool;

5th: We classified the images using the "graduated style" tool. Manual adjustments were then made directly in the attribute tables of the shapefile files, primarily to address reflectance similarities among pixels from different classes;

6th: We manually delineated urban perimeters using Google Earth Pro® software together with the "add polygon" and "historical imagery" tools. These polygons were then merged with the shapefile from the previous step.

To improve classification interpretation, we combined bands 5, 4, and 3 for Landsat 5; bands 6, 5, and 4 for Landsat 8; and bands 4, 3, and 2 for Sentinel 2 in RGB channels. This combination primarily highlights vegetation, facilitating comparative analysis with the NDVI results.

To assess forest fragmentation in the Rio Branco sub-basin, we used the *Landscape Ecology Statistics* (LecoS) tool, evaluating parameters such as the number of fragments, total edge length, and minimum, mean, and maximum fragment areas.

After land-cover classification, the data were partitioned for each private agricultural establishment using the "Split by Lot" tool in QGIS. Next, to evaluate the dynamics of LR area loss and gain in the study area, we developed a forest-cover percentage classification to determine the number of properties corresponding to each LR percentage class. The forest-cover percentage classes were: < 20, 20 to 40, 40 to 60, 60 to 80, and > 80.

3. Results: forest cover loss and legislative changes

From 1984 to 1996, rural properties in the Rio Machado micro-basin collectively complied with the Legal Reserve percentage, retaining 61.42% forest cover in 1996 (Table 1 and Figure 3). At the time, the minimum requirement was 50% of the rural property, referred to as a lot, in accordance with Article 44 of the 1965 Forest Code. However, that same year, Provisional

Table 1 Area, in hectares, under agriculture, forest, and water across all properties (total area 16,367.67 ha) in the Rio Branco sub-basin during the years analyzed.

Years	Agriculture	%	Forest	%	Water	%
1984	1,014.09	6.20	15,353.58	93.80	0	0.00
1989	3,482.64	21.28	12,885.03	78.72	0	0.00
1996	6,294.93	38.46	10,052.33	61.42	20.42	0.12
2008	10,648.23	65.06	5,676.44	34.68	42.91	0.26
2012	11,785.91	72.01	4,560.03	27.86	21.74	0.13
2020	10,253.93	62.65	6,056.71	37.00	57.03	0.35

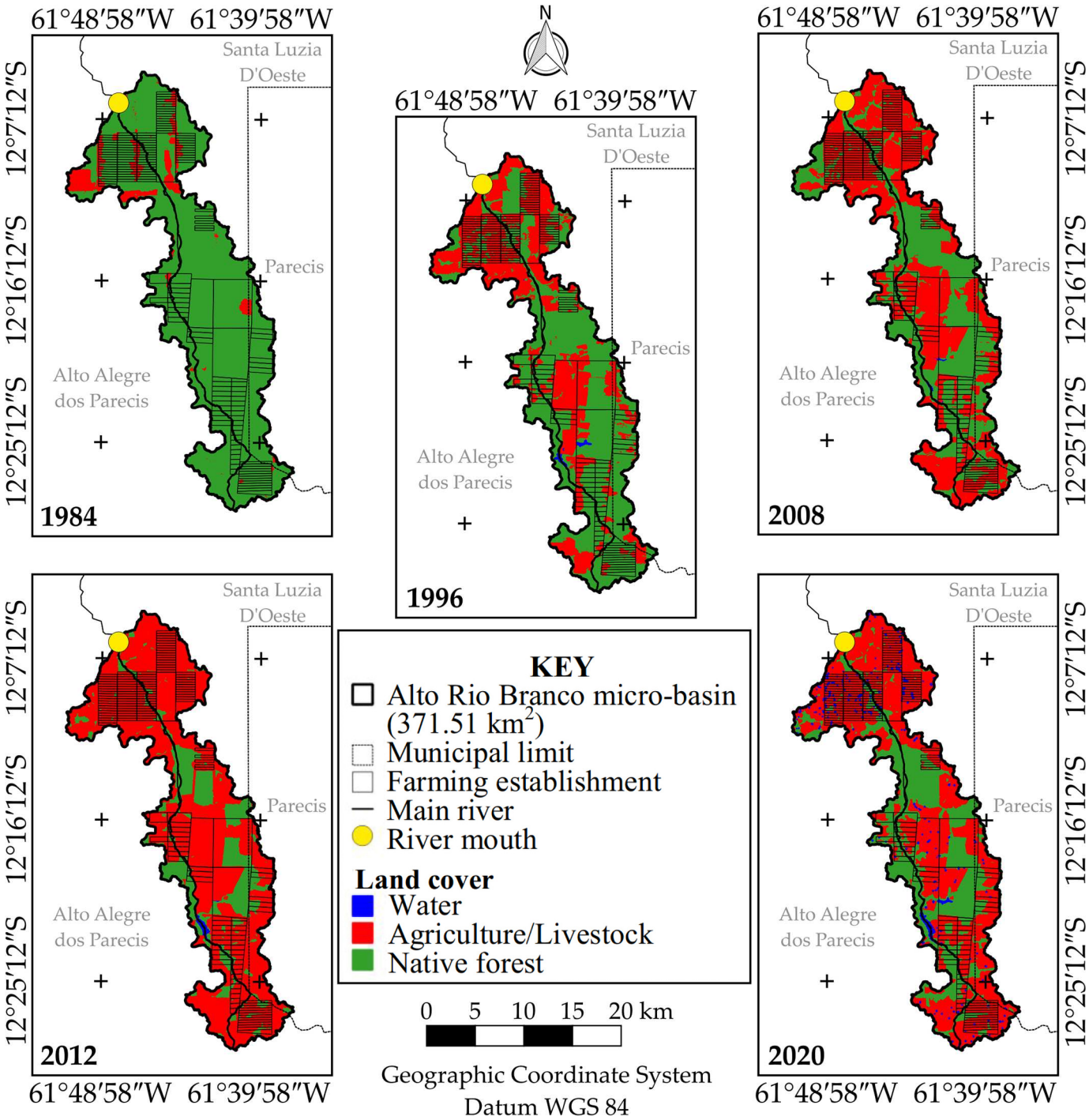


Figure 3
Land-cover dynamics in the study area between 1984 and 2020.

Measure No. 1.511 (July 25, 1996) increased the LR requirement to 80% for properties in forested areas within the Legal Amazon. This change, which applied to the study area, immediately placed most rural properties in a state of LR deficit.

Increasing the Legal Reserve requirement from 50% to 80% of the property area did not halt or reduce deforestation in the study micro-basin, let alone drive the restoration of native vegetation in illegally anthropized areas. On the contrary, deforestation continued to increase until 2012, the year in which new native vegetation legislation was introduced (Table 1 and Figures 3 and 4).

Beginning in 2012, when the Native Vegetation Protection Law (NVPL, Law No. 12,651) replaced the 1965 Forest Code, the new legislation affected forest-cover dynamics (Table 1 and Figures 3 and 4), resulting in a modest gain in forest area and a slight reduction in agricultural area.

In 1984, most rural properties in the Rio Machado micro-basin (137 properties) retained more than 80% forest cover, while 21 properties had between 60% and 80% forest cover (Table 2 and Figure 5).

Particularly between 1996 and 2012, deforestation was so severe that 54.43% of properties retained less than 20% forest cover. This directly violated the legislation, which allowed deforestation of no more than 20% for that specific forest type in the micro-basin (Table 2 and Figure 5).

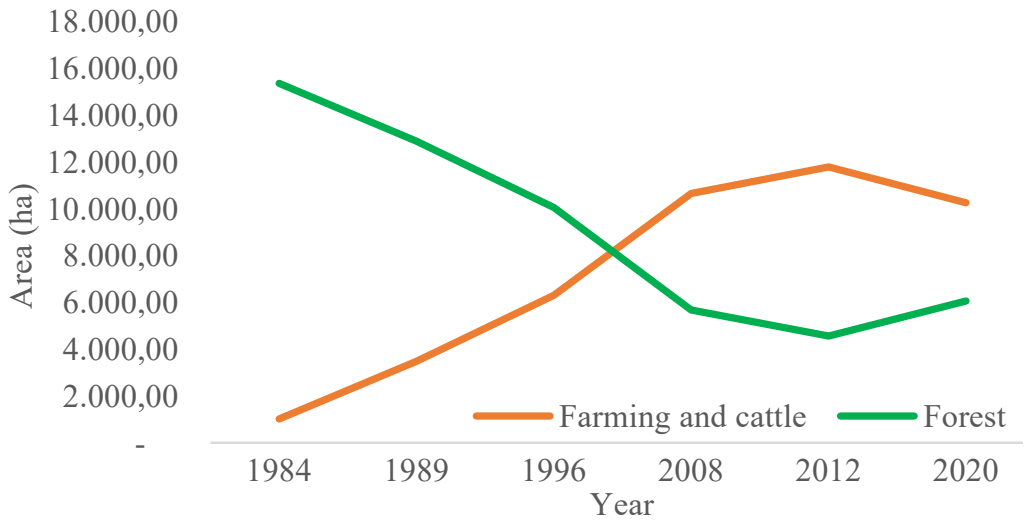


Figure 4
Graphical representation of agricultural and forest area dynamics across micro-basin lots over the study years.

Table 2 Number and percentage of lots in each LR percentage class by year analyzed.

	1984		1996		2008		2012		2020	
LR % Class[1]	**NP[2]**	**%**	**NP**	**%**	**NP**	**%**	**NP**	**%**	**NP**	**%**
< 20			22	13.92	65	41.14	86	54.43	53	33.54
> 20 < 40			35	22.15	46	29.11	43	27.22	63	39.87
> 40 < 60			22	13.92	29	18.35	24	15.19	29	18.35
> 60 < 80	21	13.29	36	22.78	12	7.59	5	3.16	9	5.70
> 80	137	86.71	43	27.22	6	3.80		0.00	4	2.53

[1] Forest-cover percentage class on properties (lots), constituting the Legal Reserve.
[2] NP: Number of properties.

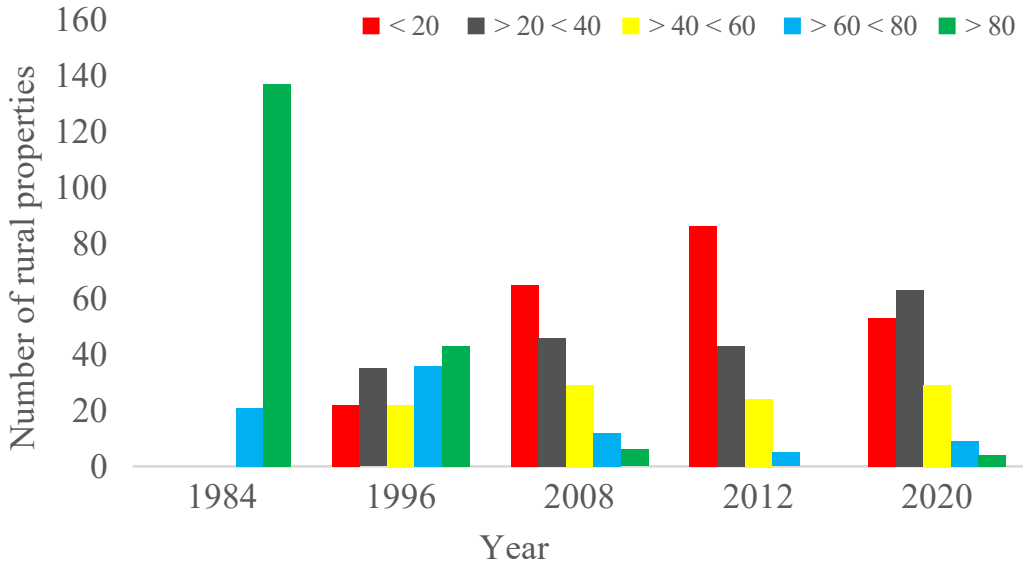


Figure 5
Number of properties in each forest-cover percentage class for each year analyzed.

Combining the forest-cover classes up to 40% shows that 81.65% of properties fell within this range in 2012. This figure declined to 73.41% in 2020 (Table 2 and Figure 5), likely as an effect of the new legislation.

In 2012, only four of the 165 properties complied with Item I of Article 16 of the 1965 Forest Code, which remained in force until that year, when it was superseded by the NVPL.

The 1996 increase in the LR requirement from 50% to 80% of the rural property area (Table 2 and Figure 5) in forested areas of the Legal Amazon failed to achieve its intended objective of conserving native vegetation remnants in the Rio Machado micro-basin.

4. Discussion

After the 1965 Forest Code was replaced by the Native Vegetation Protection Law (NVPL, Law No. 12,651) in 2012, forest cover increased slightly. This contrasts with the trend observed after the 1996 legislative amendment introduced by Provisional Measure No. 1,511. Although modest, this increase is a positive indicator. This pattern of LR forest-cover dynamics after the 2012 reforms is linked to the institutional capacity of the democratic state governed by the rule of law, reflecting the slow pace at which institutions enforce forest and environmental legislation (Metzger et al., 2019; Pinillos et al., 2021).

We observed that the pace of Legal Reserve loss in the micro-basin between 1984 and 2012 is directly linked to the consolidation of colonization in this area, which is located farther from the BR-365 highway, driven by agricultural promotion initiatives such as the Integrated Development Program for the Northwest of Brazil (POLONOROESTE) (Becker, 2001, 2005; Browder et al., 2008; Alves et al., 2021). This policy was at odds with the legislation in force at the time. This contradiction was compounded by the inability of executive branch institutions to combat deforestation, as

well as by the fragility and complicity of other institutions within the justice system, as previously demonstrated by Sparovek et al. (2011).

It is therefore no coincidence that enforcement of the 1965 Forest Code failed so markedly – not only in the Rio Machado micro-basin but throughout the state of Rondônia – that the political process to amend forest legislation was led by a federal representative from Rondônia in 1999 through the introduction of Bill 1.876. The bill stalled in the Brazilian Congress for several years until the interests of most lawmakers and the political class converged, largely because the situation of rural properties across the rest of the country closely mirrored that of the Rio Machado micro-basin. This bill underwent numerous amendments, culminating in the promulgation of Law No. 12,651 on May 25, 2012 (Brancalion et al., 2016; Silva et al., 2016).

To resolve the widespread illegality of rural properties in Brazil, the existing legislation was amended by introducing the concept of the 'consolidated rural area' as a solution to LR non-compliance. Item IV of Article 3º of Law No. 12,651/2012 defines the consolidated rural area in a way that legitimizes most activities occurring in areas originally designated as LR. The law established a cutoff date, applying retroactively to July 22, 2008, the date on which the Environmental Crimes Law was regulated. This retroactivity effectively regularized environmental violations on rural properties. Thus, the new legislation granted amnesty to rural producers who had violated the former Forest Code. This amnesty provided two main benefits: a reduction of the LR requirement to as low as 50% of the property – to be defined by Ecological-Economic Zoning (EEZ) for environmental regularization purposes under Article 13 of Law No. 12,651/2012 – and a full pardon for properties measuring up to four fiscal modules. This perspective is corroborated by Soares-Filho et al. (2014), Brancalion et al., (2016), Silva et al. (2016) e Guidotti et al. (2017), noting that the fiscal module for the study area corresponds to 60 hectares, the standard established by INCRA.

Landowners with up to 4 fiscal modules, equivalent to up to 240 hectares in Rondônia, who deforested before July 22, 2008, are exempt from mandatory LR restoration, even if the clearing was illegal.

In the Rio Machado micro-basin, only five properties exceed 240 hectares; although they represent just 3.10% of the total number of properties, they account for 39% of the total land area. All other properties fall under Article 67 of the NVPL, which exempts them from restoring forest areas designated as LR that were cleared before July 22, 2008. After excluding the five properties exceeding four fiscal modules, the average size of the remaining properties is 65.24 hectares, with an average of 31% forest remnants. However, this does not rule out the possibility that multiple properties are owned by a single individual; similar patterns have been documented in the Amazon region Yanai et al. (2020). Nevertheless, the five properties exceeding four fiscal modules had an average forest cover of 40%

in 2020. These properties may benefit from Article 13, Item I of the NVPL, which requires restoration of only 50% of the property for environmental regularization if the state updates its state-level EEZ, a process that is currently underway.

Under the NVPL, the Rio Machado micro-basin will permanently lose the opportunity to restore 6,980 hectares of former LR areas. This leaves more than 10,200 hectares available for alternative land uses out of the micro-basin's total area of 16,300 hectares, a finding that corroborates the study by Guidotti et al. (2017).

Among the 161 micro-basin properties mentioned above, only 5 exceed 4 fiscal modules, and 3 of these had less than 50% forest cover in 2020. If deforestation occurred before July 22, 2008, only approximately 666.67 hectares across these 3 properties will need to be restored to reach the 50% threshold, thereby satisfying Item I of Article 13 of Law No. 12,651/2012.

Consequently, there is a permanent reduction in forest cover dedicated to biodiversity conservation, local biomass supply, and the provision of non-timber forest products such as food, oils, and resins. This also reduces groundwater recharge areas and impairs microclimate regulation, as also evidenced by Metzger et al. (2019).

One of the most evident and difficult-to-reverse consequences of inappropriate land use is the presence of several gullies identified within the river basin (Figure 6). Thus, reducing the Legal Reserve (LR) to regularize properties environmentally is fundamentally misaligned with sustainable development goals (United Nations [UN], 2023).

5. Final considerations

The fragility of law enforcement stems from two primary dimensions:

i) lack of interest on the part of the executive branch and its leadership, who are sometimes co-opted by political groups whose interests oppose the maintenance of forest remnants;

ii) inability of the democratic state institutions to fulfill their roles, including state environmental and forestry management agencies, the Public Prosecutor's Office, and the broader Judiciary.

Given the climate emergency, coordinated action between the federal executive branch and the states is urgently needed, in close partnership with the other branches of government. This action must focus on strengthening the organizational management of state agencies responsible for forest governance. This entails improving organizational models, technological infrastructure, training, and human resource management policies. It also requires upgrading equipment and materials, supported by robust transparency processes and management indicators that society can actively monitor. Furthermore, the Public Prosecutor's Office must play a vigilant role

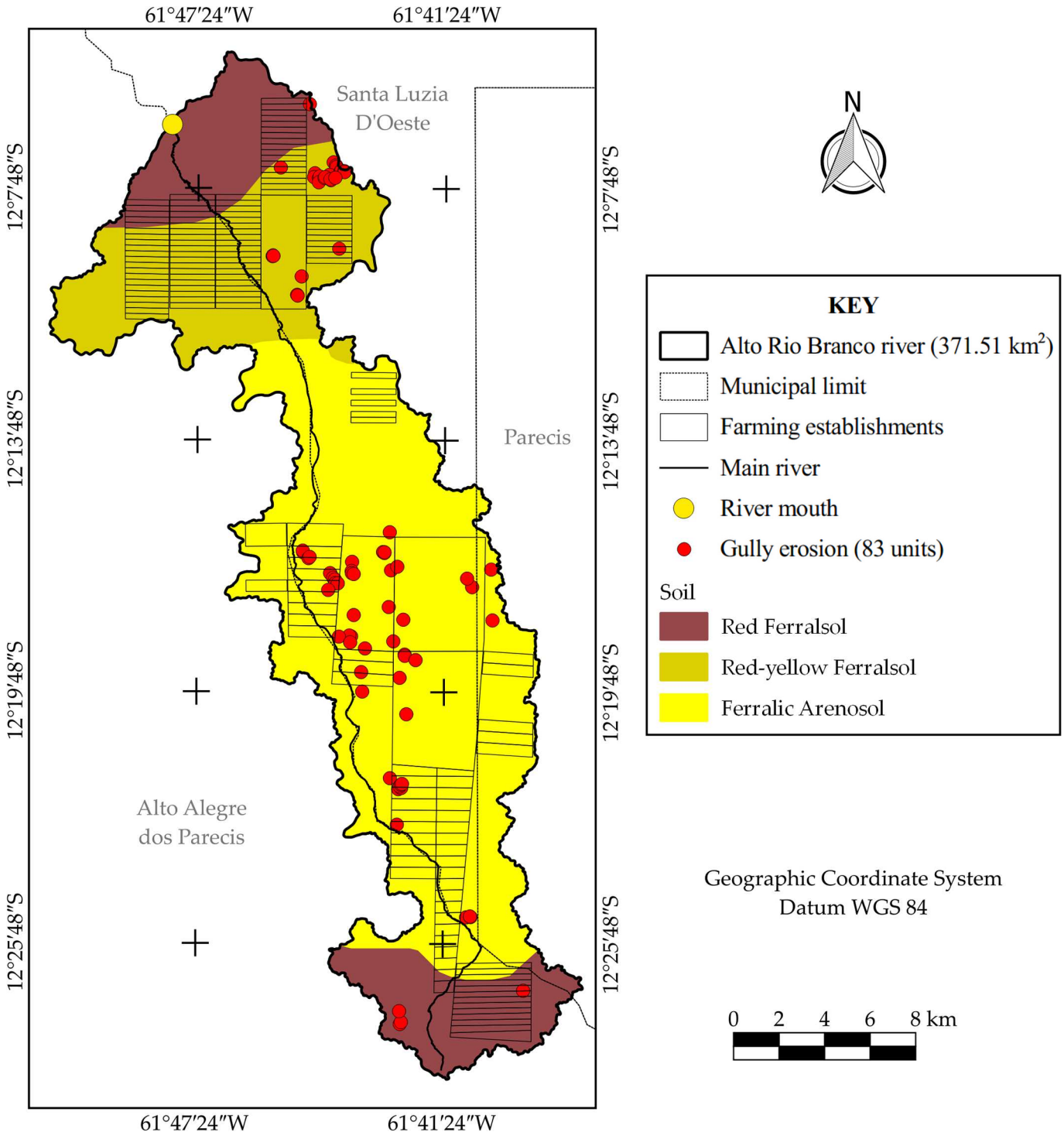


Figure 6
Gullies identified in the river basin under study.

in overseeing executive agencies to ensure effective compliance with the NVPL. Otherwise, the new regulatory framework risks being discredited and ignored, much like the former Forest Code that preceded it.

We recommend conducting socioeconomic studies of the micro-basin to generate data and indicators for a more detailed analysis of the drivers of current environmental degradation. These studies will support short-, medium-, and long-term action planning for ecological restoration and sustainable management of the micro-basin's natural and landscape resources.

References

Ahmed, M. N. Q., & Atiqul Haq, S. M. (2019). Indigenous people's perceptions about climate change, forest resource management, and coping strategies: a comparative study in Bangladesh.Environment Development and Sustainability, *2*1, 679-708. https://doi.org/10.1007/s10668-017-0055-1

Alencar, A., Silvestrini, R., Gomes, J., & Savian, G. (2022). *O novo e alarmante patamar do desmatamento na amazônia, nota técnica.* Instituto de Pesquisa Ambiental da Amazônia. https://ipam.org.br/bibliotecas/amazonia-em-chamas-9-o-novo-e-alarmante-patamar-do-desmatamento-na-amazonia/

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M. de, & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift,* 711- 728. https://doi.org/10.1127/0941-2948/2013/0507

Alves, M. T. R., Piontekowski, V. J., Buscardo, E., Pedlowski, M. A., Sano, E. E., & Matricardi, E. A. T. (2021). Effects of settlement designs on deforestation and fragmentation in the Brazilian Amazon. *Land Use Policy*, *109*, 105710. https://doi.org/10.1016/j.landusepol.2021.105710

Becker, B. K. (2005). Geopolítica da Amazônia. *Estudos avançados*, *19*, 71-86. https://doi.org/10.1590/S0103-40142005000100005

Becker, B. K. (2001). Revisão das políticas de ocupação da Amazônia: é possível identificar modelos para projetar cenários? *Parcerias Estratégicas, 12*, 135-159. https://www.cgee.org.br/revista

Benjamin, A. H. de V. (2000). A proteção das florestas brasileiras: ascensão e queda do Código Florestal: da medida provisória 1.511/96 ao projeto de conversão do deputado Moacir Micheletto. *Revista de Direito Ambiental: RDA, 5*, 21-37. https://ibira.stj.jus.br/Record/rvbi-04559

Benjamin, A. H. V. (2014). Hermenêutica do novo Código Florestal. *Revista de Direito Ambiental*. São Paulo, v.19, n.73, p. 15-24, jan./mar. https://bd.tjdft.jus.br/collections/a8665ef2-8bc9-4a1d-b022-f6feef131ae1/search

Brancalion, P. H. S., Garcia, L. C., Loyola, R., Rodrigues, R. R., Pillar, V. D., & Lewinsohn, T. M. (2016). Análise crítica da Lei de Proteção da Vegetação Nativa (2012), que substituiu o antigo Código Florestal: atualizações e ações em curso. *Natureza & Conservação*, *14*, e1–e16. https://doi.org/10.1016/j.ncon.2016.03.004

Browder, J. O., Pedlowski, M. A., Walker, R., Wynne, R. H., Summers, P. M., Abad, A., Becerra-Cordoba, N., & Mil-Homens, J. (2008). Revisiting Theories of Frontier Expansion in the Brazilian Amazon: A Survey of the Colonist Farming Population in Rondônia's Post-Frontier, 1992–2002. *World Development*, *36*, 1469-1492. https://doi.org/10.1016/j.worlddev.2007.08.008

Camargo, W., & Rodrigues, W. (2018). Código florestal brasileiro e sustentabilidade: uma interpretação a partir da análise do discurso. *Revista Observatório*, *4*, 972-995. https://doi.org/10.20873/uft.2447-4266.2018v4n3p972

Dwyer, M. B., Ingalls, M. L., & Baird, I. G. (2016). The security exception: development and militarization in Laos's protected areas. *Geoforum, 69*, 207-217. https://doi.org/10.1016/j.geoforum.2015.11.002

Fanta, J., & Petřík, P. (2018). Forests and climate change in czechia: an appeal to responsibility. *Journal of Landscape Ecology, 11*, 3-16. https://doi.org/10.2478/jlecol-2018-0009

Fearnside, P. (2017). Deforestation of the Brazilian Amazon. *Oxford Research Encyclopedia of Environmental Science*. https://doi.org/10.1093/acrefore/9780199389414.013.102

Fisher, L. A., Kim, Y.-S., Latifah, S., & Mukarom, M. (2017). Managing forest conflicts: perspectives of Indonesia's forest management unit directors. *Forest and Society, 1*, 8-26. https://doi.org/10.24259/fs.v1i1.772

Franca, R. R. da. (2015). Climatologia das chuvas em Rondônia – período 1981-2011. *Revista Geografias*, *11*, 44-58. https://doi.org/10.35699/2237-549X..13392

Gonzalez, R. C., & Woods, R. E. (2008). *Digital Image Processing* (3th ed). Prentice Hall.

Guidotti, V., Freitas, F. M. de., Sparovek, G., Fernando, L., Pinto, L. F., Hamamura, C., Carvalho, T., & Cerignoni, F. (2017). Números detalhados do Novo Código Florestal e suas implicações para os pras principais resultados e considerações.*Imaflora*. https://doi.org/10.13140/RG.2.2.23229.87526

Instituto Brasileiro de Geografia e Estatística . (2012). *Manual técnico da vegetação brasileira: sistema fitogeográfico : inventário das formações florestais e campestres : técnicas e manejo de coleções botânicas : procedimentos para mapeamentos*. https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=263011

Instituto Brasileiro de Geografia e Estatística. (2022). *Produção Agropecuária no Brasil*. https://www.ibge.gov.br/explica/producao-agropecuaria/

Instituto Brasileiro de Geografia e Estatística. (2024). *Produto Interno Bruto – PIB*. https://www.ibge.gov.br/explica/pib.php

Instituto Nacional de Pesquisas Espaciais. (2024). *Desmatamento – Amazônia Legal*. http://terrabrasilis.dpi.inpe.br/app/map/deforestation?hl=pt-br

Instituto Socioambiental. (2024). *Terras Indígenas no Brasil*. https://terrasindigenas.org.br/pt-br/node

Intergovernmental Panel on Climate Change. (2022). *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Cambridge University Press. https://doi.org/10.1017/9781009157988

Killian, H. (2000). Das queimadas à ciência florestal. *Ciência & Ambiente*, *14*(2), 157-168. https://www.scielo.br/j/cflo/a/sC4Z8kqK9TGLJLCSwKmykFK/?format=pdf&lang=pt

Lei n.° 4.771, de 15 de setembro de 1965. (1965, 15 setembro). Institui o Novo Código Florestal. Diário Oficial da União. https://www.planalto.gov.br/ccivil_03/leis/l4771.htm#:~:text=%C3%89%20proibido%20o%20uso%20de,e%20estabelecendo%20normas%20de%20precau%C3%A7%C3%A3o

Lei nº 12.651/2012, de 25 de maio 2012. (2012, 25 de maio). Dispõe sobre a proteção da vegetação nativa; altera as Leis nºs 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nºs 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória nº 2.166-67, de 24 de agosto de 2001; e dá outras providências. Diário Oficial da União. https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm

Machado, L. A. T., Unfer, G. R., Brill, S., Hildmann, S., Pöhlker, C., Cheng, Y., Williams, J., Hartwig, H., Andreae, M. O., Artaxo, P., Curtius, J., Franco, M. A., Cecchini, M. A., Edtbauer, A., Hoffmann, T., Holanda, B., Khadir, T., Krejci, R., Kremper, L. A., Liu, Y., Meller, B. B., Pöhlker, M. L., Quesada, C. A., Ringsdorf, A., Riipinen, I., Trumbore, S., Wolff, S., Lelieveld, J., & Pöschl, U. (2024). Frequent rainfall-induced new particle formation within the canopy in the Amazon rainforest. *Nature Geoscience*, *17*, 1225-1232. https://doi.org/10.1038/s41561-024-01585-0

Magalhães, J. P. (2001). *Comentários ao Código Florestal: doutrina e Jurisprudência* (2nd ed.). Juarez de Oliveira.

MapBiomas.(2023). *Projeto MapBiomas – Coleção [2023] da Série Anual de Mapas de Uso e Cobertura da Terra do Brasil*. https://plataforma.brasil.mapbiomas.org/

Medida Provisória nº 1.511, de 25 de julho de 1996. (1996, 25 de julho). Dá nova redação ao art. 44 da Lei nº 4.771, de 15 de setembro de 1965, e dispõe sobre a proibição do incremento da conversão de áreas florestais em áreas agrícolas na região Norte e na parte Norte da região Centro-Oeste, e dá outras providências. Diário Oficial da União. www.planalto.gov.br/ccivil_03/mpv/antigas/1511.htm

Medida Provisória nº2.166-67, de 25 de agosto, de 2001.(2001, 25 de agosto). Altera os arts. 1o, 4o, 14, 16 e 44, e acresce dispositivos à Lei no 4.771, de 15 de setembro de 1965, que institui o Código Florestal, bem como altera o art. 10 da Lei no 9.393, de 19 de dezembro de 1996, que dispõe sobre o Imposto sobre a Propriedade Territorial Rural – ITR, e dá outras providências. Diário Oficial da União. https://www.planalto.gov.br/ccivil_03/mpv/antigas/1511.htm

Metzger, J. P., Bustamante, M. M. C., Ferreira, J., Fernandes, G. W., Librán-Embid, F., Pillar, V. D., Prist, P. R., Rodrigues, R. R., Vieira, I. C. G., & Overbeck, G. E. (2019). Why Brazil needs its Legal Reserves. *Perspectives in Ecology and Conservation*, *17*, 91-103. https://doi.org/10.1016/j.pecon.2019.07.002

Mezacasa, R. (2021). Por histórias indígenas: o povo Makurap e o ocupar seringalista na Amazônia. [Tese de Doutorado, Universidade Federal de Santa Catarina]. https://repositorio.ufsc.br/bitstream/handle/123456789/226949/PHST0719-T.pdf?sequence=-1&isAllowed=y

Miguel, J.C.H. (2014). Ciência, política e a reformulação do Código Florestal. *Política & Sociedade*, *13*, 137-152. https://doi.org/10.5007/2175-7984.2014v13n27p137

Ministério do Meio Ambiente e Mudança do Clima. (2024). *Painel Unidades de Conservação Brasileiras.* https://cnuc.mma.gov.br/relatorio_ucs

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Seroa da Motta, R., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O., & Hess, L. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science, 344*, 1118-1123. https://doi.org/10.1126/science.1248525

United Nations. (2023). *Take action for the sustainable development goals*. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Pinillos, D., Poccard-Chapuis, R., Bianchi, F. J. J. A., Corbeels, M., Timler, C. J., Tittonell, P., Ballester, M. V., & Schulte, R. P. (2021). Landholders' perceptions on legal reserves and agricultural intensification: Diversity and implications for forest conservation in the eastern Brazilian Amazon. *Forest Policy and Economics, 129*, 102504. https://doi.org/10.1016/j.forpol.2021.102504

Poteete, A., & Ostrom, E. (2002). *An institutional approach to the study of forest resources*. Center for International Forestry Research. CABI Publishing. https://www.cbnrm.net/pdf/poteete_a_001.pdf

Przybyszewski, K. R., Vicente, R. E., Ferreira, J. V. A., Pereira, M. J. B., Izzo, T. J., Storck-Tonon, D. (2022). Legal reserves ensure alpha and beta ant diversity in highly modified agricultural landscapes. *Perspectives in Ecology and* Conservation, *20*, 330-337. https://doi.org/10.1016/j.pecon.2022.08.001

QGIS Development Team. (2024). Spatial without compromise. https://qgis.org

Rocha, J. das D. de S., Silva, J. de A. (2019). A lei de proteção da vegetação nativa e a efetividade para a recomposição das áreas de preservação permanente e reserva legal. Revista Geográfica Venezolana,*esp*., 268-272. http://erevistas.saber.ula.ve/regeoven

Rocha, J. das D. de S., Silva, J. de A., & Paupitz, J. (2020). Governance and decentralization of forest management in the construction of public policies: process applied to amapá and sergipe – Brazil. *Forestry Research and Engineering: International Journal*, *4*. https://doi.org/10.15406/freij.2020.04.00097

Rocha, J. D. D. D. S., & Silva, J. D. A. (2009). As funções de estado na área florestal: suas inter-relações com a Constituição Federal e com o programa nacional de florestas. *Revista Floresta*, *39*. https://doi.org/10.5380/rf.v39i2.14554

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1973). Monitoring vegetation systems in the Great Plains with ERTS. Third ERTS Symposium, NASA SP-351, 309–317. https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf

Secretaria de Estado do Desenvolvimento Ambiental. (2002). *Atlas Geoambiental de Rondônia*. SEDAM.

Silva, A. P. M. da., Marques, H. R., Sambuichi, R. H. R.(Orgs.). (2016). *Mudanças no Código Florestal brasileiro : desafios para a implementação da nova lei*. Ipea. https://repositorio.ipea.gov.br/handle/11058/6912

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., Alencar, A. (2014). Cracking Brazil's Forest Code. *Science*, *344*, 363–364. https://doi.org/10.1126/science.1246663

Sparovek, G., Barretto, A., Klug, I., Papp, L., & Lino, J. (2011). A revisão do Código Florestal brasileiro. *Novos estududos. CEBRAP*, 111-135. https://doi.org/10.1590/S0101-33002011000100007

Swann, A. L. S., Longo, M., Knox, R. G., Lee, E., & Moorcroft, P. R. (2015). Future deforestation in the Amazon and consequences for South American climate. *Agricultural and Forest Meteorology*, *214-215*, 12-24. https://doi.org/10.1016/j.agrformet.2015.07.006

Teixeira, M. A. D., & Xavier, D. F. B. (2018). Santo Antônio do Guaporé: direitos humanos, conflitos e resistência socioambiental. *Revista Direito e Práxis*, *9*(1), 351-371. https://doi.org/10.1590/2179-8966/2018/32718

U.S. Geological Survey. (2020). *Pesquisa Geológica dos EUA*. https://www.usgs.gov/centers/community-for-data-integration-%28cdi%29/science/science-topics/2020

Vendruscolo, J., Souza, E., Ferreira, K. R., & Cavalheiro, C. S. (2021). Características da paisagem para subsidiar o manejo dos recursos naturais na Microbacia Alto Rio Branco, Amazônia Ocidental, Brasil. *Geografía y Sistemas de Información Geográfica (GEOSIG)*, *20*, 1–21. https://revistageosig.wixsite.com/geosig/geosig-20-2021

Yanai, A. M., Graça, P. M. L. de A., Escada, M. I. S., Ziccardi, L. G., & Fearnside, P. M. (2020). Deforestation dynamics in Brazil's Amazonian settlements: Effects of land-tenure concentration. *Journal of Environmental Management*, *268*, 110555. https://doi.org/10.1016/j.jenvman.2020.110555