Panorama of Brazil's Forest Code

3rd ed.

CSR
CENTRO DE SENSORIAMENTO REMOTO

CIT
Centro de Inteligência Territorial

UFMG
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DECEMBER | 2024

Policy brief

Centro de Sensoriamento Remoto – CSR/UFMG
Universidade Federal de Minas Gerais – UFMG
Centro de Inteligência Territorial – CIT

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1. Forest Code, 2. Environmental Balance, 3. Rural Environmental Registry, 4. Legal Reserve, 5. Deforestation.

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Forest Code, Law nº 12,651/2012

The Forest Code (FC) is the main legislation on environmental conservation in rural properties in Brazil[1]. In summary, it defines where native vegetation must be conserved or may be suppressed, as well as regulating the use of natural resources in areas with native vegetation. The law essentially defines two types of conservation areas: Permanent Preservation Areas (APP), which include land strips along rivers, water bodies and springs, as well as steep slopes and hilltops; and the Legal Reserve (LR) – a percentage (ranging from 20% to 80%, depending on the biome and location) of the rural property's area where native vegetation must be conserved. For non-compliant properties, the FC also determines areas needed to be restored to native vegetation at the owners' expense, i.e., LR and APP liabilities, or areas illegally deforested after 2008.

In 2024, the FC revision reached its 12th anniversary. This legislative amendment eased requirements related to environmental conservation and relaxed enforcement measures, including granting amnesty to illegal deforesters, the massive suspension of applied penalties and the reduction of the need for native vegetation restoration. Today, there are practically two sets of rules: one that maintained the previous guidelines regarding restrictions or authorizations for native vegetation suppression, including the immediate suspension of activities in LR irregularly deforested after July 22, 2008, and another that concerns the recovery of areas deforested prior to that date. For example, rural properties smaller than four fiscal modules (which vary by municipality from 5 to 110 hectares in the Amazon) no longer need to recover the LR deficit. While the width of riparian APP for conservation is maintained, for recovery, the FC establishes a set of rules so-called "escadinha" (little ladder), with successive strips ranging from 5 to over 30 meters, depending on the property's size (defined in fiscal module numbers) and river widths. The FC revision also made the concept of hilltop APP more restrictive (see Methods). Moreover, the Law establishes a maximum percentage of the property for LR restoration, depending on the total of its riparian APP or, in the case of the Amazon, reduces it to 50% based on the year of deforestation, the percentage of protected areas in the state and municipality, and the existence of an approved Ecological-Economic Zoning. These exceptions (articles 12, 15, 67, 68)[1] mean that, in the Legal Amazon, the RL area to be restored representing, on average, 49% of the rural property, a percentage significantly below the maximum value of 80%, which is often incorrectly cited as applicable to all rural properties in the region. Finally, properties with APP and LR deficits must necessarily present degraded area recovery plans or join the Environmental Regularization Program (PRA) to comply with the legislation over a 20-year period.

Rural Environmental Registry

The 12 years following the revision of the Forest Code (FC) have been predominantly marked by setbacks and limitations in governmental actions aimed at conserving vast expanses of Brazil's native vegetation. Normative Instruction No. 2 of 2014 from the Ministry of the Environment[2] outlines the technical requirements for the Rural Environmental Registry (CAR), initiating a one-year registration period, extendable by another year, starting on May 6, 2014—a deadline subsequently extended several times[3-6]. Nonetheless, registration remains open, reaching more than 7.3 million entries by November 2024, a number greatly driven by the obligation established from December 31, 2017 (Art. 78-A)[1] for access to agricultural credit, notary requirements, and also due to fraudulent use for land grabbing.

Although the number of registrations and the registered area continue to grow consistently, even surpassing previous official estimates of agricultural areas in the country, little to no progress has been made in using the CAR as the main instrument for compliance with the Forest Code. Registration in the CAR, the first step toward regularization, is a self-declaration process conducted through the National Rural Environmental Registry System (SICAR) or an equivalent state system (e.g., the one in Mato Grosso). The software supporting the operationalization of SICAR, crucial for the effective implementation of the Forest Code, has seen little technological advancement and remains inadequate to handle the demands of land registration and monitoring in a country the size of Brazil. It is an outdated software with an unfriendly interface, operating offline without integrating cartographic databases, and limited to using LandSat and RapidEye satellite images—the latter being of lower quality than free-access imaging currently available. For example, users must manually draw drainage courses, even if the property contains or is bordered by large rivers, disregarding the existence of national drainage databases. Additionally, the delineation of hilltops is left to the declarant, despite the availability of algorithms capable of extracting them from digital terrain models. These are only a few of the system's deficiencies; the most critical issue is the lack of systematic monitoring and verification of fraudulent declarations, often used to conceal illegal deforestation, legal reserve deficits, or even land grabbing, particularly of public lands such as conservation units, indigenous lands, territories of traditional peoples and communities, and, most notably, unallocated public lands. This last misuse of the CAR has only increased. In the Legal Amazon, the overlap of CAR registrations with these public areas increased from 12.4% in 2023 to 18.3% in 2024, representing a significant growth in just one year (Overlays, p. 6).

Despite Brazil having access to advanced technology and territorial intelligence, this comprehensive verification is still not performed by SICAR, currently managed by the Ministry of Management and Information (MGI). Since SICAR is proprietary software with a closed and even inaccessible source code, both state and federal governments are unable to update it freely, let alone integrate it with other federal systems. In this regard, a significant portion of CAR overlaps with other properties, as well as the cancellation of fraudulent registrations, could be resolved by integrating CAR with SIGEF (INCRA's Land Management System), requiring the registration of properties larger than 4 fiscal modules (MF) in the latter system.

This technological impasse, also stemming from political and institutional limitations, has raised growing concerns, as it results in both the misuse of the CAR and its ineffectiveness in combating illegal deforestation. Consequently, it calls into question the achievement of the ambitious goals outlined in Brazil's Climate Plan and its Nationally Determined Contribution (NDC) to eliminate illegal deforestation and reduce greenhouse gas emissions.

As CAR is self-declared, state environmental agencies are responsible for verifying the accuracy of the information provided. However, due to the predominance of manual processes based on visual interpretation, the analysis and validation of records have faced significant delays, with only 1.8% of SICAR registrations analyzed[9], despite the availability of technology for automatically verifying most criteria related to environmental liabilities (e.g., illegal deforestation) and FC compliance levels for rural properties (CAR 2.0, p. 31). As a result, this lack of progress negatively impacts the implementation of other key mechanisms aimed at helping rural landowners achieve legal compliance, such as the Environmental Regularization Program (PRA), the Environmental Reserve Quota Market (CRA)[10], and even agricultural traceability, a growing demand in international markets[11,12].

In addition to addressing FC environmental liabilities, these mechanisms are essential for other national policies like the NDC, as they can drive large-scale native vegetation restoration programs, such as PLANAVEG and payments for environmental services[13], while improving ecosystem services like rainfall regulation[14,15], and providing financial returns to landowners who maintain or restore native vegetation.

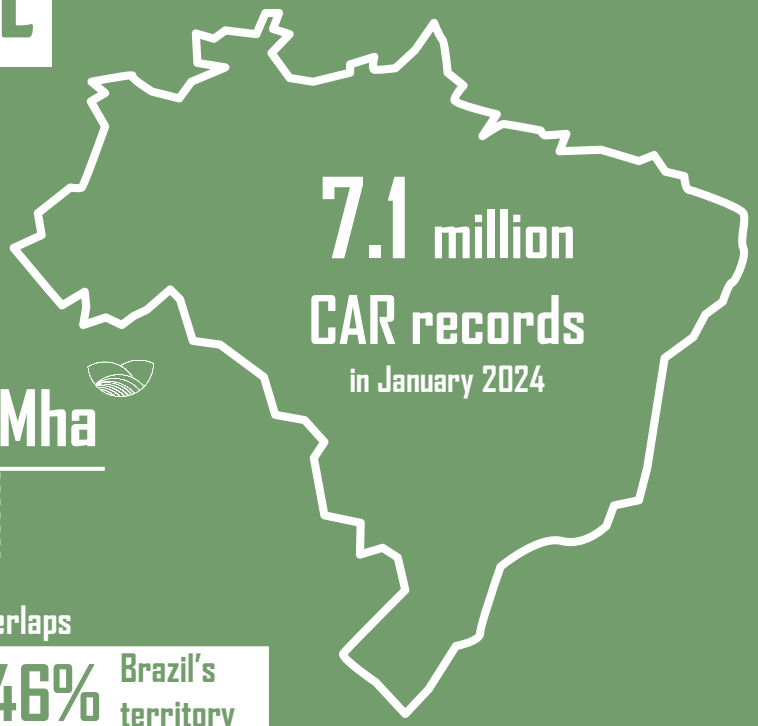
Despite numerous obstacles, Brazilian civil society and the scientific community have been actively mobilizing. Their efforts have supported states in transforming CAR into an effective tool to achieve its legal purpose: integrating environmental information from rural properties and possessions into a database for environmental and economic monitoring, planning, and control while combating deforestation.

Advances in computational models and infrastructure in Brazil, along with the immediate availability of rural property boundaries through CAR, combined with high-resolution land-use mapping by national institutions, have enabled analyses[16,17] of the individual balance of the FC (liabilities and assets) for all CAR records across Brazil's vast territory, an unparalleled effort globally.

In this study, we the methods and results of our FC model's nationwide application conducted in July 2024. The computational model calculates FC requirements and the level of compliance for each of the more than 7 million Rural Property (IRU) records in the CAR. For each IRU, the system identifies conservation and restoration requirements for native vegetation (such as LR and APP) and calculates deficits (vegetation needing restoration) and surpluses (vegetation above compliance levels). The system also reports accumulated deforestation post-2008.

Based on these scientific and technological advancements, state governments and civil society now have updated FC balance estimates to foster comprehensive public policies for conserving and restoring native vegetation on rural properties. The state of Pará pioneered applying this technology to advance CAR analysis processes (the so-called CAR 2.0) and the SeloVerde platform — a public and transparent tool for tracing cattle and soy production from all rural properties in the state. CAR 2.0 is a science-based system that accelerates analysis and validation through cutting-edge spatial modeling algorithms, including machine learning, alongside high-resolution remote sensing data. Meanwhile, the SeloVerde platform is a revolutionary technology supporting due diligence for deforestation-free agricultural supply chains. Both systems have been expanded to Minas Gerais and are being replicated in other Brazilian states. This national, open-source, and free technology is also available to the Federal Government, enabling Brazil to advance CAR as the primary tool for enforcing environmental legislation.

BRAZIL



≅ 74% of the registrable area

7.1 million CAR records in January 2024

451 Mha

Without overlaps

391 Mha | **46%** Brazil's territory

81-68 Mha
Legal reserve surplus

19-16 Mha
Legal reserve deficit

3.4-3.0 Mha
APP deficit

74-63 Mha Potentially subjet to suppression*
in **2.8 million** CAR records

25-21 Mha Deforestation after 2008 inside the CAR

26% Deforestation on APPs or with a LR below the minimum

*Subject to compliance with legislation and authorization from the competent authorities.

Observation of infographics

XX-ZZ

Result using the **SFB** rural property database with **self-overlap**

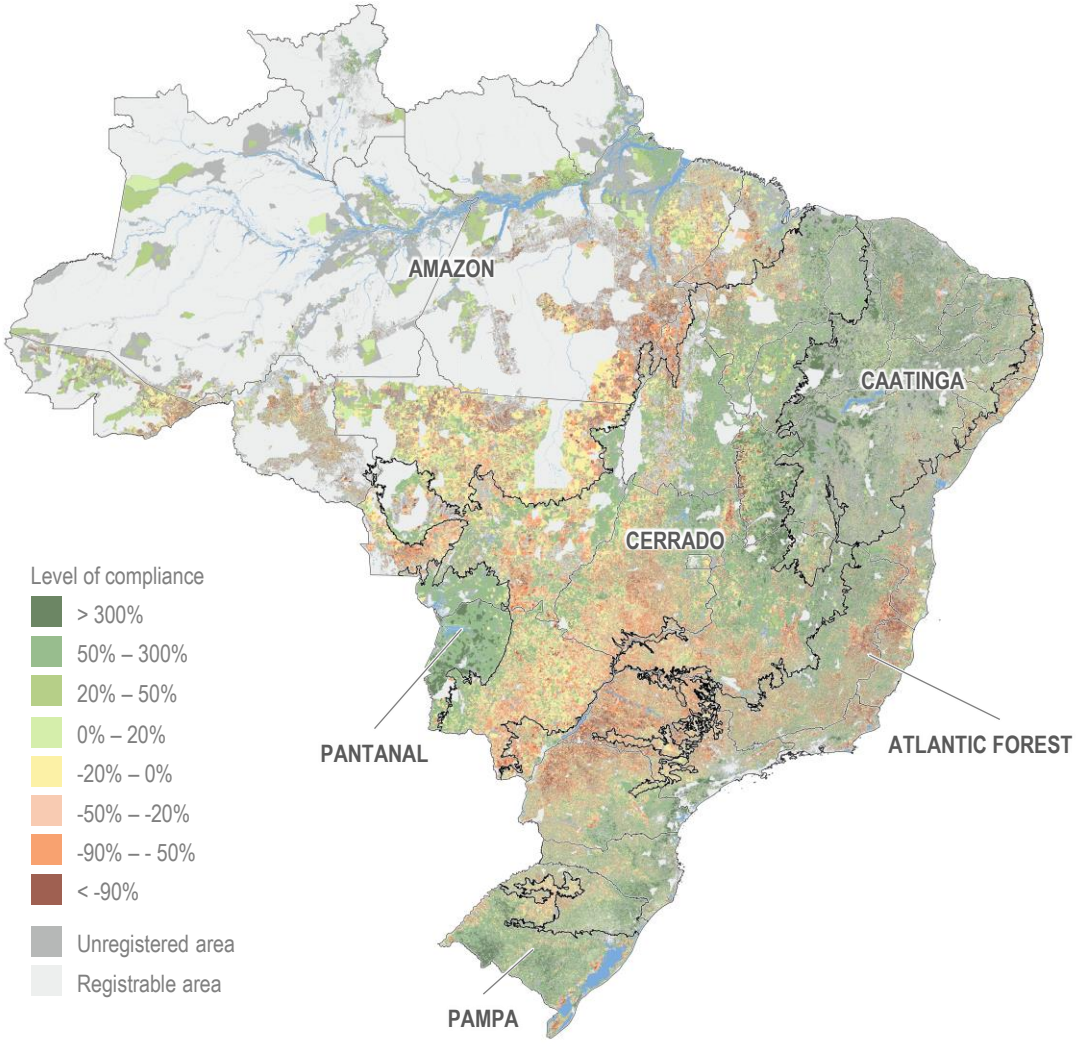
Result using the **Imaflora** rural property database without **self-overlap**

YY%

Percentages always refer to the **average between the values** of the two databases.

Balance of the Forest Code across the national territory

Percentage difference between the remaining native vegetation area and the area required to comply with the 2012 FC.

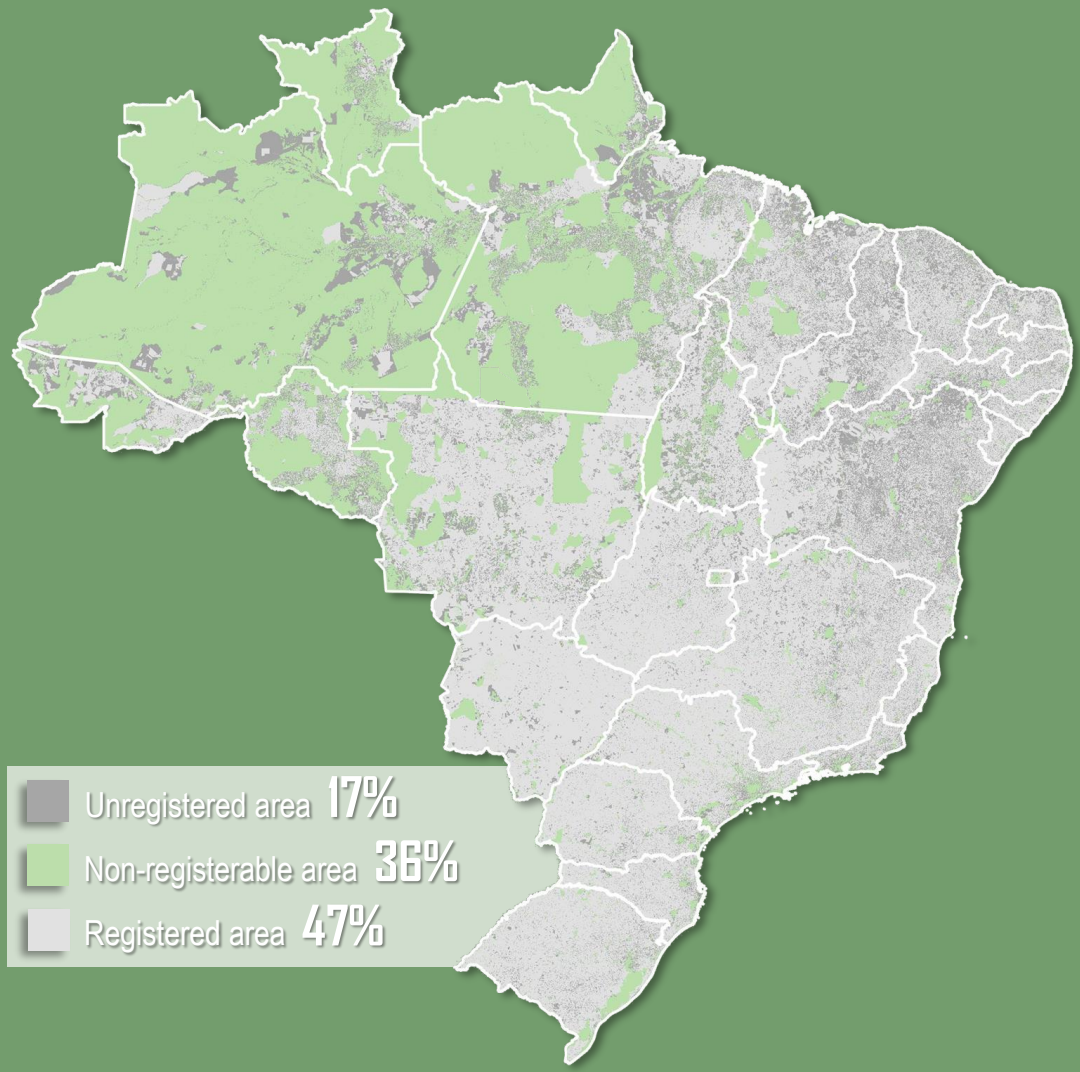


Positive values indicate forest surpluses or vegetation above legal compliance.

Negative values indicate forest deficits or areas that need to be restored.

Progress of the Rural Environmental Registry

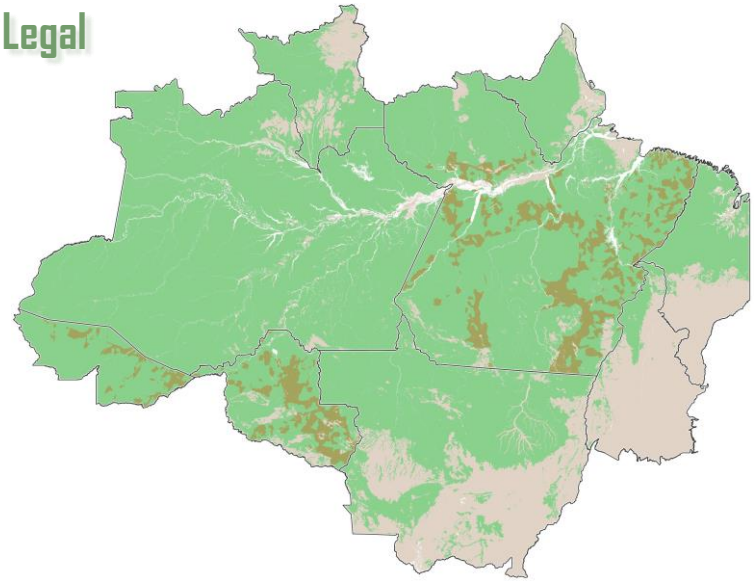
- Mato Grosso is the state with the largest area of CAR records: 71-58 Mha.



- The state with the highest number of CAR registrations is Bahia: approximately 1.1 million.

LEGAL AMAZON

Percentage of Legal Reserve for regularization purposes



80%
50%
35%

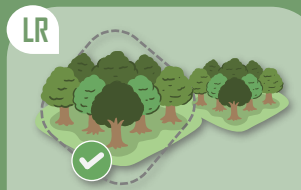
CAR records

37% Average native vegetation per IRU

31% Average native vegetation protected per IRU (LR + APP)

Area registered in the CAR

CAR records



19.3-15.2 Mha surplus

12.4-10.0 Mha deficit

1.05-0,88 Mha deficit

49%
Average LR to be restored within the CAR

12.6-9.8 Mha
Deforestation after 2008 within the CAR

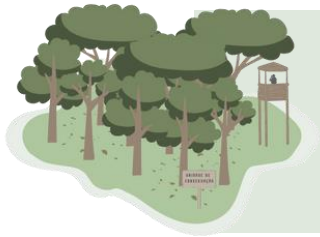
169-138 Mha

Region that extends across nine Brazilian states: Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Rondônia, Roraima and Tocantins. It extends beyond the entirety of the Amazon biome, also encompassing areas of the Cerrado and Pantanal.

0.91 million
CAR records

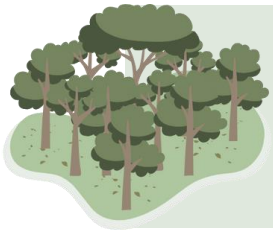
Overlays

Legal Amazon



13,433 records overlapping Conservation Units

2,360 records overlapping Indigenous Lands



206,495 records overlapping Undesignated Public Lands

MPF Protocol

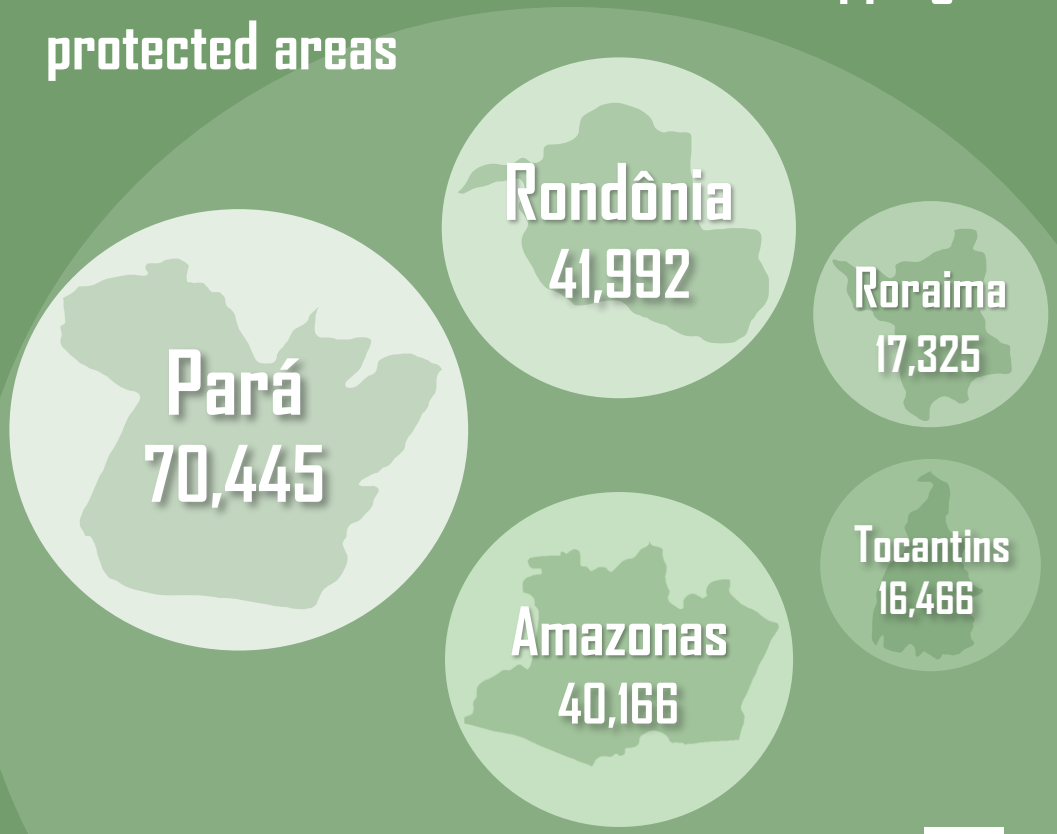
219,879 records with overlays in Protected Areas according to the Monitoring Protocol Cattle Suppliers in the Amazon

Comparison of records overlapping with Undesignated Public Lands

2023
12.4%

2024
18.3%

States with the most records overlapping protected areas



Biomes

The **Amazon** and **Cerrado** are the two largest Brazilian biomes and the most impacted by agricultural frontier expansion and deforestation. These are critical areas for the conservation of sociobiodiversity, climate change mitigation, and water regulation, which are vital for agribusiness productivity, hydropower generation, urban water supply and food security.

Amazon

Legal reserve
8.1-6.0 Mha surplus | 9.7-7.5 Mha deficit

CAR records
0.67 Million | 110-86 Mha

APP
0.8-0.6 Mha deficit

Deforestation after 2008 inside the CAR
6.7-4.8 Mha

Cerrado

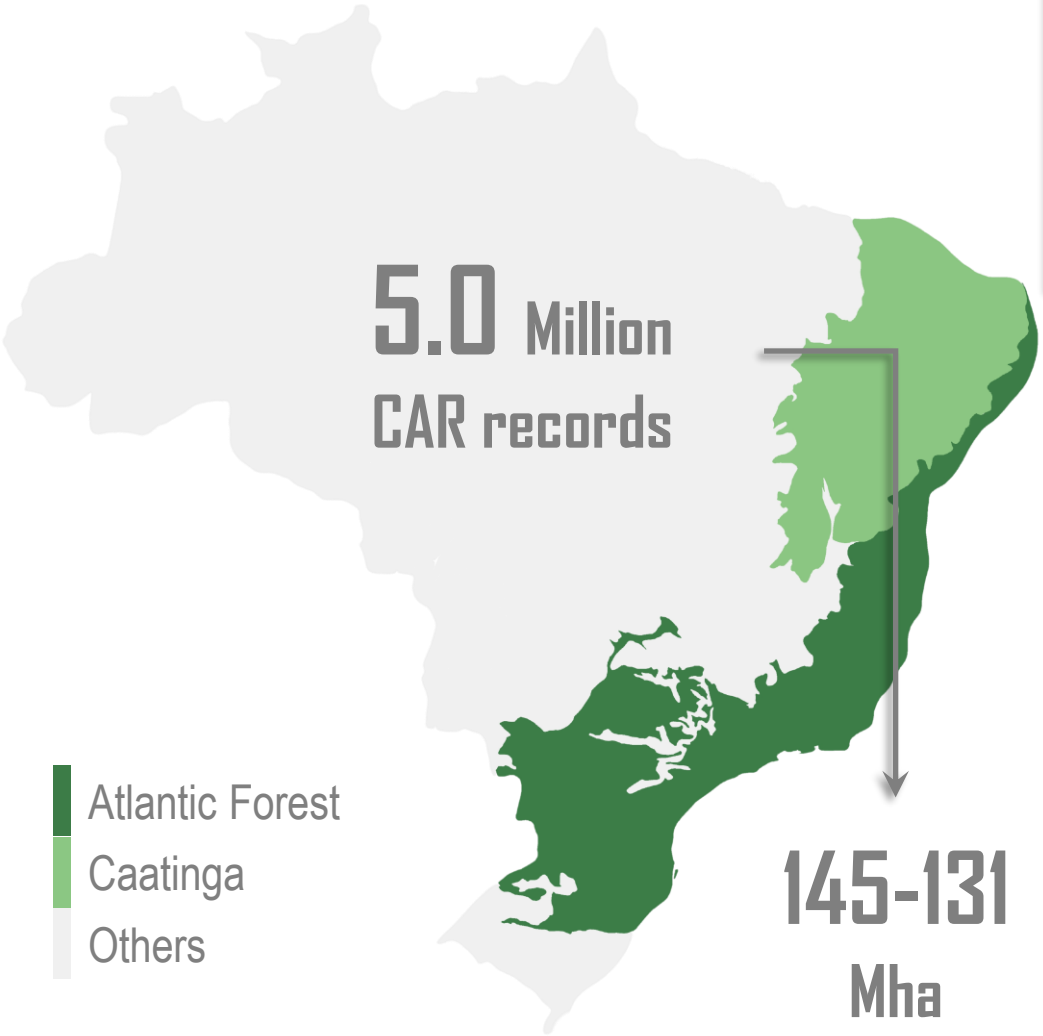
CAR records
1.20 Million | 165-146 Mha

Deforestation after 2008 inside the CAR
12.9-10.9 Mha

APP
1.0-0.9 Mha deficit

Legal reserve
30.2-24.9 Mha surplus | 5.8-5.4 Mha deficit

The **Atlantic Forest** houses the largest cities in Brazil. Only about 15–20% of its forests remain. This biome has its own legal framework, established by Law No. 11,428 of December 22, 2006, which, for forest balance purposes, sets broader conservation guidelines for Permanent Preservation Areas (APP) than the Forest Code. The **Caatinga**, in turn, is the only biome that occurs exclusively in Brazil, harboring great diversity of endemic species.



Atlantic Forest

Legal reserve

11.0-9.5 Mha surplus* | 3.0-2.7 Mha deficit

CAR records

2.85 Million | 90.2-81.8 Mha

APP

1.1-1.0 Mha deficit (FC)

2.2-2.0 Mha deficit (Atlantic Forest Law)

Difference: 1.1-1.0 Mha

Deforestation after 2008 inside the CAR

1.1-1.0 Mha

*For vegetation suppression, Decree no. 6,660 of 2008 must be observed.

Caatinga

CAR records

2.13 Million | 54.9-49.2 Mha

Legal reserve

20.4-17.9 Mha surplus | 0.38-0.35 Mha deficit

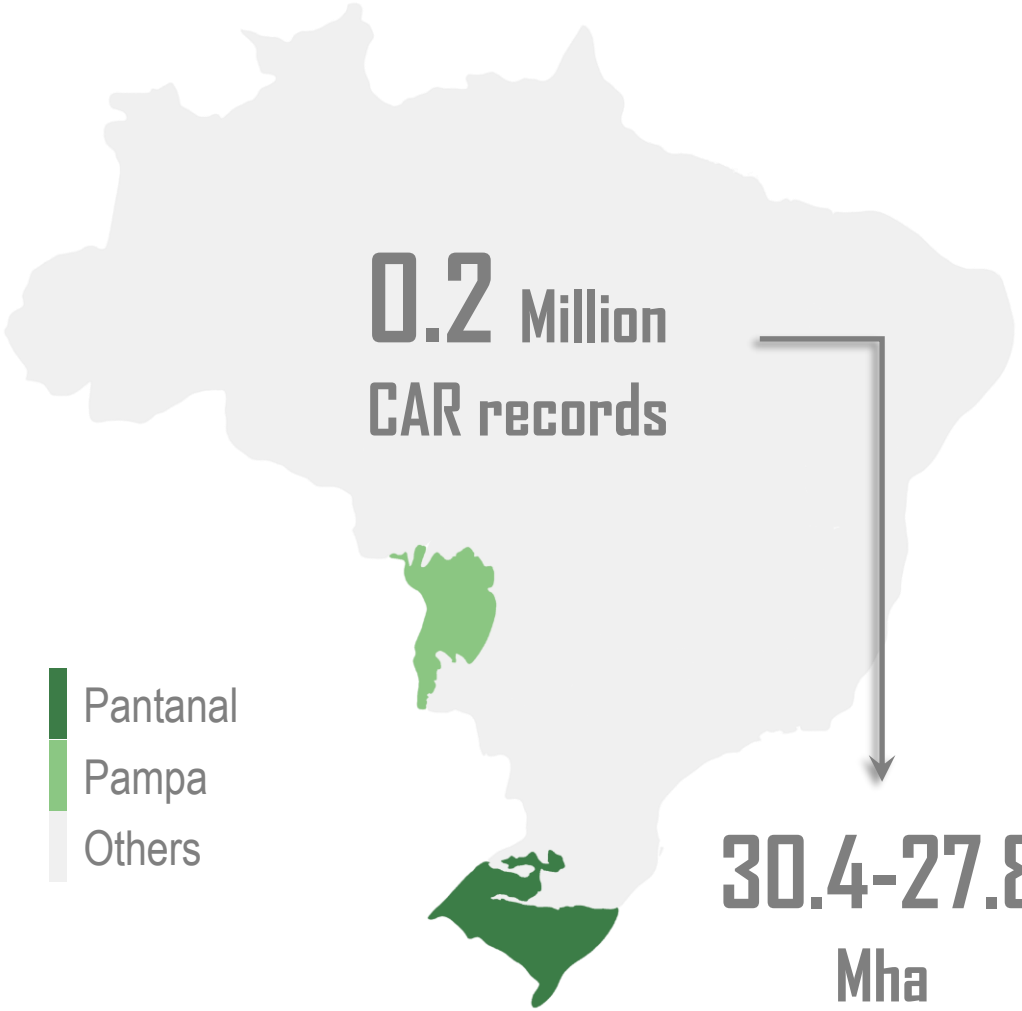
APP

0.32-0.29 Mha deficit

Deforestation after 2008 inside the CAR

2.3-2.1 Mha

The **Pantanal** forms unique ecosystems prone to floods and wildfires. Occupying parts of Mato Grosso and Mato Grosso do Sul, only 4.68% of this biome is protected by conservation units. The **Pampa** biome, where native grasslands predominate, has been largely converted for agriculture. With very little of its natural ecosystem under legal protection, it is the biome with the smallest participation in the National System of Conservation Units.



Pantanal

Legal reserve

6.0-5.3 Mha surplus | 0.05-0.04 Mha deficit

CAR records

0.01 Million | 14.3-12.6 Mha

APP

0.06-0.05 Mha deficit

Deforestation after 2008 inside the CAR

0.8-0.7 Mha

Pampa

CAR records

0.21 Million | 16.1-15.2 Mha

Legal reserve

4.9-4.6 Mha surplus | 0.23-0.22 Mha deficit

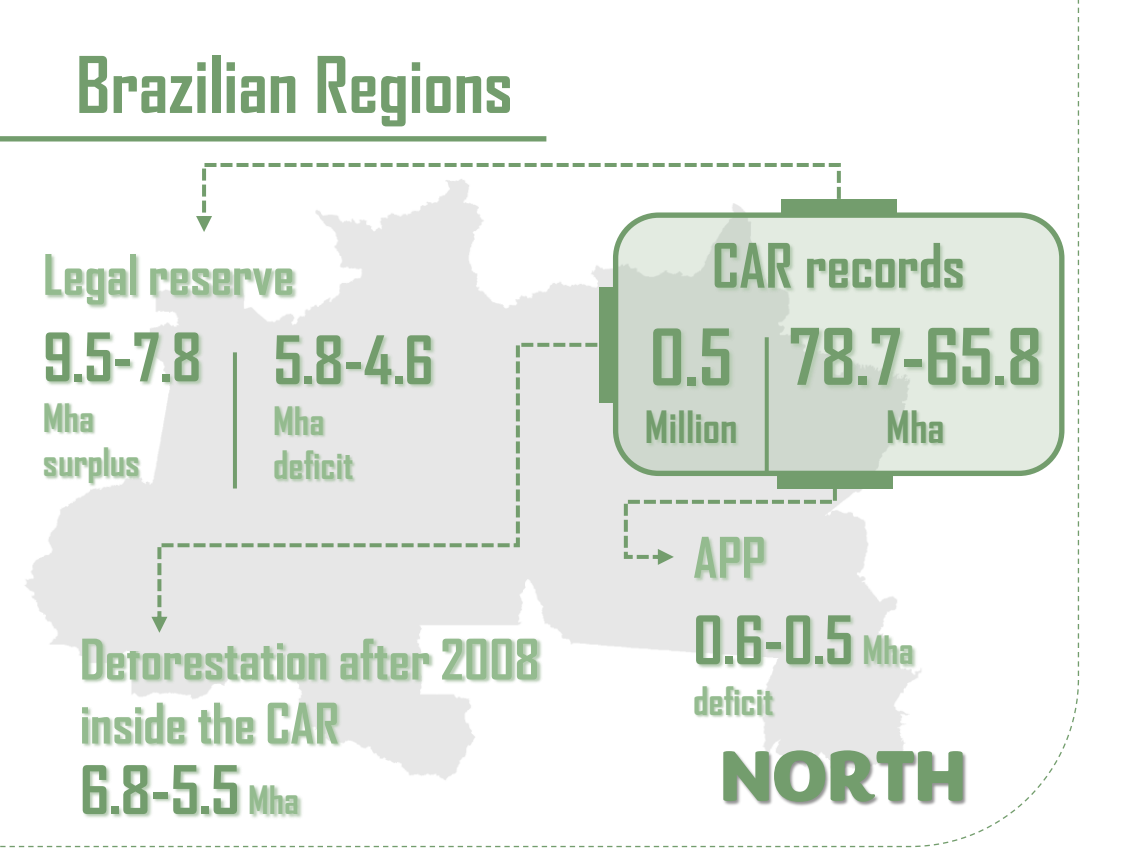
APP

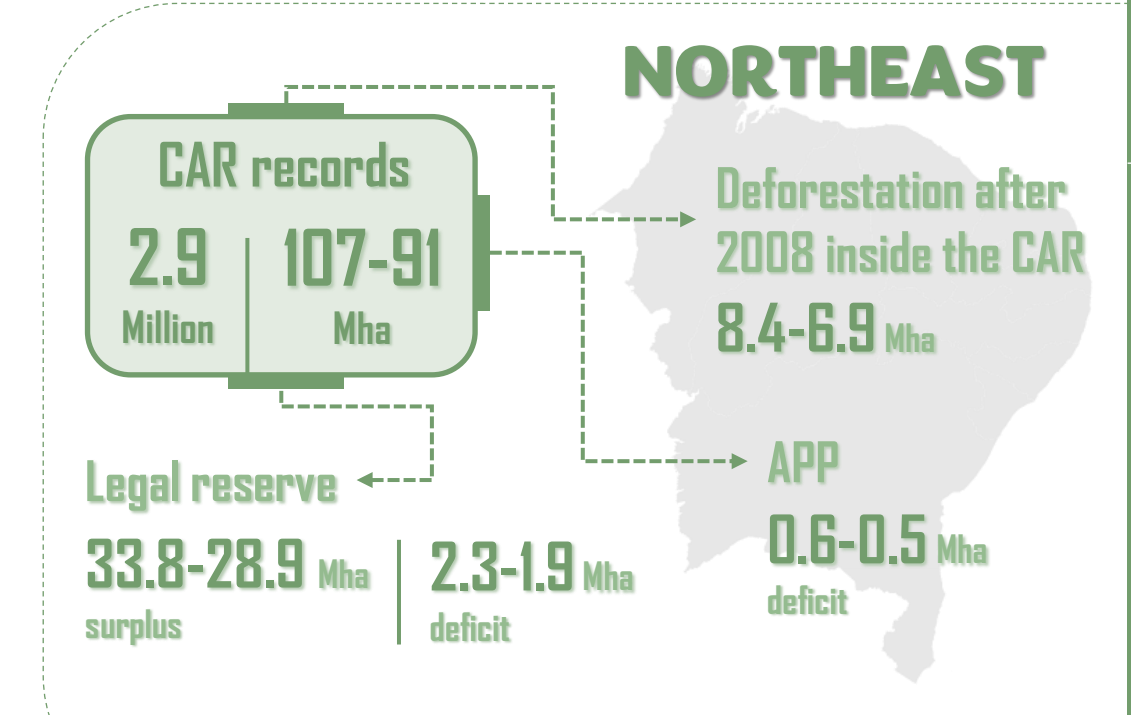
0.122-0.116 Mha deficit

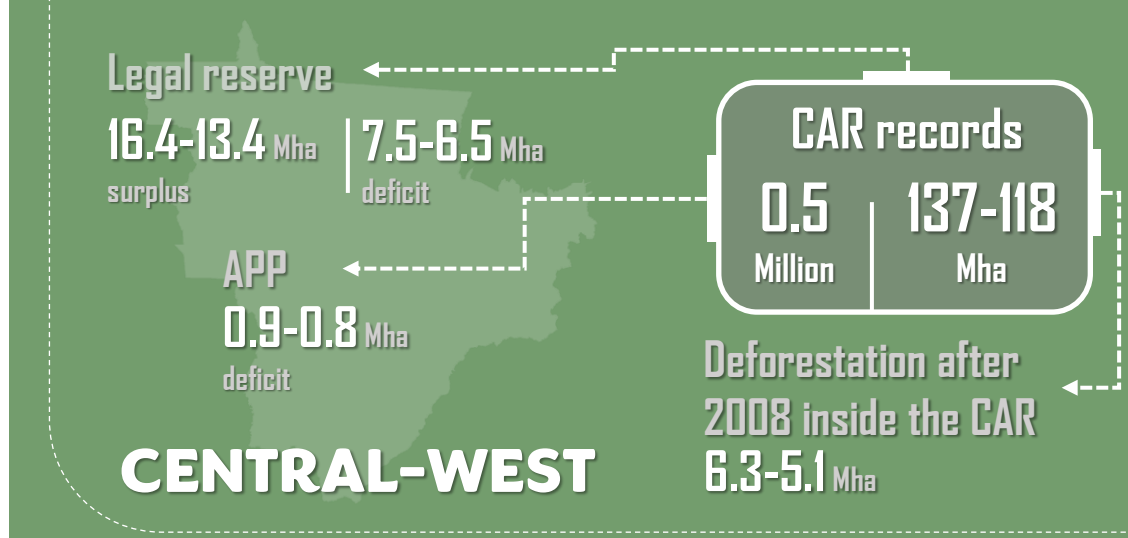
Deforestation after 2008 inside the CAR

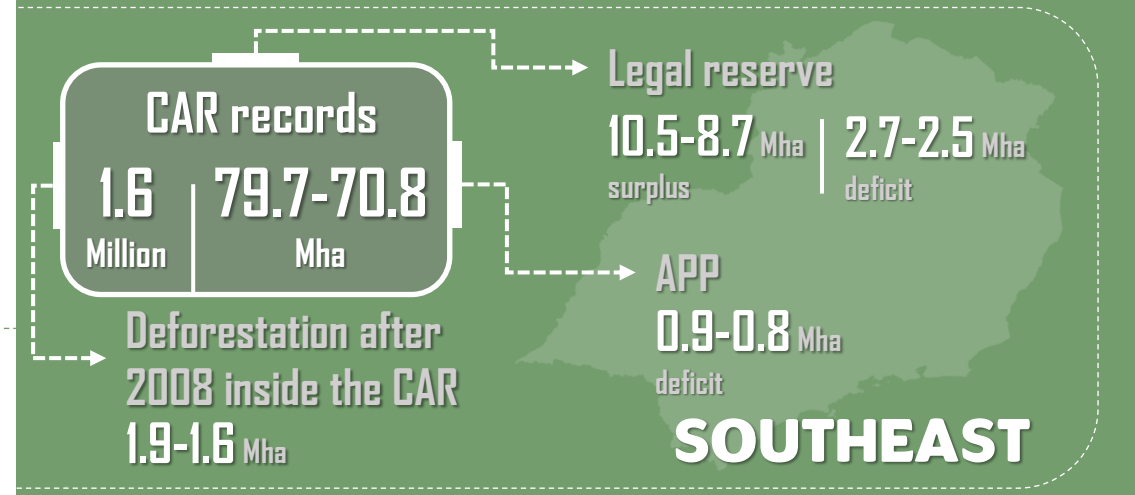
1.4-1.3 Mha

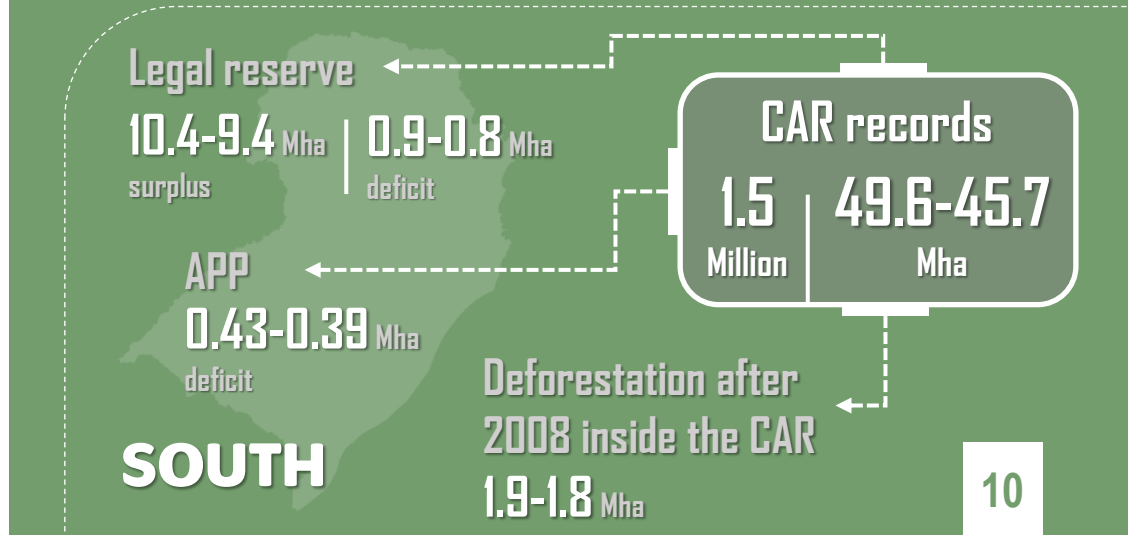
Brazilian Regions





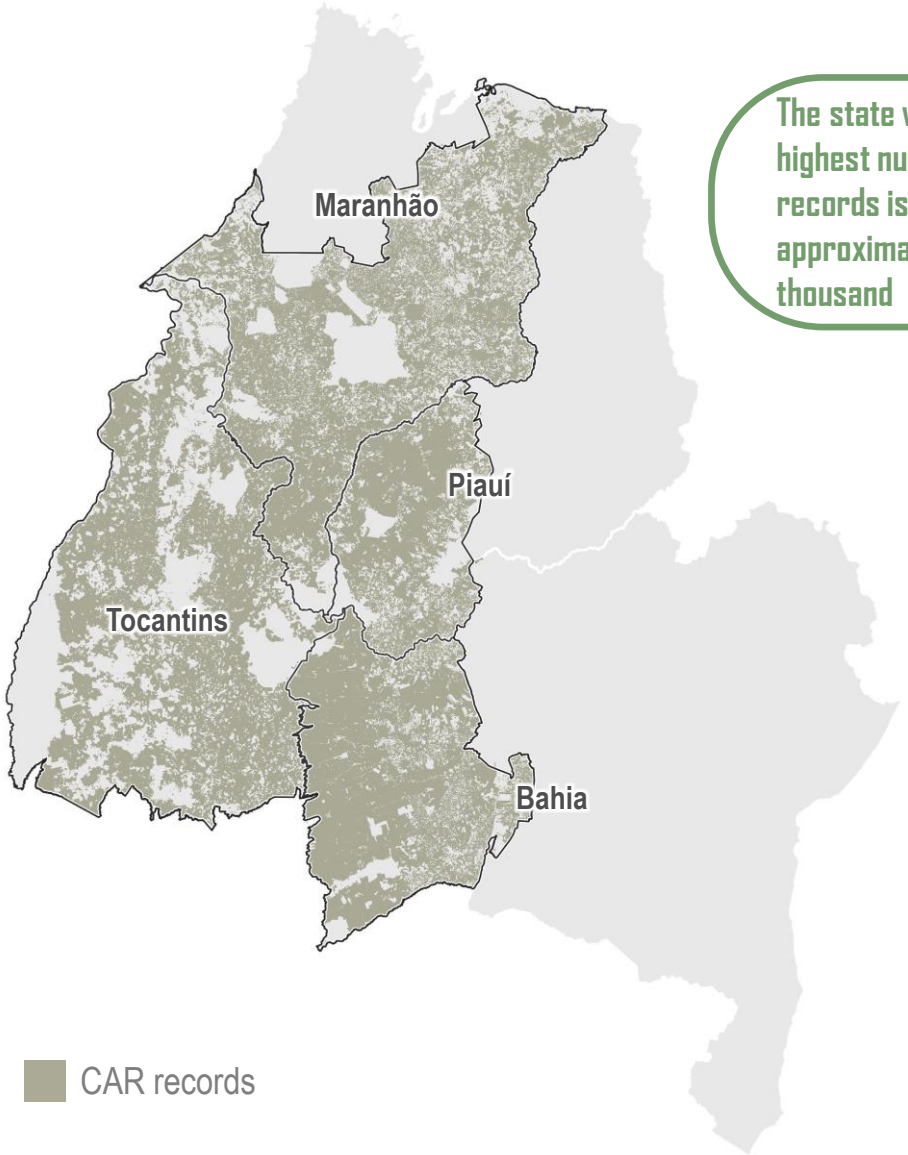




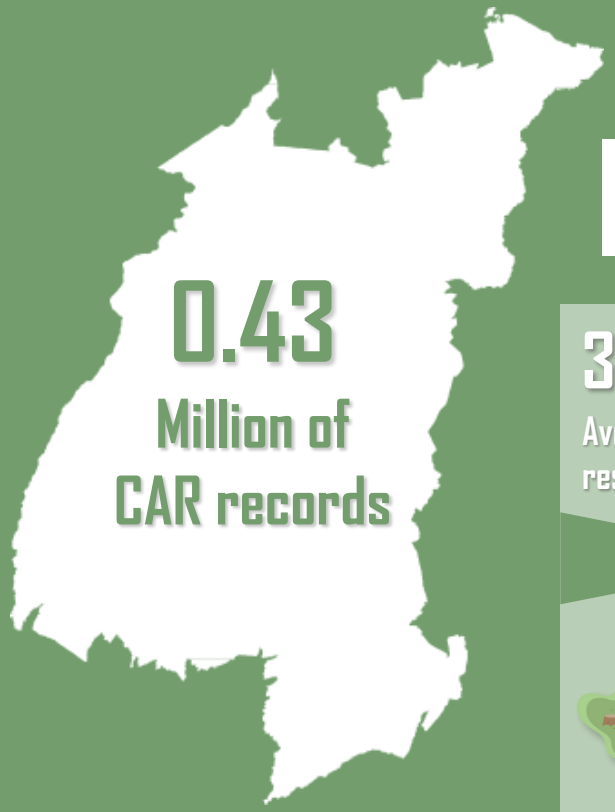


MATOPIBA

Mostly covered by the Cerrado biome, it extends through the states of Maranhão, Tocantins, Piauí, and Bahia, where agriculture began to expand in the second half of the 1980s and which today concentrates a large part of the deforestation in the Cerrado.



The state with the highest number of CAR records is Maranhão: approximately 213.5 thousand



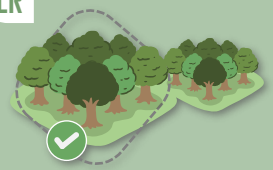
0.43
Million of CAR records

52.0-46.5 Mha

32%
Average LR to be restored inside the CAR

7.92-6.76 Mha
Deforestation after 2008 inside the CAR

LR



14.7-12.6 Mha
surplus

LR

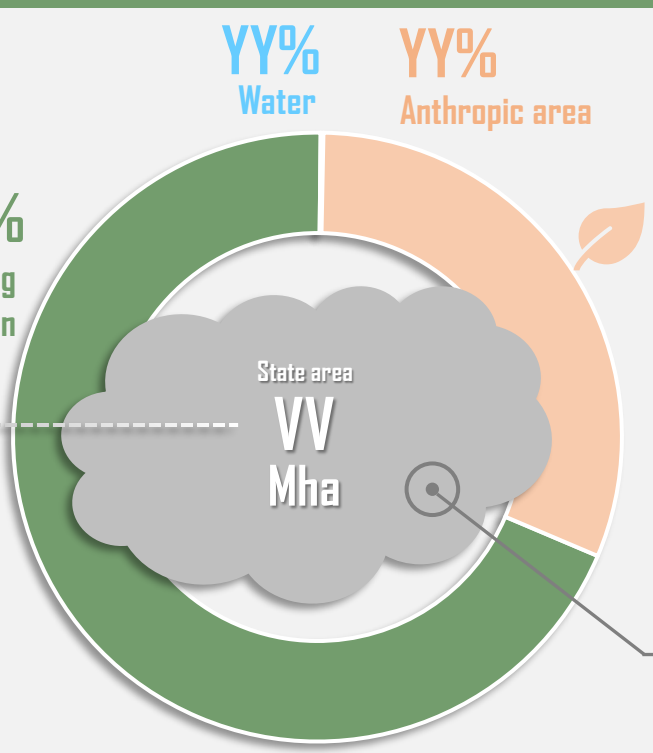
1.85-1.73 Mha
deficit

APP

0.25-0.24 Mha
deficit

Exemple

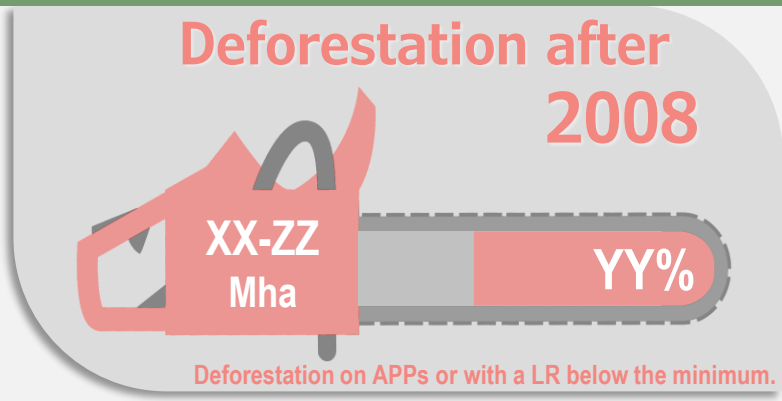
Data referring to CAR records and not the state's area



XX: **SFB** property database (with self-overlap).

ZZ: **Imaflora** property database (without self-overlap).

YY%: Always refers to the **average between the values** of the two databases.



XX CAR records

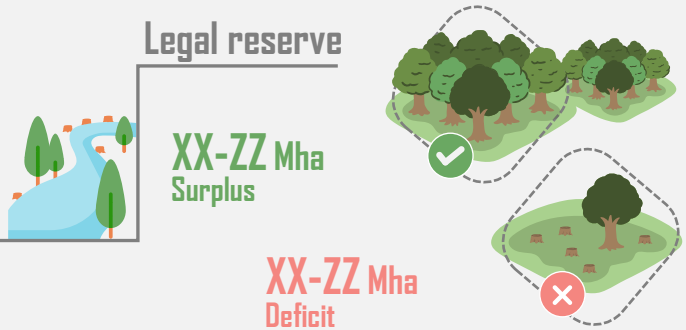
YY%

Covered area

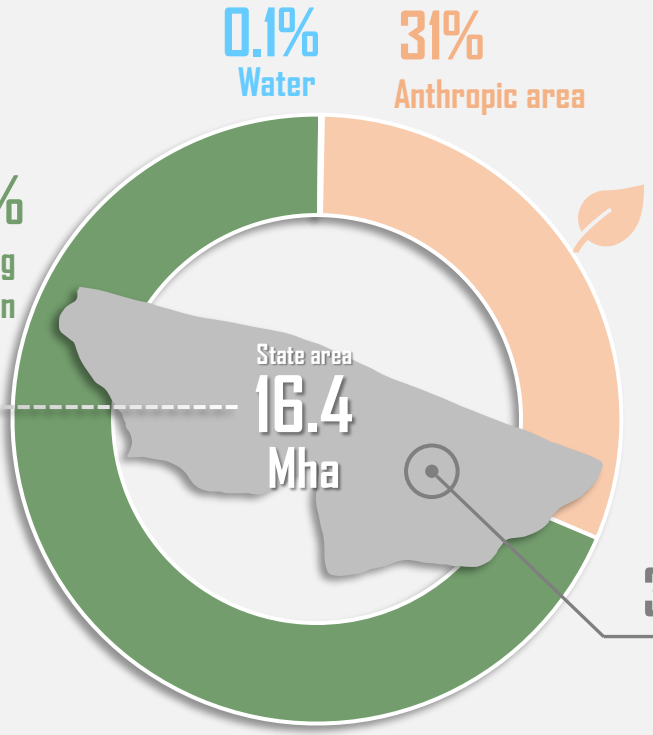
XX-ZZ Mha

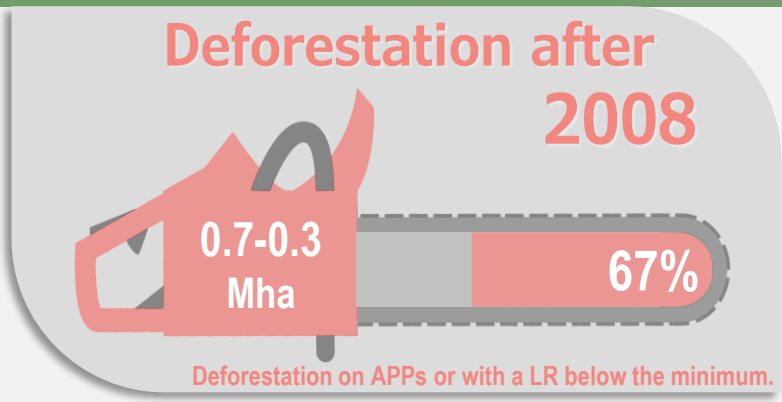
XX-ZZ kha

APP deficit



Acre





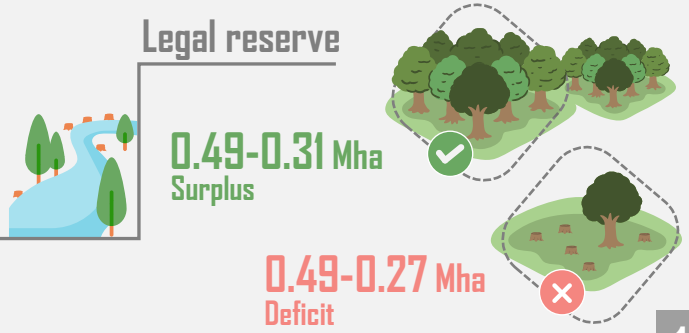
44,821 CAR records

33%

6.7-4.1 Mha

38.4-23.3 kha

APP deficit



Alagoas

121,345 CAR records

2.2-1.8 Mha

72%

0.5% Water

81% Anthropic area

19% Remaining vegetation

State area 2.8 Mha

17.3-14.4 kha

APP deficit

Deforestation after 2008

50-41 kha

32%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.18-0.15 Mha Surplus

0.09-0.08 Mha Deficit

Amapá

5,043 CAR records

1.3-0.7 Mha

7%

2.7% Water

6% Anthropic area

91% Remaining vegetation

State area 14.2 Mha

1.96-0.97 kha

APP deficit

Deforestation after 2008

51-31 kha

7%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.47-0.22 Mha Surplus

0.003-0.002 Mha Deficit

Amazonas

37,565 CAR records

11.0-9.6 Mha

7%

91% Remaining vegetation

1.9% Water

7% Anthropic area

State area 156 Mha

16.8-15.6 kha APP deficit

Legal reserve

1.75-1.53 Mha Surplus

0.28-0.23 Mha Deficit

Deforestation after 2008

0.4-0.3 Mha

64%

Deforestation on APPs or with a LR below the minimum.

Bahia

1,094,585 CAR records

33.8-32.9 Mha

59%

48% Remaining vegetation

0.3% Water

51% Anthropic area

State area 56.5 Mha

203-198 kha APP deficit

Legal reserve

10.7-10.4 Mha Surplus

0.53-0.52 Mha Deficit

Deforestation after 2008

2.3-2.2 Mha

8%

Deforestation on APPs or with a LR below the minimum.

Ceará

362,835 CAR records

10.3-8.9 Mha

1.2% Water

40% Anthropic area

59% Remaining vegetation

65%

State area 14.9 Mha

79.6-68.1 kha APP deficit

Deforestation after 2008

0.6-0.5 Mha

8%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

4.05-3.50 Mha Surplus

0.054-0.047 Mha Deficit

Distrito Federal

17,892 CAR records

0.6-0.3 Mha

0.3% Water

66% Anthropic area

34% Remaining vegetation

84%

State area 0.6 Mha

3.25-1.69 kha APP deficit

Deforestation after 2008

14-7 kha

10%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.10-0.06 Mha Surplus

0.02-0.01 Mha Deficit

Espírito Santo

113,993 CAR records

3.7-3.3 Mha

76%

22% Remaining vegetation

0.4% Water

78% Anthropic area

State area 4.6 Mha

71.7-63.5 kha APP deficit

Legal reserve

0.34-0.32 Mha Surplus

0.13-0.12 Mha Deficit

Deforestation after 2008

12-10 kha

34%

Deforestation on APPs or with a LR below the minimum.

Goiás

210,600 CAR records

31.8-28.5 Mha

89%

26% Remaining vegetation

0.4% Water

73% Anthropic area

State area 34 Mha

310-281 kha APP deficit

Legal reserve

3.58-2.78 Mha Surplus

1.07-1.00 Mha Deficit

Deforestation after 2008

1.4-1.2 Mha

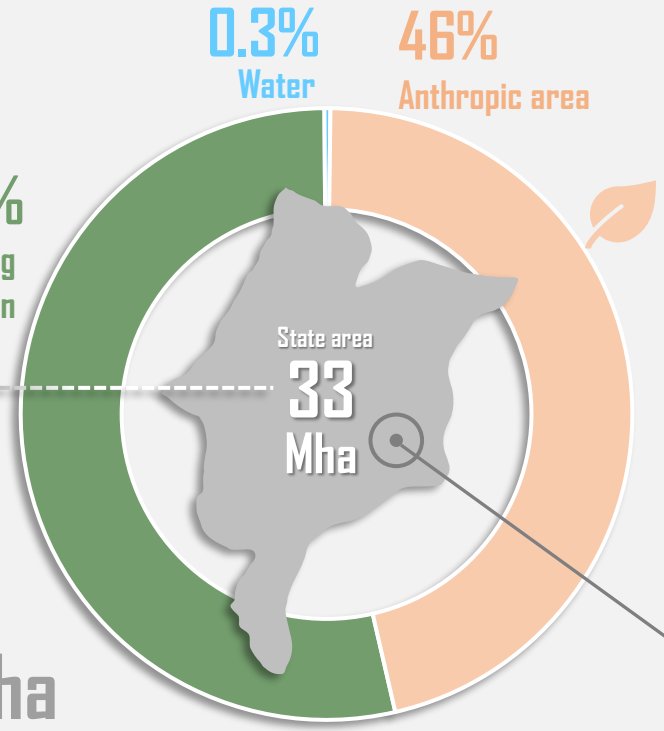
14%

Deforestation on APPs or with a LR below the minimum.

Maranhão

317,849 CAR records

25.4-18.1 Mha



112-85 kha
APP deficit

Legal reserve

5.02-3.72 Mha
Surplus

1.30-0.99 Mha
Deficit

Deforestation after 2008

2.9-2.1 Mha

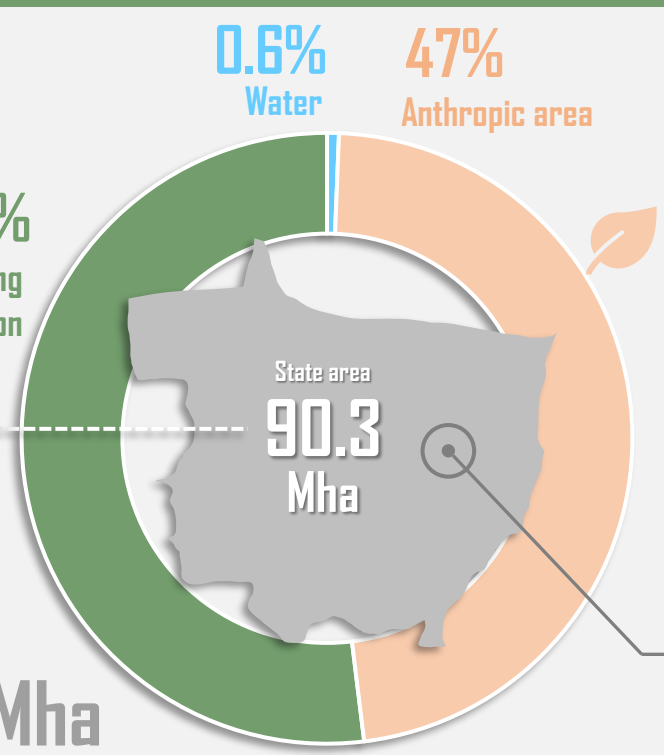
20%

Deforestation on APPs or with a LR below the minimum.

Mato Grosso

164,449 CAR records

70.5-57.6 Mha



384-314 kha
APP deficit

Legal reserve

7.35-5.54 Mha
Surplus

5.31-4.42 Mha
Deficit

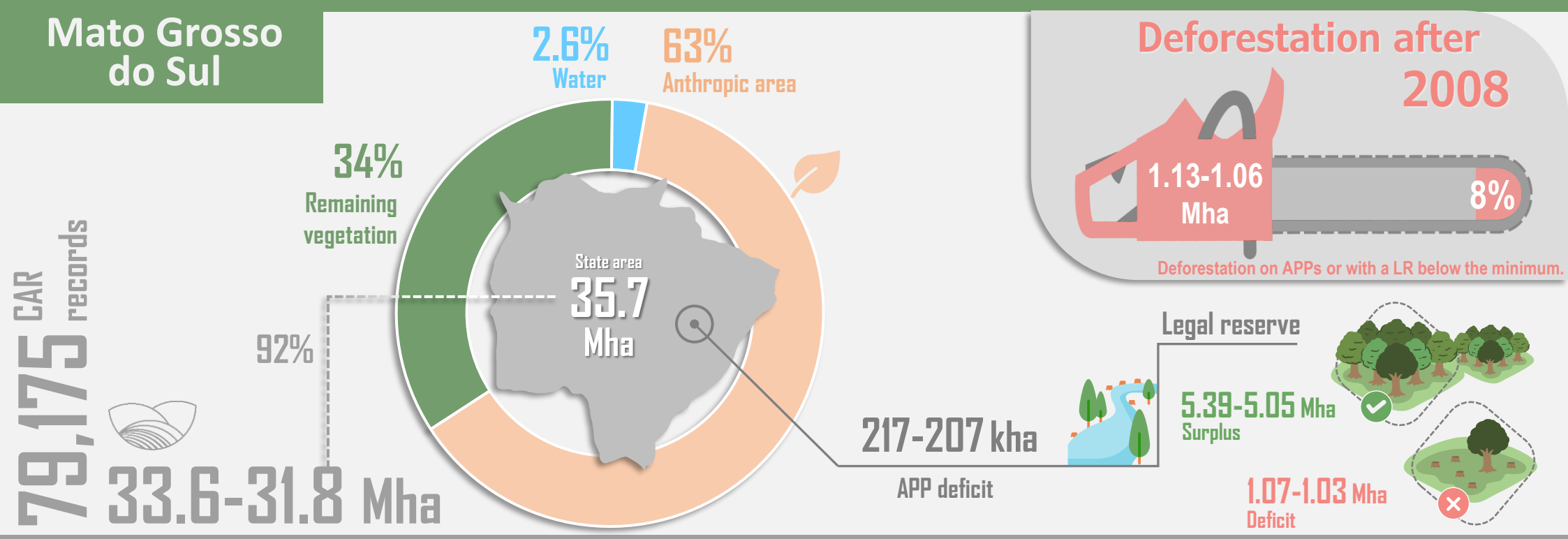
Deforestation after 2008

3.8-2.8 Mha

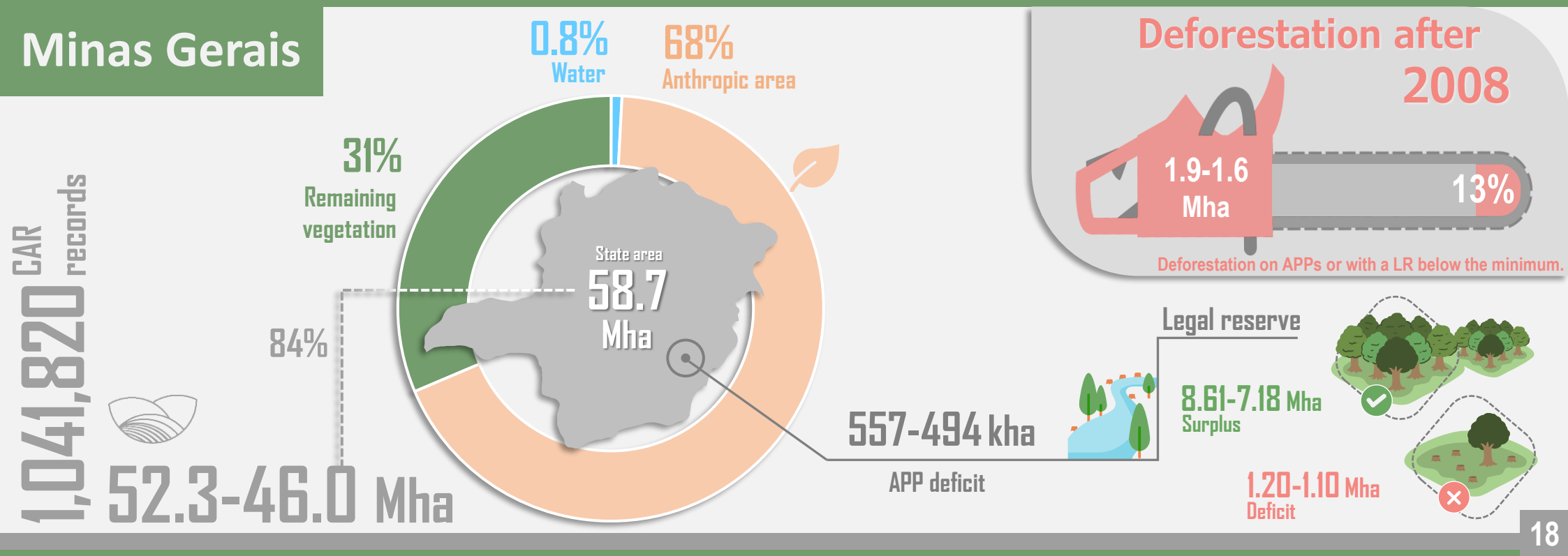
41%

Deforestation on APPs or with a LR below the minimum.

Mato Grosso do Sul



Minas Gerais

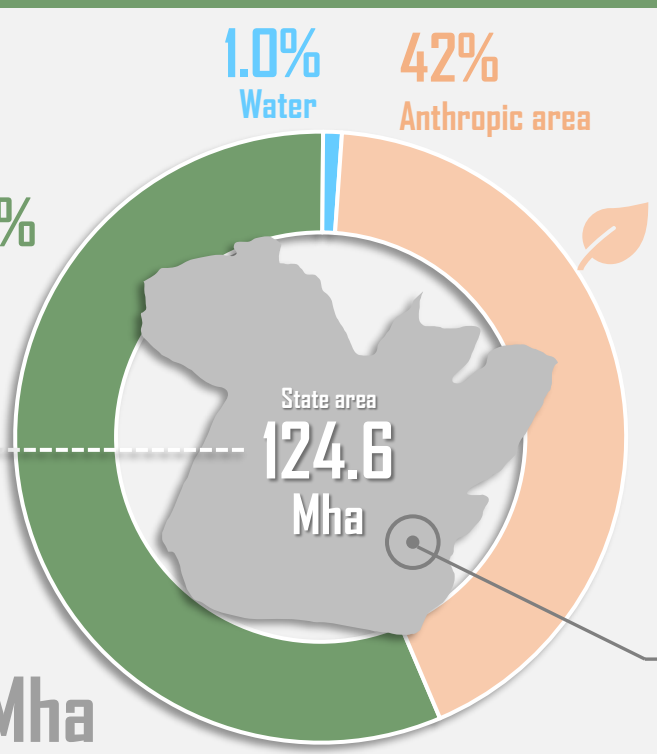


Pará

232,170 CAR records

35.7-25.5 Mha

25%



336-261 kha

APP deficit

Legal reserve

3.06-1.97 Mha
Surplus

3.32-2.50 Mha
Deficit

Deforestation after 2008

2.6-1.8 Mha

70%

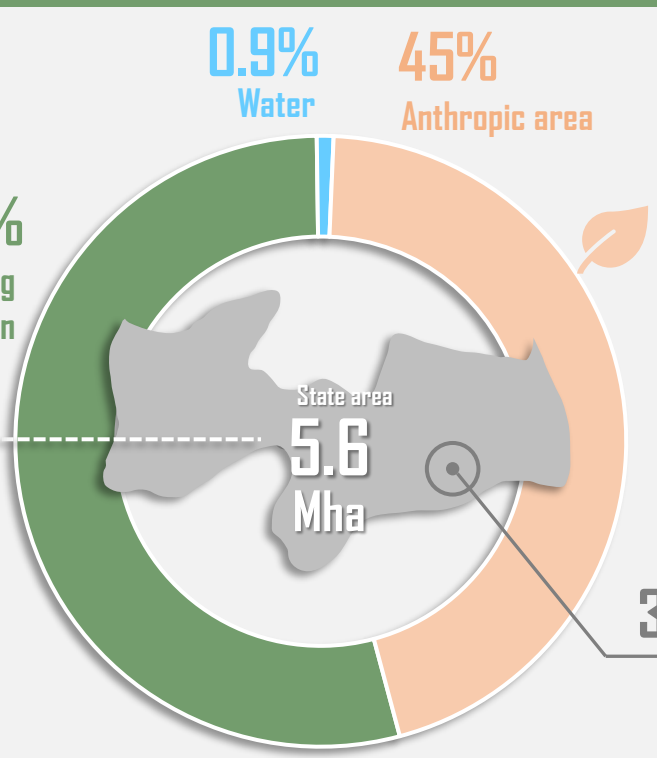
Deforestation on APPs or with a LR below the minimum.

Paraíba

185,067 CAR records

4.0-3.7 Mha

69%



33.3-30.4 kha

APP deficit

Legal reserve

1.39-1.28 Mha
Surplus

0.034-0.032 Mha
Deficit

Deforestation after 2008

0.2-0.1 Mha

13%

Deforestation on APPs or with a LR below the minimum.

Paraná

512,243 CAR records

18.2-16.4 Mha

87%

23% Remaining vegetation

1.2% Water

75% Anthropic area

State area 19.9 Mha

203-182 kha APP deficit

Legal reserve

1.96-1.57 Mha Surplus

0.57-0.54 Mha Deficit

Deforestation after 2008

0.11-0.09 Mha

12%

Deforestation on APPs or with a LR below the minimum.

Pernambuco

369,498 CAR records

6.5-5.8 Mha

63%

46% Remaining vegetation

0.5% Water

53% Anthropic area

State area 9.8 Mha

49.7-43.7 kha APP deficit

Legal reserve

1.93-1.74 Mha Surplus

0.11-0.10 Mha Deficit

Deforestation after 2008

0.3-0.2 Mha

19%

Deforestation on APPs or with a LR below the minimum.

Piauí

281,511 CAR records

0.1% Water

26% Anthropic area

74% Remaining vegetation

68%

19.2-14.8 Mha

State area 25.2 Mha

48.5-39.5 kha APP deficit

Deforestation after 2008

1.9-1.4 Mha

6%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

9.33-7.02 Mha Surplus

0.11-0.09 Mha Deficit

Rio de Janeiro

59,675 CAR records

0.6% Water

74% Anthropic area

26% Remaining vegetation

55%

2.5-2.2 Mha

State area 4.4 Mha

50.7-45.1 kha APP deficit

Deforestation after 2008

5.6-4.8 kha

25%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.33-0.28 Mha Surplus

0.09-0.08 Mha Deficit

Rio Grande do Norte

96,897 CAR records

3.6-3.2 Mha

65%

50% Remaining vegetation

2.1% Water

48% Anthropic area

State area 5.3 Mha

32.7-29.5 kha APP deficit

Legal reserve

1.10-1.00 Mha Surplus

0.04-0.03 Mha Deficit

Deforestation after 2008

0.15-0.13 Mha

15%

Deforestation on APPs or with a LR below the minimum.

Rio Grande do Sul

621,151 CAR records

23.5-22.1 Mha

85%

47% Remaining vegetation

1.4% Water

52% Anthropic area

State area 26.9 Mha

167-157 kha APP deficit

Legal reserve

6.45-6.03 Mha Surplus

0.27-0.26 Mha Deficit

Deforestation after 2008

1.65-1.55 Mha

5%

Deforestation on APPs or with a LR below the minimum.

Rondônia

115,881 CAR records

6.5-6.6 Mha

28%

25% Remaining vegetation

0.2% Water

75% Anthropic area

State area 23.8 Mha

43.9-46.1 kha APP deficit

Deforestation after 2008

0.8-0.5 Mha

86%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.07-0.09 Mha Surplus

0.88-0.70 Mha Deficit

Roraima

6,315 CAR records

1.4-2.2 Mha

8%

80% Remaining vegetation

0.8% Water

19% Anthropic area

State area 22.4 Mha

5.4-12.2 kha APP deficit

Deforestation after 2008

0.2-0.3 Mha

24%

Deforestation on APPs or with a LR below the minimum.

Legal reserve

0.36-0.44 Mha Surplus

0.02-0.07 Mha Deficit

Santa Catarina

386,242 CAR records

8.0-7.2 Mha

79%

44% Remaining vegetation

0.7% Water

56% Anthropic area

State area 9.6 Mha

61.6-56.1 kha APP deficit

Legal reserve

2.01-1.77 Mha Surplus

0.05-0.04 Mha Deficit

Deforestation after 2008

0.13-0.12 Mha

8%

Deforestation on APPs or with a LR below the minimum.

São Paulo

416,538 CAR records

21.1-19.2 Mha

81%

15% Remaining vegetation

1.3% Water

83% Anthropic area

State area 24.8 Mha

246-221 kha APP deficit

Legal reserve

1.17-0.94 Mha Surplus

1.26-1.18 Mha Deficit

Deforestation after 2008

35-31 kha

37%

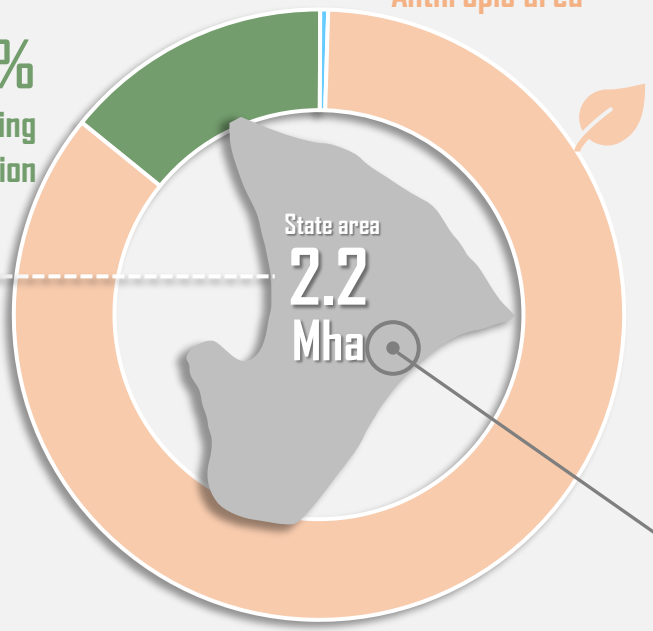
Deforestation on APPs or with a LR below the minimum.

Sergipe

103,739 CAR records

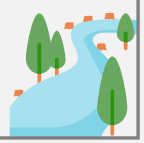
1.7-1.4 Mha

71%



14.3-11.6 kha

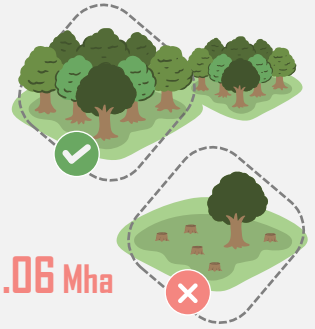
APP deficit



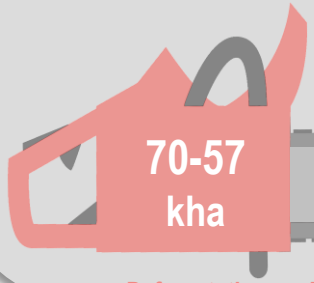
Legal reserve

0.11-0.09 Mha
Surplus

0.07-0.06 Mha
Deficit



Deforestation after 2008



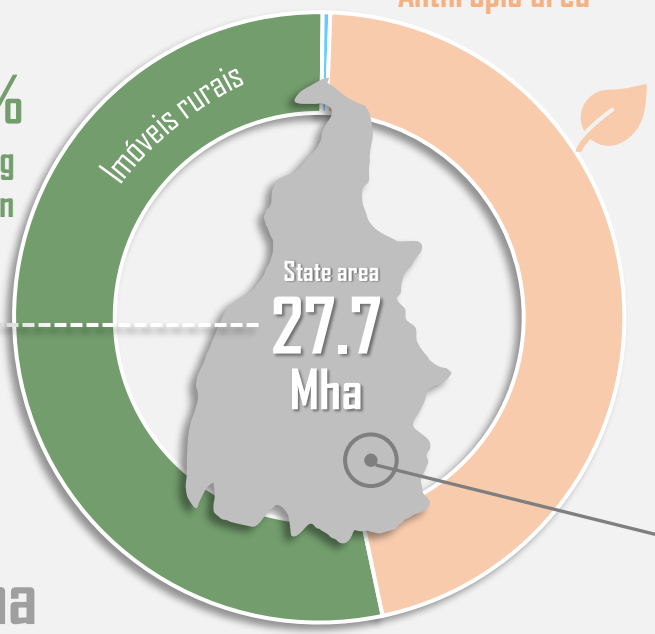
Deforestation on APPs or with a LR below the minimum.

Tocantins

72,690 CAR records

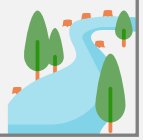
16.2-16.9 Mha

60%



126-131 kha

APP deficit



Legal reserve

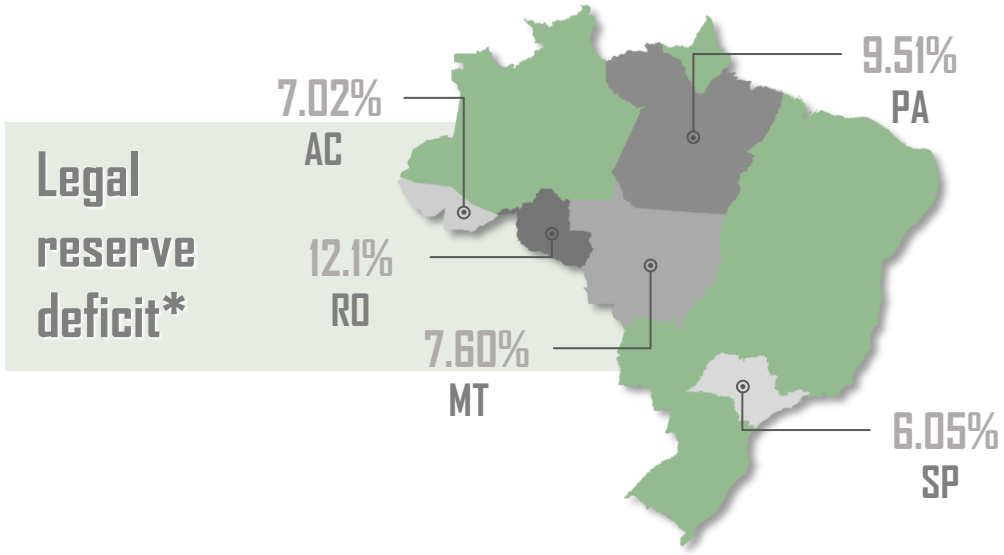
3.27-3.28 Mha
Surplus

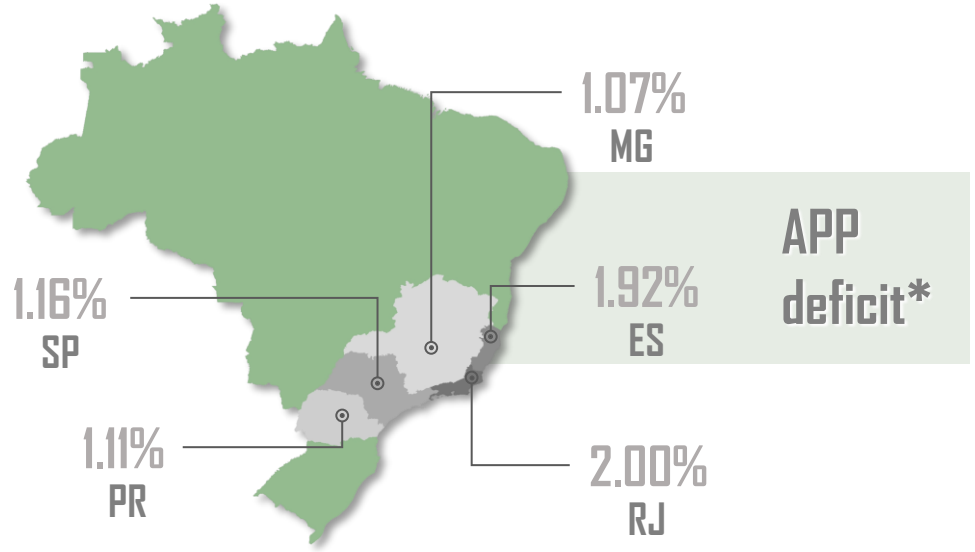
0.77-0.80 Mha
Deficit

Deforestation after 2008

Deforestation on APPs or with a LR below the minimum.

Top 5 ranking





In relation to the total area of rural properties.

Deforestation after 2008 inside the CAR

3.28 Mha	MT
2.53 Mha	MA
2.28 Mha	BA
2.18 Mha	PA
2.15 Mha	TO

Estimated deforestation in CAR records, considering the threshold of 6.25 ha.

Deforestation after 2008 in APP or with LR below the minimum*

8.43%	RO	552 kha
6.34%	AC	
4.97%	PA	
2.86%	RR	
2.31%	AM	

Deforestation after 2008 in APP or with legal reserve below the minimum required for authorization of vegetation suppression.

Methods

Data

Our study considered two rural property databases for executing the Forest Code (FC) model: the Brazilian Forest Service database (downloaded in January 2024)[18] and the processed database from the Institute of Forest and Agricultural Management and Certification (IMAFLORA)[19]. Only Rural Properties (IRU) were included from both datasets, excluding settlements (AST) and quilombola (maroon) territories (PCT). After cartographic processing of the databases, registrations overlapping conservation units (except Environmental Protection Areas – APAs and Private Natural Heritage Reserves – RPPNs), Indigenous lands, and type B public forests (here referred to as undesignated public lands - TPSD) were excluded, adhering to the Federal Prosecutor's Office protocol thresholds[20]. Additionally, registrations with canceled status were not included in either dataset. The IMAFLORA processed dataset, beyond removing IRU overlaps with INCRA settlements and quilombola (maroon) territories, also included a cleaning process to resolve overlaps among different IRU types through metric calculations and hierarchy definitions to mitigate spatial inconsistencies in the self-declared SICAR records. The data sources for protected areas are listed in the table below.

	SFB (CSR/UFMG)	Imaflora
Maroon Territories	-	INCRA (2024)
Settlements	-	INCRA (2024)
Public Forests Type B	SFB/CNFP (2022)[21]	SFB/CNFP (2020)
Indigenous Lands	FUNAI (2023)[22]	FUNAI (2024)
Conservation Units	MMA/CNUC (2023)[23]	MMA/CNUC (2024)

The model also uses input maps such as state and municipal boundaries, municipal fiscal modules, the Legal Amazon boundary, vegetation distribution, hydrography, land use, deforestation, and protected areas[7,8,22-31]. We used the IBGE (Brazilian Institute of Geography and Statistics) municipality map to assign the municipal geocode to each CAR record.

Since each Brazilian municipality has a specific fiscal module size, the geocode allows the fiscal module size to be assigned to the CAR. The FC classifies properties as small if they are 1 to 4 fiscal modules[25], medium if they are between 4 and 15 fiscal modules, and large if they are larger than 15 fiscal modules.

Public conservation units (except APAs) and homologated and regularized Indigenous lands were used to calculate the area covered by protected areas per municipality and state, and the resulting numbers were assigned to the CAR code via geocode.

The Legal Amazon boundary has been extended several times due to changes in the country's political divisions. For our model exercise, we used the IBGE-defined Legal Amazon boundary[26] to determine the percentage of Legal Reserve (LR) for restoration purposes.

The PRODES vegetation formations were used to determine the LR percentage in the Legal Amazon: 80% for forest formations and 35% for other vegetation types. Outside the Legal Amazon, the FC establishes 20% of the rural property as LR. When a property overlaps more than one vegetation type, a weighted average is applied. Specifically, in the state of Piauí, a 30% LR was applied within the Cerrado biome domain, as defined by State Law No. 5,699 of November 26, 2007[32]. The LR restoration percentage map included a 50% class representing regions eligible for LR reduction for regularization purposes under Article 13 of the FC. To identify these areas, databases on biodiversity conservation priority areas[33] and state ecological-economic zoning (ZEE) approved by the federal government were used.

To calculate APP conservation and restoration requirements, we used hydrography maps, including drainage networks, springs, and water bodies, from the National Water and Basic Sanitation Agency (ANA)[7,8]. The land use map is a mosaic composed of water bodies, remaining native vegetation, and agricultural areas ("consolidated areas") from MapBiomas (2008 dataset, collection 8.0)[27] and deforestation maps from PRODES-Brazil, PRODES-Legal Amazon, and PRODES-Cerrado[28-30]. Complementary datasets from the PRODES-Amazon biome31 were also considered, including suppression polygons smaller than 6.25 hectares and those occurring in non-forest areas. Additionally, the class of deforested areas after 2008 was filtered to remove areas smaller than 6.25 hectares before incorporating them into the land use mosaic.

The Model

Based on the CAR perimeter, we applied the rules and definitions of the Forest Code (FC)[1] for each IRU in the CAR database (SFB and Imaflora). By doing so, we provided estimates of compliance levels with the FC, i.e., deficits—areas that must be reforested at the owners' expense—or surpluses, native vegetation areas exceeding FC conservation requirements (Fig. 1).

To achieve this, we developed a set of geoprocessing tools capable of handling large datasets (Big Geodata) using PostgreSQL and PostGIS extensions, and the open-source software Dinamica EGO 7*[34]. Dinamica EGO employs intrusive parallel processing[35]. Its execution system uses a variable number of execution threads (called workers) driven by task-stealing algorithms to balance the load and increase flexibility for running tasks in parallel. In theory, all model components can run in parallel, including operators, loops and independent map tiles[36,37].

Substantial improvements in our computational capacity, including the development of modeling tools, have enabled a fine-scale reanalysis of the CF[17,10], making it feasible to estimate FC balances (compliance levels) across Brazil's territory at the rural property scale. These advances allowed us to move from a spatial resolution of 60 meters[17] to 5 meters (the minimum width of APP for restoration). All model components ran using computational resources from the Remote Sensing Center of the Federal University of Minas Gerais[38]. The model (csr.ufmg.br/radiografia_do_car) can be inspected and replicated via Dinamica EGO's graphical interface, ensuring an open, transparent, and accessible methodology.

To calculate the forest balance (deficit and surplus), the model first calculates the total area of each IRU where the law applies. The model then generates minimum-width buffers for APP required for both conservation and restoration along rivers, around springs and water bodies (Fig. 1). To define buffer sizes, the model uses the IRU size (defined by the number of fiscal modules specified for each municipality) and river width. For riparian APP restoration buffers, the model applies a series of rules known as the “escadinha”, based on property size (defined by number or fiscal module as specified for each municipality) and river width.

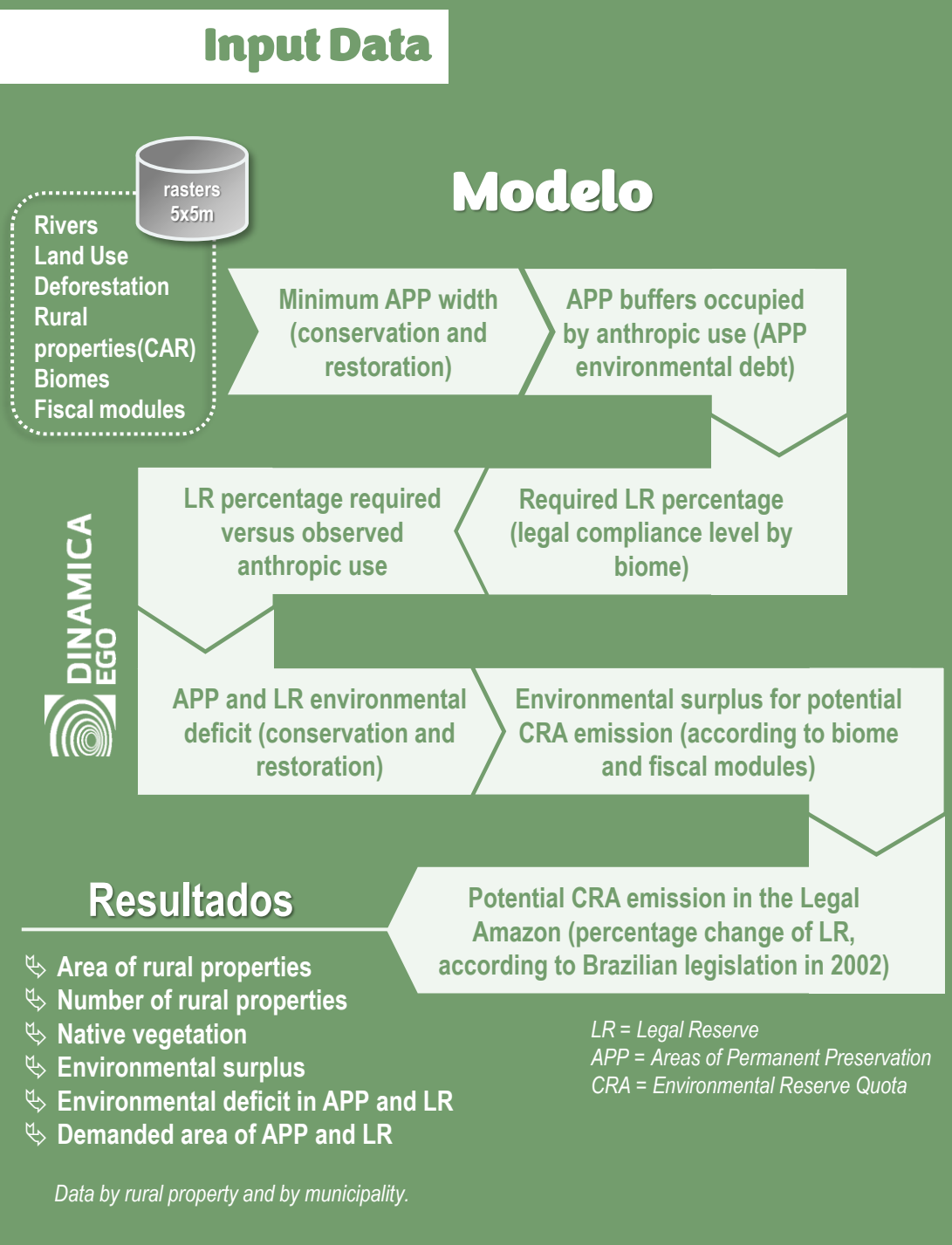


Fig. 1: Flowchart of the Forest Code compliance analysis model indicating main input data, calculations and results.

Next, the model applies FC rules according to property size to define LR requirements. In the Amazon biome, we considered increasing the LR size from 50% to 80%, as established by Provisional Measure 1,511 of 1996 and 2,166-67 of 2001 for conservation purposes. However, article 68 of the FC establishes that landowners who cleared native vegetation in compliance with previous legislation are not required to restore LR to the current legal percentage (i.e., 80%). This resolved conflicting prior legislation to legalize "properties pushed into illegal status." Additionally, the FC allows LR restoration percentages to be reduced by up to 50% in municipalities where over 50% of the territory is occupied by conservation units or Indigenous reserves (Art. 12, II - §4) and specifies a maximum percentage of the property for APP restoration (Art. 61-B), depending on the total riparian APP (Art. 15). The FC also establishes that LR restoration percentages can be reduced to 50% in consolidated zones within Legal Amazon states with approved Ecological-Economic Zoning (ZEE). Finally, the law exempts smallholders (up to 4 fiscal modules) from restoring LR deficits (Art. 67).

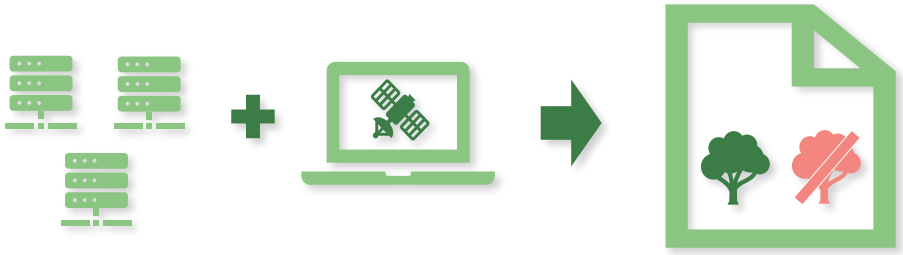
The difference in LR definition by Article 68 of the FC is why we separate deforestation before and after 2002. Deforestation before and after this date must be analyzed under different LR size specifications. Furthermore, the deforestation occurrence date is also evidence for applying article 68 of the 2012 FC, as specified in paragraph 1:

"Owners or possessors of rural properties may prove these consolidated situations through documents such as historical descriptions of regional occupation, marketing records, agricultural data, contracts, and banking documents related to production, and by all other means of evidence admitted by law"[1].

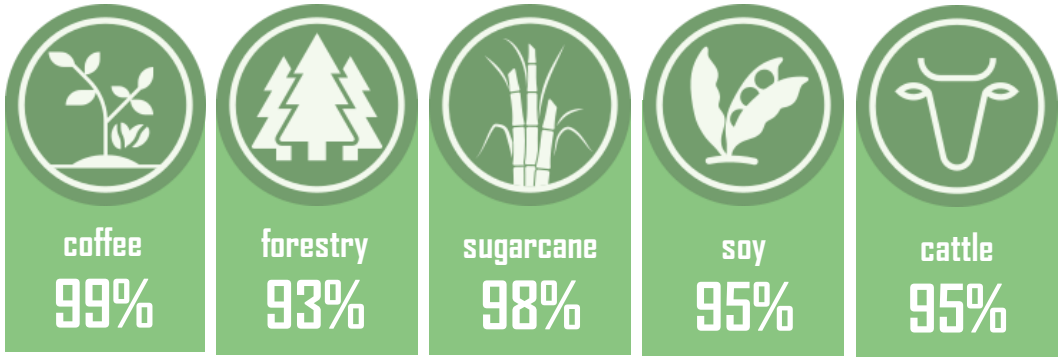
The primary sequence to obtain the FC balance is shown in figure 1. For each IRU, the model subtracts the total LR area required from the remaining native vegetation within each private property and from native vegetation within APP buffers to determine compliance levels. Positive results indicate environmental surplus, while negative results indicate environmental deficits. Legal reserves declared outside rural properties were not evaluated. Uncertainties in FC estimates arise from property overlaps, differing drainage databases, and the accuracy and cartographic scale of land-use mappings.

The SeloVerde platform

For traceability and verification of the environmental compliance of agricultural commodity suppliers, the results of the FC balance for rural properties are integrated with deforestation maps[28-31], land-use maps from the Mappia project and crops (MapBiomas, collection 8)[27,39-41], environmental enforcement records (e.g., embargoes), authorizations for native vegetation suppression, and other relevant federal and state data to ensure transparency in supply chains. These analyses enable the identification of deforestation, further distinguishing between legal and illegal deforestation (without native vegetation suppression authorization). Currently, three states — Pará, Minas Gerais and Maranhão — use the technologies provided by the platform, and other versions are under development for additional states.

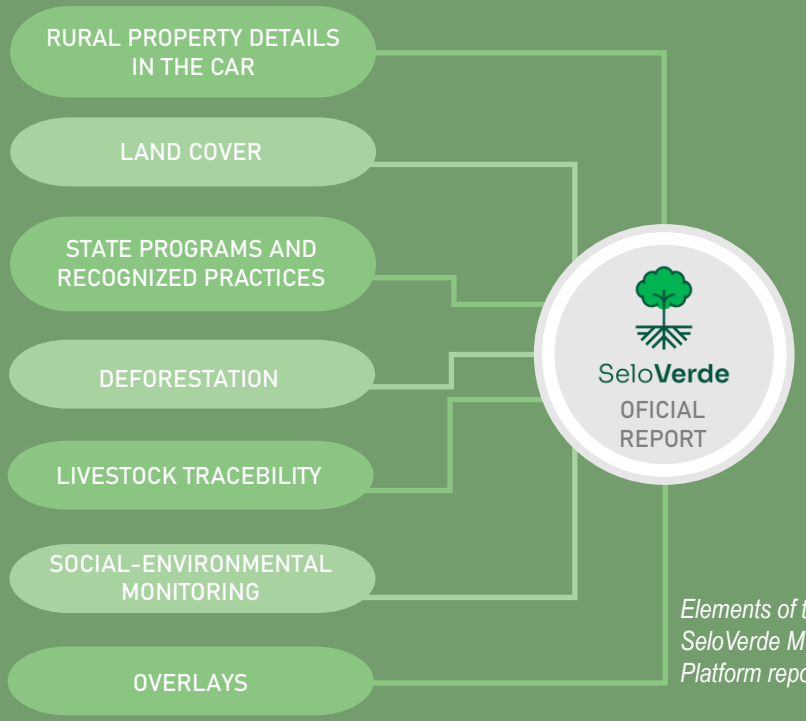


Analyses using SeloVerde indicate, for example, that agricultural products from Minas Gerais show a high level of compliance with the Forest Code. Transparently, SeloVerde demonstrates that the five currently monitored commodities can be considered deforestation-free or low-risk according to international regulations (e.g., European Union and United Kingdom).



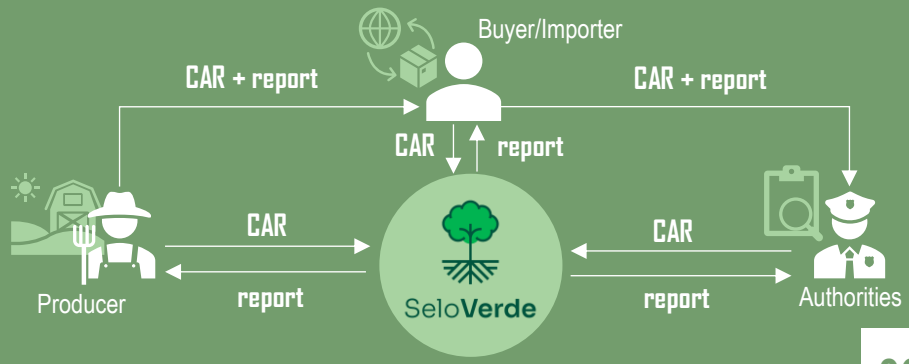
Compliance level (no evidence of deforestation)

Through the SeloVerde platform, any user can access and download an official report with indicators of the socio-environmental compliance level of a rural property and its production, as well as a property map that, in the online version, is interactive. To do so, users simply enter the CAR code of the record on the SeloVerde PA or SeloVerde MG platform website.



Elements of the SeloVerde MG Platform report

Being public and free, the platform can be easily used for due diligence in available commodity supply chains: cattle and soy in Pará; coffee, forestry, sugarcane, soy, and cattle in Minas Gerais.

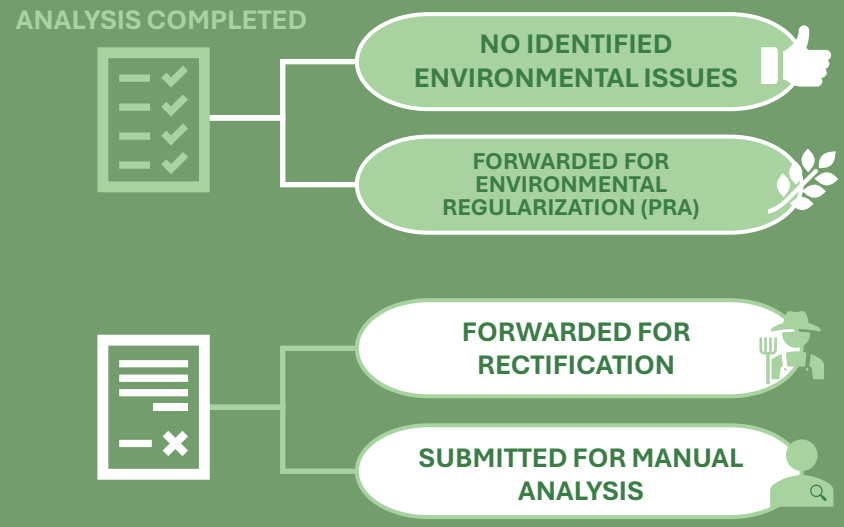


CAR 2.0

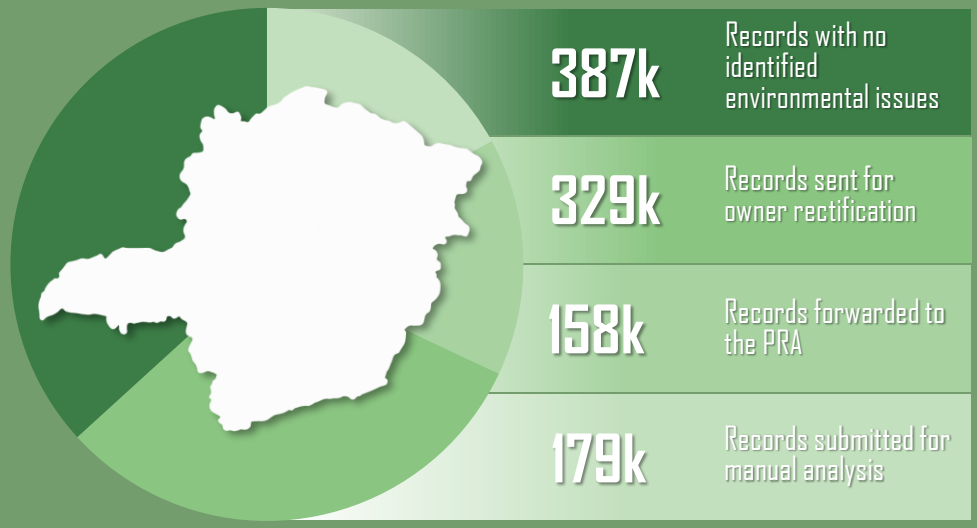
The CAR 2.0 system, in turn, uses spatially explicit models based on high-resolution land-use mapping to support CAR analysis and validation. It is a tool designed to automatically analyze all rural properties registered in a territory and monitor compliance with legislation, identifying potential impediments or environmental liabilities to be addressed by landowners or occupants.

Producers whose automatic analyses are completed (with no environmental impediments or with LR surpluses) can also use the results to apply for reduced interest rates in rural credit, in accordance with the Plano Safra. This territorial intelligence solution has already been implemented in two states, Pará and Minas Gerais, and is under development for other states in Brazil.

The automatic analysis allows authorities to prioritize CAR records with potential socio-environmental irregularities, promptly identifying necessary solutions for registry regularization.



With CAR 2.0, the number of registrations with completed analysis in Minas Gerais increased from 0.02% to 36.78%. As a result, approximately 387,000 rural properties are now eligible for economic benefits due to their environmental compliance.



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Panorama of Brazil's Forest Code

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