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Illegal Deforestation in Mato Grosso: How Loopholes in Implementing Brazil's Forest Code Endanger the Soy Sector

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Abstract: Brazil's Forest Code (FC) is a landmark law that, despite dating back to the 1930s, has low compliance. Illegal deforestation continues, and millions of hectares that were set to be reforested remain degraded. Although sector agreements such as the Amazon Soy Moratorium (ASM) have been important in the fight against deforestation, the implementation of the FC represents the key long-term strategy to halt deforestation in the soy supply chain. Here, we used datasets of the boundaries of rural properties, deforestation permits, environmental licensing, and land cover in Mato Grosso to quantify illegal deforestation and analyzed compliance with the Forest Code (FC) on soy farms to explore how loopholes in the implementation of the FC allow deforestation to continue unabated. Our analyses show that between August 2009 and July 2019, soy farms in Mato Grosso State, the largest Brazilian soy producer, were responsible for 15% (or 468.1 thousand hectares) of all land cleared in registered properties. Half of this deforestation was illegal. The FC implementation within these properties has been slow: only 11% of registered soy farms have made it to the final stage of the registration process, thus being considered fully compliant. This novel analysis reinforces that accelerating the implementation of the FC could significantly reduce deforestation and advance the restoration of illegally cleared land particularly in the Cerrado, where 50% of the original cover has already been lost, as well as in the Amazon. By achieving full compliance in the soy sector, Brazil's position in the international market would be strengthened as a supplier of sustainably produced, deforestation-free commodities.

Keywords: deforestation; Forest Code; soybeans supply chains; Mato Grosso

Citation: Carvalho, R.; Rausch, L.; Gibbs, H.K.; Bastos Lima, M.G.; Bernasconi, P.; Valdiones, A.P.; Vasconcelos, A.; Silgueiro, V. Illegal Deforestation in Mato Grosso: How Loopholes in Implementing Brazil's Forest Code Endanger the Soy Sector. *Land* **2024**, *13*, 1828. https://doi.org/10.3390/land13111828

Academic Editor: Hossein Azadi

Received: 3 October 2024
Revised: 21 October 2024
Accepted: 23 October 2024
Published: 4 November 2024

1. Introduction

Ten percent of all native vegetation lost in South America between 2000 and 2020 resulted from the expansion of soy cropland over natural ecosystems, making soy the continent's second-leading cause of deforestation after cattle ranching. During this period, approximately 3.4 million hectares (Mha) of native vegetation were directly converted for soy cultivation, with another 2.9 Mha being indirectly converted—firstly becoming pasture and, typically within three years of clearing, being turned into soy [1]. Indeed, the role of soy in deforestation is likely even greater when the full effects of displacement and indirect land-use change are considered [2,3]. In the Brazilian Amazon, the presence of pastures was nearly as significant as the existence of neighboring soybean areas in driving the expansion of this crop, and a 10% reduction in soy expansion over old pastures could have resulted in 40% less deforestation [2,3]. In Mato Grosso, from 2005 to 2009, 91% of new soybean areas replaced pastures—a land market strategy to capitalize on the high opportunity costs of renting land for cropping and overcome soil degradation of poorly managed pastures when capital and knowledge were lacking [3,4].

In Brazil, the world's largest soy producer and exporter, the cultivated area has more than tripled in the past two decades, expanding from 11 Mha in 2000 to 35.5 Mha in 2020 [1]. Mato Grosso State, which holds one-third of the country's soy cropland, has experienced both the well-documented rapid deforestation in the Amazon biome and alarming levels of the disappearance of the Cerrado, a biodiversity hotspot that also plays vital functions in underground carbon storage, the hydrological cycle, and local livelihoods [5,6].

Brazil's Forest Code (FC) was designed to regulate land use on private properties, specifying rules for registering, licensing, and ensuring compliance regarding the conservation and use of native vegetation [7]. Under the FC, landowners must register property boundaries in the Rural Environmental Registry (Cadastro Ambiental Rural—SIMCAR), preserve 20% to 80% of the native vegetation depending on the region, obtain licenses for deforestation, and restore areas that were illegally deforested. However, more than a decade after its latest revision in 2012, compliance with the FC remains low, partly due to significant implementation gaps in key components.

The soy sector in Mato Grosso State is a powerful illustration of some key shortcomings in the FC implementation. Illegal clearing remains high, with up to 90% of deforestation in the Amazon and Cerrado biomes being illegal [8]. Many illegally deforested areas must be replanted for properties to comply with the FC. In the Amazon, most areas cleared beyond the limits established in the FC date from before 2008 and, as such, are not subject to requirements for replanting but will need to be compensated through other mechanisms for the property to achieve full compliance. Amid this complex legal backdrop, soy (and cattle) producers are also subject to zero-deforestation agreements, such as the Amazon Soy Moratorium (ASM), which impose additional land-use restrictions beyond the FC, though their effects have had mixed success [9–14].

Here, we introduce background on the FC and the sector policies governing land use in the soy sector. Then, we use datasets of the boundaries of rural properties, deforestation permits, environmental licensing, and land cover in Mato Grosso to quantify illegal deforestation and analyze compliance with the Forest Code (FC) on soy farms. Then, we explore how loopholes in FC implementation allow deforestation to continue unabated on soy farms. Our results highlight the ongoing illegal deforestation of soy properties that is often overlooked because of the reported success of the ASM [11] in eliminating the use of deforestation to create new soy fields. The ASM remains crucial to maintaining the sector's commitment to fighting deforestation. However, only accelerating the FC implementation can lead to a sustained reduction in deforestation and advance the urgent restoration of illegally cleared areas not only in the Amazon and Cerrado, where 50% of the original vegetation cover has already been lost.

2. Brazil's Forest Code: Historical Background

Designed to protect forests and foster the sustainable use of land and natural resources, the Forest Code (FC) regulates the suppression of native vegetation, aiming at the appropriate management of land resources inside private properties. In this section, we explore the historical background and key events related to the FC to illustrate the complexity of this critical environmental regulation from its first declaration until its latest version, approved in 2012 (Figure 1).

First declared in 1934 and revised in 1965, 1989, 1996, and 2012, Brazil's Forest Code (FC) is a landmark in Brazilian environmental legislation [7,15–19]. At the core of this framework is the idea that limiting changes in land cover within private properties is necessary to protect forests and other natural environments and provide environmental services such as water, soil fertility, and forest resources. However, it was not until 1995, after the obligation of Legal Reserves in the Legal Amazon went from 50% to 80% of the property and the concept of Permanent Protected Areas was expanded, that the robustness of the FC impacts began to be felt [15].

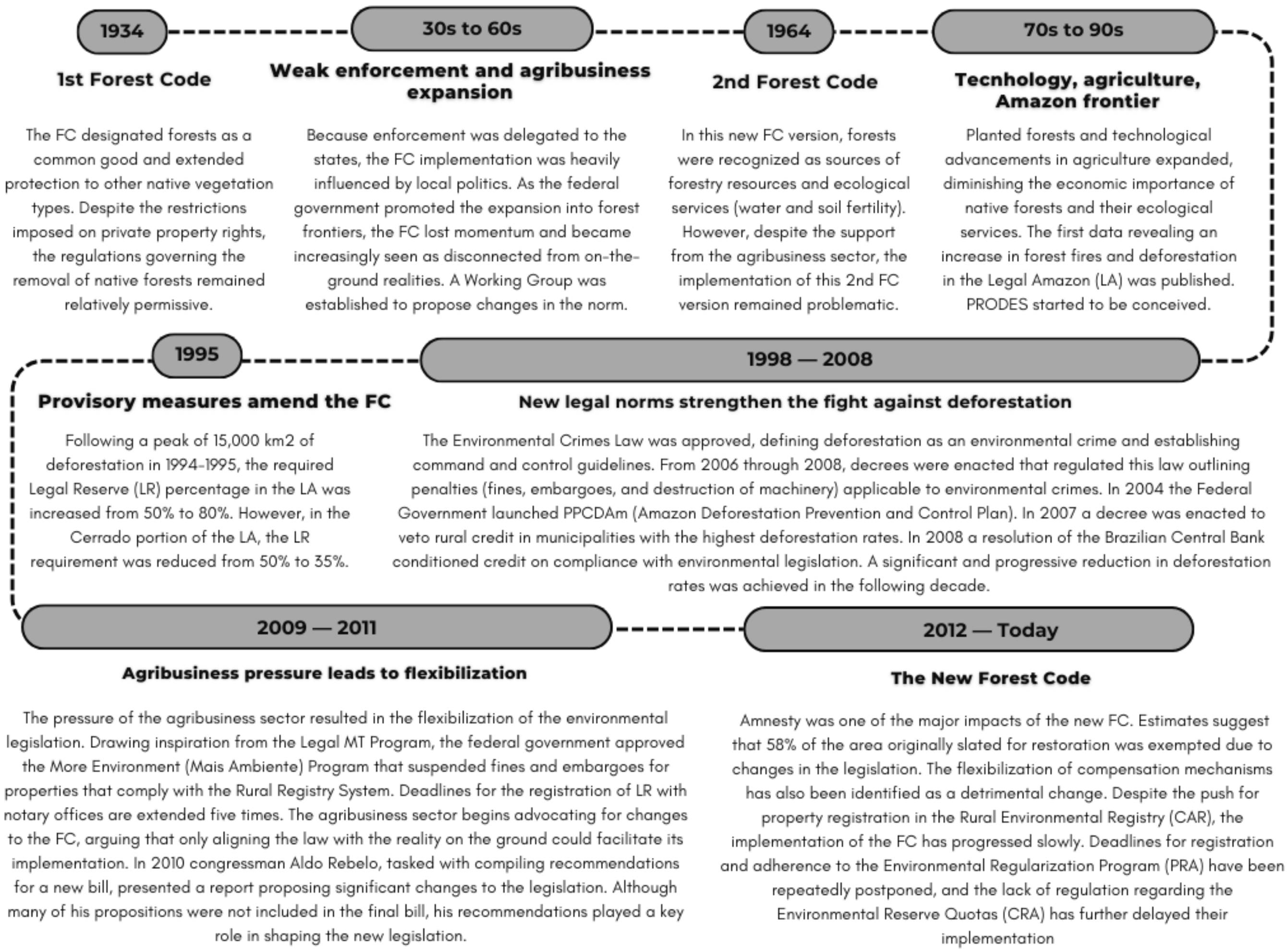

Figure 1. Major events and changes that marked the history of the Forest Code from 1934 until its latest version, approved in 2012.

In the 1960s, state efforts including research, subsidized credit, and investments in machinery and infrastructure deeply modernized Brazilian agriculture [5–7]. These transformed the Cerrado, and more recently, the Amazon biomes, from pristine areas into agriculturally productive lands, resulting in progressively increased deforestation rates in these biomes [20]. By the end of the 1990s, the Amazon's increasing deforestation and fires were already alarming [21,22]. As soy crops and cattle ranching started to be pointed out as causes of forest loss, the alleged success of Brazilian agribusiness expansion began to be questioned [23–25].

In 1995, a 15 thousand km^2 peak of deforestation motivated the enactment of a Provisory Measure that increased the Legal Reserve percentage from 50% to 80% in rural properties in the Legal Amazon (LA) (meanwhile, for properties in the Cerrado portion of the Legal Amazon, the Legal Reserve requirement was reduced from 50% to 35%). Additionally, approving the Environmental Crimes Law (1998), which criminalized deforestation, and Decree 6.321/2007, which vetoed credit to properties in municipalities with high deforestation, put extra pressure on offenders. In 2004, following the highest level of deforestation ever recorded (27.7 km^2), the federal government conceived the Amazon Deforestation Prevention and Control Plan (PPCDAm). Although conceived to broadly tackle deforestation through land and territorial planning to foster sustainable land use and forestry and procure investments in infrastructure (energy and transportation), the primary focus of the PPCDAm was to monitor and command and control. This included the implementation of the Rural Registering System (CAR) as a tool to support monitoring and planning of land use inside private properties [26,27]. In this scenario, the protection of forests became a top priority and a contentious matter in the political agenda [3,24,26,27].

In parallel, the soybean industry agreed in 2005 to sign the Amazon Soy Moratorium (ASM). The ASM, a voluntary sector agreement, brought together trading companies responsible for more than 90% of the soybeans traded in the country to agree not to purchase soy cultivated on lands deforested after July 2006 in the Brazilian Amazon [9,12,28–32]. Initially set to be renewed annually, the ASM was converted in 2015 into a permanent commitment by the soybean industry, which has been celebrated as the most innovative and successful zero-deforestation private sector initiative put in place so far.

Notwithstanding its relevance to maintaining the private sector engaged in a conservation agenda, the ASM's impact on reducing deforestation has been the subject of some debate, especially when indirect conversion is considered [3,4,6]. Other studies have noted that in the two years before the ASM was signed, nearly 30% of soy expansion occurred through deforestation; after the agreement, only 1% of the expansion of soybeans took place in the Amazon biome, and the forest-to-soy conversion rate was halved after the implementation of the ASM in Mato Grosso [29]. However, between 2009 and 2016, 54 out of 141 municipalities in Mato Grosso State had farms that were not compliant with the ASM, and 12.45% of the deforestation in these municipalities during this period was due to the conversion of almost 60 thousand hectares into soybeans [30].

Backlash pressure from agribusiness culminated in the current version of the FC approved in 2012 [15]. Flexibilization of specific regulations in this version resulted in significant forest losses: the total area of forests to be recovered was reduced from 50 to 21 million hectares because of amnesty, reduction of Legal Reserves in municipalities with more than 50% of its territory under Indigenous Lands and Conservation Units, and reductions of Permanent Protected Areas [15]. For the Cerrado, where fewer restrictions to forest conversion apply, the Prodes Cerrado deforestation monitoring program estimated that, by 2013, 50% of the biome was already under anthropization [33,34].

In the current format, the Brazilian FC specifies, among other rules, the area of each property that can be legally deforested and the procedures for doing so. Under the FC, landowners must register their property boundaries into a Rural Environmental Registry (Cadastro Ambiental Rural—SIMCAR) (credit restrictions and market incentives have proved crucial for producers to join CAR registration, an essential tool to monitor deforestation. Implementation of the CAR in the Cerrado was not achieved until 2014, but estimates are that by 2020, deforestation had decreased from 10,904 km^2 to 7905 km^2), preserve 20% (in most Brazilian regions) to 80% (forested areas in the Legal Amazon) of their farms as native vegetation, request licenses to deforest, and recover forested areas cleared without permits or face legal penalties for violating these rules. However, more than ten years after its most recent revision in 2012, compliance rates with the FC remain low, partly due to the considerable implementation gaps that persist for critical components of the regulation.

The rules to implement the registering system and advance the Plans of Environmental Regularization (PRA) were defined only two years after the 2012 FC approval. Various deadlines were set afterward to address the delayed implementation of state environmental agencies' operational systems [15,25]. Similarly, despite their potential to facilitate compliance and protect forest surpluses, the rules for Environmental Reserve Quotas (CRA)—a tradable legal system for titles to areas with intact or regenerating native vegetation exceeding the FC requirements—remain unclear [17].

3. Materials and Methods

3.1. Study Area

With more than 90.3 million hectares, the state of Mato Grosso spreads over three biomes (Amazon, Cerrado, and Pantanal). It is a core region of cattle and soybean production (Figure 2). Having almost half (or 43.1 million hectares) of its area covered by forests, Mato Grosso's potential to advance a green agenda of sustainable production, conservation of carbon stocks, and natural resources cannot be neglected.

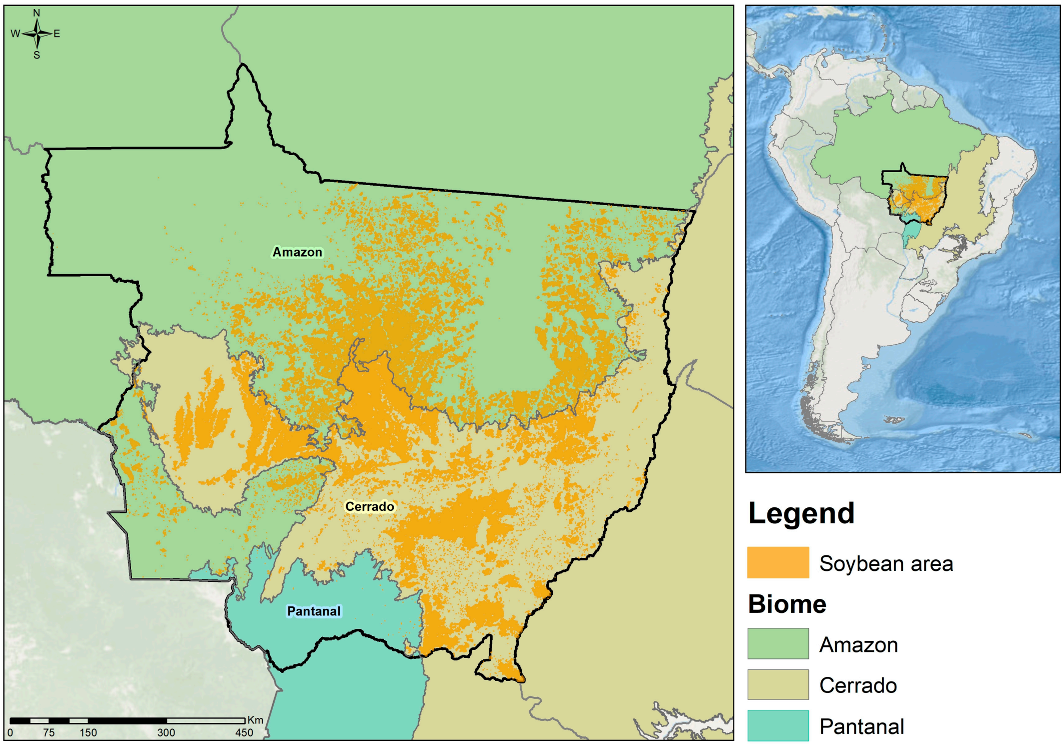

Figure 2. State of Mato Grosso and the distribution of soy cropland in 2019 in the Amazon, Cerrado, and Pantanal biomes. Geographic Coordinate System Datum Sirgas 2000. Source: Political Boundaries and Biomes (IBGE, 2019) [35]. Soybean area—Mapbiomas (2019) [36].

3.2. Building a Consolidated Database of Rural Properties

Property boundaries were compiled using the SIMCAR [37], the SICAR [38], and the SIGEF [39] (INCRA, 2020) databases. The SIMCAR (Mato Grosso Environmental Registering System) database was developed to support the planning and regularization of rural properties and is managed by the State Secretariat for the Environment (SEMA/MT) [37].

The dataset from SIMCAR used in our analysis comprises all rural properties registered up to 15 January 2021. The SICAR (Brazil's National Environmental Registering System) is a database similar to SIMCAR but managed by the Federal Government. The dataset from SICAR used in our analysis comprises all rural properties registered up to 23 April 2017. Both systems rely on georeferenced information (property boundaries and amount of native vegetation) provided by the owners themselves. The state environmental agencies then validate these data. Most properties in these systems have not yet been validated, so there may be inconsistencies with the registrations. Nevertheless, both databases have been used as a reference to analyze the environmental impacts of agricultural supply chains. Neither SIMCAR nor SICAR constitutes a land-tenure registering database. The SIGEF (National Institute of Land Tenure—INCRA) is a land tenure management system created to integrate INCRA's rural registering system and local notary's systems, thus constituting a land-tenure database. The SIGEF dataset used in our analyses comprises properties registered up to 24 June 2020.

We prioritized the latest updated data sources and consistency of ownership to generate a consolidated database of rural properties where overlapping was eliminated. Overlapping errors were corrected separately at each land-tenure typology database (SIMCAR, SICAR, and SIGEF) based on the status of each property and prioritizing the validation process of the agency responsible for the data management. At this step, we used the 'Exclude Geometries' and 'Dissect and Dissolve' tools from QGIS version 3.26.

As a next step, we used ArcCatalog 10.8.2 to create a geodatabase file wherein we established topology rules for each database. The rule 'Must Not Overlap' was applied to identify overlap errors among properties within the same layer. The remaining overlapping errors were corrected using the 'Error Inspector' tool in ArcMap 10.8.2.

After correcting topology errors in all property databases, these were merged using the 'Load' tool in ArcCatalog 10.8.2. To do that, we adopted the following hierarchical criteria:

(i) the first database added was SIMCAR because it is more frequently updated and has a more significant number of registered properties;
(ii) secondly, we included the SIGEF database, which, although smaller regarding the number of properties registered, is the most robust, considering the validation process follows more strict rules. Here, only the SIGEF properties that do not overlap with SIMCAR properties were included;
(iii) the third and final database included was SICAR. Here, we included only properties that did not overlap with properties in the SIMCAR and SIGEF databases.

After all databases were included, we checked, validated, and corrected the remaining eventual overlapping errors according to the above hierarchical criteria. This dataset of private rural properties includes 112,741 rural properties and covers 60.7 million hectares or approximately 67% of Mato Grosso's territory. The remaining areas consist of conservation units, Indigenous lands, agrarian reform settlements, or areas not designated by the federal government (This includes public areas belonging to the national or state heritage that have not been designated as Indigenous lands and Conservation Units, or transferred to private owners through land tenure programs).

3.3. Identifying Soy Farms, Quantifying Deforestation, and Assessing Compliance with the FC

To identify soy farms, we overlaid soy crops mapped in 2019 (Collection 5 of Mapbiomas) [36] and rural property boundaries (item 3.1). We applied a filter to select properties from the sample with at least 25 hectares of soy, resulting in a sample of 19,936 soy farms.

We used data from deforested polygons mapped between August 2008 and July 2019 by PRODES (Deforestation Satellite Monitoring in Brazilian Biomes) Amazônia and PRODES Cerrado. Where PRODES Amazônia and PRODES Cerrado data overlapped, the PRODES Amazon data were used. The PRODES Cerrado data that covered "non-forest" areas of PRODES Amazônia were preserved. The boundaries of the Amazon and Cerrado biomes were defined according to IBGE [35].

As a next step, we overlaid deforestation polygons with the boundaries of the 19,936 sample to identify deforestation in these soy farms. Assuming a conservative approach and to reduce inconsistencies when overlaying these two databases, only deforested polygons summing up 5 hectares (ha) within each property were considered. For instance, if two deforested polygons of 2 hectares each were identified in 2013 (totaling 4 ha) and three polygons of 2 hectares were identified in 2014 (totaling 6 ha), only the deforestation detected in 2014 was included.

After applying this filter, the resulting sample had 3515 soy farms. Deforested polygons identified in these properties were classified into (i) polygons cultivated with soy in 2019, either legal or illegal, and (ii) polygons not cultivated with soy in 2019 but inside soy farms, either legal or illegal.

To assess the legality of deforested polygons, we surveyed deforestation permits at the Transparency Portal website of the State Secretariat for the Environment (SEMA/MT) issued from August 2008 through July 2019. Activities that were licensed and had a valid deforestation authorization, such as dams (Teles Pires, Colíder, São Manuel, and Sinop), were considered legal. To identify illegally deforested polygons, we crossed the spatial data of deforested polygons and deforestation licenses, observing what the FC determines: spatial boundaries, location, and period (i.e., 2009 to 2019). These areas were then classified as legal (authorized) or illegal (unauthorized).

To assess rural properties' registration status and environmental liability, we analyzed attributes as specified in SIMCAR and environmental recovery plans available in the SEMA/MT database updated for 5 October 2021. To verify the status of embargoed deforestation in soy farms, we accessed data on embargoed areas at SEMA/MT and

IBAMA websites updated on 15 December 2020 and 1 February 2021, respectively. We listed all types of embargos in the dataset, processed data to eliminate overlapping—as the same deforested polygon can be eventually embargoed by both agencies—and then analyzed whether these overlapped with deforested polygons. Figure 3 presents a flowchart illustrating the geospatial data and analyses.

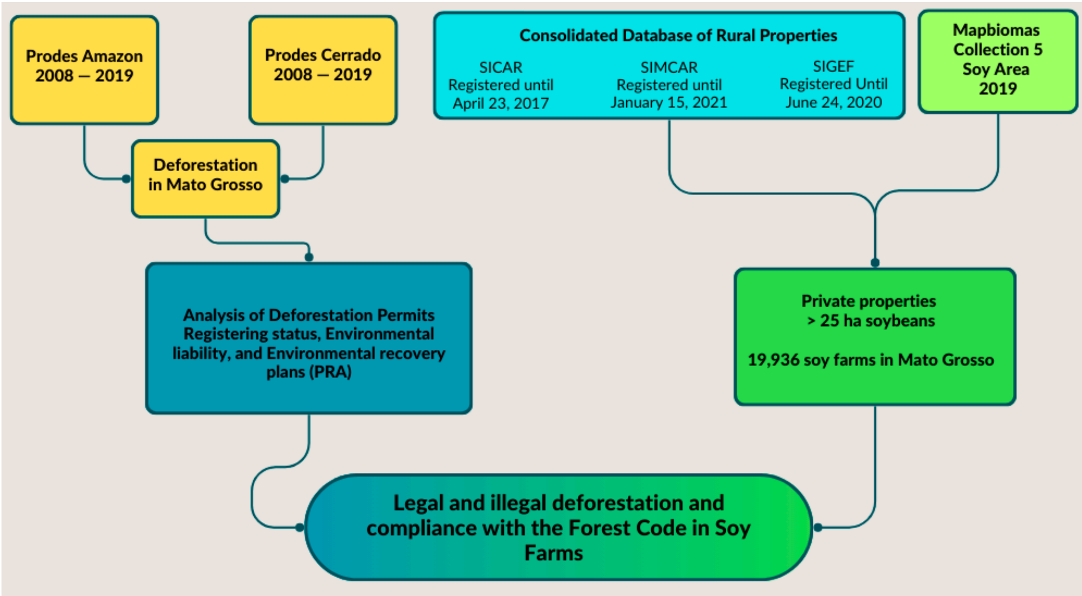

Figure 3. Summary of geospatial data and analyses.

4. Results

4.1. Size of Properties and Land Use in Soy Farms

The Brazilian land-tenure legislation identifies properties as small, medium, and large according to the number of fiscal modules—a unit of measurement in hectares that defines, at the level of municipalities, the minimum area required for a rural property to be economically viable. In Mato Grosso, 82.3% of municipalities have fiscal modules between 80 and 100 hectares. We therefore adopted 100 hectares as the standard fiscal module, thus classifying properties as small (less than 400 hectares), medium (>400 and <1500 hectares), and large (>1500 hectares). Table 1 summarizes the land-use characteristics of soy farms of different types.

Table 1. Summary of characteristics of small, medium, and large soy properties.

Characteristic	Type of Property		
	Small	Medium	Large
Number of properties	10,424	5861	3651
Total area (Mha)	1.98	4.71	16.33
Total deforestation (ha)	41,951.9	102,543.6	323,568.62
Illegal deforestation (ha)	–	20,422.6	214,279.1
Soy crops (Mha)	1.33	2.47	5.43

Eighty percent of soy farms detected with deforestation in Mato Grosso were medium (29.4%) and small properties (51.4%). However, all deforestation in small soy farms was legal. Large properties (>1500 hectares) were less than 20% of all soy farms but had four times as much soy planted than small soy farms and twice as much as medium properties. Roughly, most land illegally deforested was in large soy farms.

4.2. Compliance with the Forest Code (FC) in Soy Farms

We evaluated compliance with the FC in soy farms considering the basic requirements defined by this legal framework, which are (i) adhere to the rural properties registering system, (ii) request a deforestation license before any deforestation takes place in the property, (iii) respect the embargoes, and (iv) pursue the environmental adequacy of properties, i.e., any forest clearing that goes beyond the proportions defined by the FC must be subject to forest recovery or compensation.

4.2.1. Registering Soy Farms

Registering in SIMCAR is the first step towards environmental compliance according to the FC and has been a requirement in Mato Grosso since 2008. The registering process of rural properties follows four stages: (i) registering, (ii) analysis, (iii) validation, and (iv) monitoring. Firstly, in the registering stage, the landowner accesses the state or federal registering environmental systems to provide all information about ownership, property boundaries, and the existence of the forest remnants and areas under use. Secondly, the information is analyzed, and owners may be required to provide additional information as needed.

Most registration processes fail to advance beyond this stage because owners miss the deadlines or fail to respond. In the third stage, the information is validated by the state environmental agency. When there are environmental liabilities, e.g., illegal deforestation, owners must adhere to Plans of Environmental Regularization (PRA). Beyond this point, the rural property is considered fully compliant. However, because the Environmental Recovery Plans are legally binding, properties remain under scrutiny and must periodically present documentation to show that forest recovery plans are being implemented as agreed. Most soy farms in Mato Grosso were registered in the SIMCAR; still, 16% of soy farms (or 3318 farms) were not yet registered in this system.

Most registered soy farms (14,068 farms) were still in the initial stages of registration, i.e., although the owners have registered these farms, the processes have not advanced further, either because the information provided has not been validated or because properties have not met the environmental compliance requirements. On the other hand, a small percentage of these soy farms (11% or 2199 farms) have made it to the final stage of the registering process. Of these, only 4.03% (804 farms) were exempt from any environmental liability because they did not exceed the permitted clearing amounts in the FC, and 7% were liable, either pending regularization (6.5%) or having an approved Plans of Environmental Regularization (PRA) (0.6%).

4.2.2. Illegal Deforestation in Soy Farms

According to the Brazilian FC, the removal of native vegetation must be licensed by the State Environmental Agencies. Forest clearings must comply with the limits and size of the area as authorized, and the removal of native vegetation must take place while the license is valid. Deforestation is considered to be illegal when (i) no license is available, (ii) a license is available but clearing exceeds the authorized area, or (iii) deforestation takes place when licenses have already expired.

Of the 2.5 Mha of forests lost in this period in Mato Grosso, 1.65 Mha (66%) were cleared in registered properties but mostly illegally (92.8%) (Table 2). The proportion of land illegally deforested decreased from 98.3% to 84% over the study period; still, on average, for every hectare of forest legally cleared, another 11 hectares were illegal.

More specifically, in the soy supply chain, roughly 20% of farms were deforested during the study period (3516 properties), accounting for 15% (468.1 thousand hectares) of all land cleared in registered properties. Deforestation in soy farms was also predominantly illegal, i.e., 50% of all deforestation, totaling 234.7 thousand hectares (Table 2).

Table 2. Cerrado and Amazon biomes in Mato Grosso (MT): deforestation, registering, soy farms and crop area.

Characteristics	Biome	
	Cerrado	Amazon
Biome area in MT (Mha)	33.8	51.2
Total deforestation in MT 2009–2019 (Mha)	1.85	1.28
Total illegal deforestation in MT 2009–2019 (Mha)	1.16	1.17
Number of all registered properties (2022)	41,393	68,285
Number of registered soy farms (2022)	8805	7807
Deforestation in soy farms 2009–2019 (ha)	301,377.5	165,753.7
Illegal deforestation in soy farms 2009–2019 (ha)	166,096.58	68,018.7
Soy crops overlapping deforestation in 2019 (ha)	94,738.4	64,119.6
Soy crops overlapping illegal deforestation in 2019 (ha)	45,934	21,619.6

Illegal deforestation in rural properties is subject to embargo, which means that authorities have recognized the illegal deforestation, applied fines, and required that the deforested area must be isolated to allow regrowth. Our analysis shows that only 30% of soy farms that illegally deforested had embargoes within their boundaries, including those issued by the Federal Environmental Agency (IBAMA) and by the State Agency (SEMA/MT) as of December 2020 and February 2021, respectively.

In almost 80% of embargoed soy farms (838 properties), the embargoed areas partially or fully overlapped with recently deforested areas, indicating that illegal deforestation was the main reason for these embargoes. Soy was rarely planted in these embargoed areas. Still, even if they are not used for soy, these areas can be used for alternate activities like grazing or planting other crops [9].

Illegal deforestation in the Cerrado, where 166.1 thousand hectares were illegally deforested on farms growing soy, was twice the amount of illegal deforestation on soy farms in the Amazon (68,018.7 hectares) (Table 2). However, the number of soy farms embargoed in the Cerrado was three times lower relative to the Amazon: 804 rural properties had embargoes issued either by IBAMA or SEMA/MT in the Amazon. In contrast, the number of soy farms under embargo in the Cerrado totaled 253 properties.

Most soybean areas mapped in 2019 overlapped deforested polygons that had been detected in previous years: of all land deforested in 2009 on soy farms (9.4 thousand hectares), 62% was cultivated in 2019. However, in 2018, of all land deforested in the same year (34.2 thousand hectares), only 7% overlapped with soy crops. As a result, in addition to 67,553 hectares illegally deforested cultivated with soy in 2019, a further 166,558 thousand hectares illegally deforested not yet cultivated remain associated with soy farms.

5. Discussion

Accounting for one-third of the country's soy cropland, Mato Grosso State illustrates some of the critical shortcomings in implementing the FC in soy farms. Illegal clearing remains prevalent in the Amazon and Cerrado biomes and accounts for up to 90% of all deforestation. A considerable amount of this deforestation is concentrated in private properties: between 2013 and 2023, of the 2.8 Mha of forests cleared in the state, 67% (or 1.85 Mha) was in private properties [40]. FC violations, including those due to the failure to obtain an environmental license, are widespread on soy farms. In addition to this complex legal backdrop, producers of soy (and cattle) are also subject to zero-deforestation agreements that restrict land use beyond the FC. However, their track record is mixed, and there is no incentive to recover cleared areas [10,11,13,14,23,31]. Therefore, to achieve a sustained reduction in deforestation and advance the urgent restoration of illegally cleared areas, it is imperative to accelerate the FC implementation and create a space where sector agreements, such as the Amazon Soy Moratorium (ASM), strengthen its implementation.

Although the CAR registration process has advanced—totaling 73 million hectares of CAR-registered properties as of 2024 [19]—the analysis and validation is progressing only very slowly. Even in Mato Grosso, one of the best performers in this regard, only 5.3% out of 142,113 registered properties were validated as of December 2023. These delays are critical because landowners are only apt to execute plans, such as replanting or otherwise compensating for illegally deforested areas, to comply with the FC after CAR is validated. While the responsibility for the slow validation process relies on state agencies—as analyzing and validating CAR entries rests with public authorities—linking soy supply-chain initiatives and demand-side measures with FC criteria could be valuable.

Another critical aspect of implementing the FC relates to the embargoed areas, an administrative measure that halts the damage and allows forests to recover. Previous research has shown that fewer than 1% of embargoed properties pay their fines; perpetrators of illegal deforestation are seldom held accountable [41]. Our results showed that a small percentage of areas under embargo were planted with soy. At least in part, this could be likely due to the Soy Moratorium's prohibition on planting soy in deforested areas and the ease with which soy fields can be identified in non-compliant areas under the ASM's monitoring system.

Despite having some essential gaps, the ASM remains a valuable complementary strategy in addressing deforestation in soy farms. A stronger alignment between the ASM and the FC would better position the soy industry under probable more restrictive international trade laws, which could require evidence of no deforestation at the property level and compliance with local regulations. This could be achieved by extending the ASM to Cerrado and expanding the monitoring protocols to have entire farms as monitoring units rather than deforested polygons.

Forests in both of Mato Grosso's biomes are under pressure; approximately 1.2 Mha of vegetation was lost in each biome during our study period. Despite the more rapid pace of recent expansion of soy crops in the Amazon biome, the higher level of deforestation overall and on soy farms is in the Cerrado. The Cerrado has fewer protected areas and a lower legal reserve obligation—35% of the property rather than 80% as in the Amazon—and 50% of its original vegetation cover has already been lost, threatening its vital role as a biodiversity hotspot, underground carbon storage, water conservation, and source of food and medicine to local livelihoods [33,42]. Extending the ASM to soy farms in the Cerrado biome would significantly enhance this sector agreement's relevance and effectiveness against deforestation in the soy supply chain.

Expanding the ASM monitoring protocol to entire farms rather than deforested polygons planted with soy would address the crucial gap of indirect conversion in soy farms. Our results show that the total deforested area in MT soy farms can be as much as three times the deforested area under use for soy cultivation. This is because the direct conversion of forests into soy crops is rarely observed, but chances are that these deforested areas that are still not cultivated will be converted into soy or other crops. Because most deforested areas on soy farms are not planted with soy, the ASM fails to address the overall deforestation in soy farms. Additionally, deforestation permits are not a criterion of compliance in the scope of the ASM, thus allowing illegal deforestation into the soy supply chain.

However, as the persistence of the ASM is currently under threat and strengthening FC enforcement is poised to become all the more critical (two states in the Legal Amazon, Rondônia and Mato Grosso, have already enacted laws that remove tax incentives from companies participating in the Soy Moratorium). Ruralists and legislators argue that the policy harms the state's interests and contradicts national policies like the FC [43]. However, raising the standards of operations within the soy sector would better position Brazil as a leading global producer of more sustainable soybeans, aligned with an international market that increasingly demands deforestation-free commodity chains. As international markets become more discerning about production practices and land use associated with agricultural commodities, Mato Grosso may face challenges accessing these markets if land-use restrictions are loosened [44].

6. Conclusions

Most areas cleared in the Amazon before 2008 are beyond the limits established in the FC. As such, they are not subject to replanting requirements but must be compensated via other mechanisms, such as CRA, for the property to return to full compliance status. Still, many other properties must be replanted to comply with the FC. However, even full FC compliance may not be enough to conserve critically endangered habitats; therefore, we argue that sector agreements, like the ASM, can potentially operate as complementary policies to reduce deforestation. The rapid deforestation in the Amazon biome and the concerning levels of forest loss in the Cerrado demonstrate an increasing need for concerted efforts from the public and private sectors to implement policies to stop illegal deforestation.

Author Contributions: Conceptualization, V.S., P.B., A.P.V. and A.V.; Methodology, V.S.; Formal Analysis, V.S.; Investigation, V.S.; Data Curation, R.C., V.S., P.B. and A.P.V.; Writing—Original Draft Preparation, R.C., M.G.B.L., L.R. and H.K.G.; Writing—Review and Editing, R.C., L.R., H.K.G. and M.G.B.L.; Project Administration, P.B. and A.P.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data can be made available under request.

Conflicts of Interest: The authors declare no conflicts of interest.

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