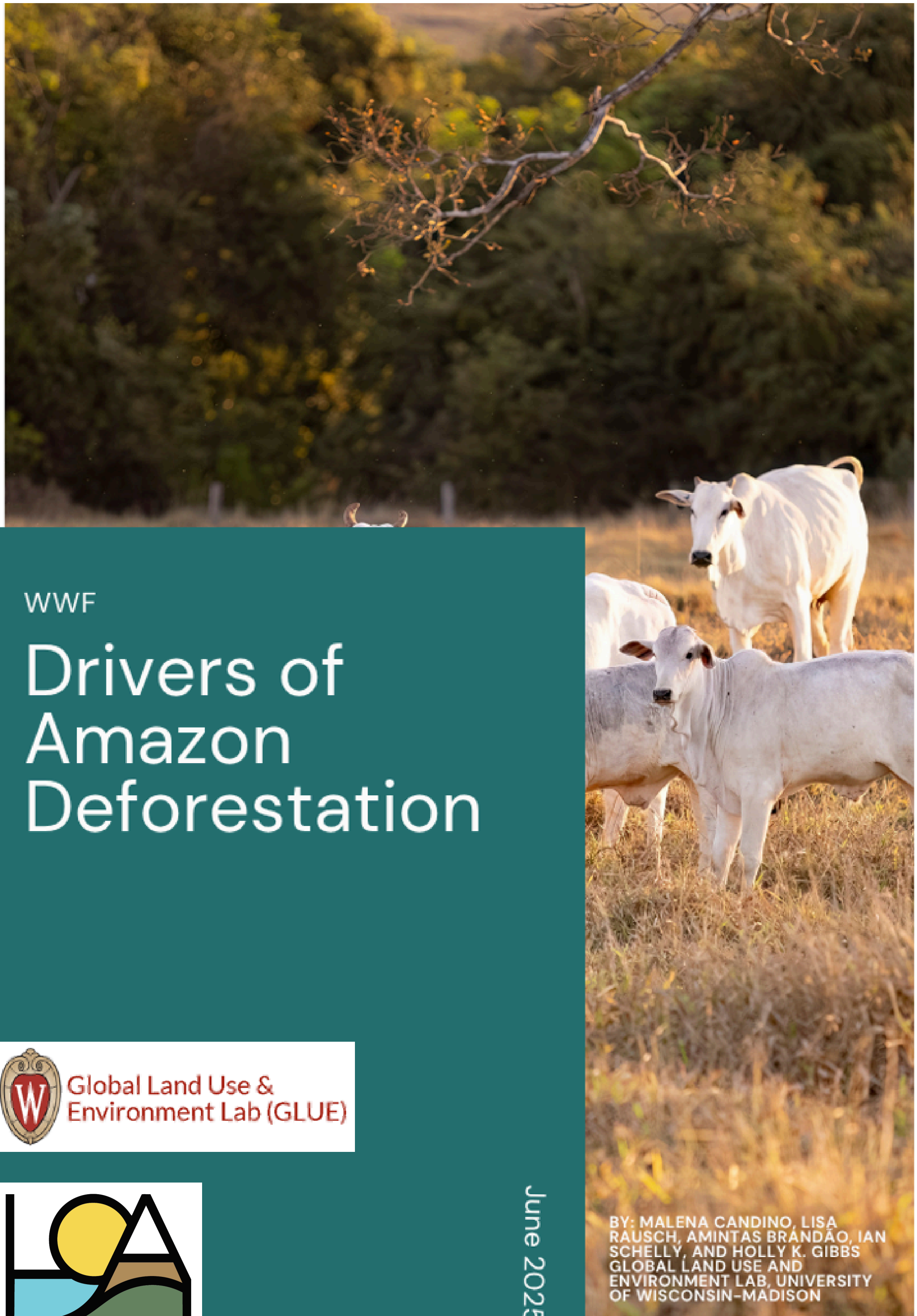


WWF

Drivers of Amazon Deforestation

Global Land Use & Environment Lab (GLUE)

Land Conservation Association

June 2025

BY: MALENA CANDINO, LISA RAUSCH, AMINTAS BRANDÃO, IAN SCHELLY, AND HOLLY K. GIBBS
GLOBAL LAND USE AND ENVIRONMENT LAB, UNIVERSITY OF WISCONSIN-MADISON

Contents

Executive Summary

Brazil continues to hold the largest expanse of tropical forest in the world despite having converted more than one-third of its territory to agricultural land. Over the last four decades, both pasture and soy frontiers have expanded steadily northward and westward, driving land conversion in key states such as Mato Grosso, Pará, Goiás, and more recently in the Matopiba region. Cattle ranching, however, consistently dominates as the major cause of deforestation. As of 2023, over 147 million hectares of native vegetation, including forested and non-forested ecosystems, had been cleared for pasture, with roughly 40% of this occurring in the Amazon and 30% in the Cerrado. Soy cultivation—though historically not the first land use established after clearing— has also expanded rapidly, especially in the Cerrado, where it occupied 19 million hectares by 2023, on top of another 6 million ha in the Amazon.

The interplay between soy and cattle is a defining feature of Brazil's agricultural frontier. Ranching typically leads the expansion front, as forestlands are often opened up for the creation of low-intensity pasture, though some of this may amount to little more than land speculation and some areas are simply abandoned, leading to secondary forest growth. In the Cerrado, soy remains an important direct driver of deforestation and natural vegetation loss, though it also expands over pasturelands in some regions. In the Amazon, soy largely ceased to cause direct deforestation after the Amazon Soy Moratorium was signed in 2006, though it has remained an important indirect driver by displacing cattle further into forested areas as it expands into already cleared pasturelands.

These two land uses have also attracted different kinds of migrants: ranching has typically drawn lower-income, less formally educated settlers with fewer resources, often supported through land redistribution or informal land markets, while soy expansion has been concentrated among larger, capitalized agribusinesses, including southern Brazilian farmers moving north.

Global demand for beef, protein, and biofuels continues to grow, redoubling pressures on Brazil's forests. Future deforestation hotspots are likely to continue to be concentrated in the Matopiba region, along the Arc of Deforestation, and near emerging infrastructure corridors, where land values and development pressures are highest. At the same time, climate change is reshaping the viability of these frontiers, with many current farming areas—especially in Southern Brazil and Matopiba—expected to fall outside their optimal climate zones by mid-century.

Despite these challenges, Brazil has the technical capacity to increase beef and soy production through intensification and use of already converted land rather than further deforestation. More effective enforcement of environmental legislation and pressure from markets, including international markets, to avoid deforestation could incentivize greater uptake of these technologies in both the beef and soy sectors.

Baseline statistics: Soy and cattle production in Brazil and its impact on deforestation through time

Brazil's national territory is over 850 Mha, a third of which is now occupied by agricultural land (Maranhão et al., 2019). Over the last four decades, soy farming and cattle ranching, the two most dominant forces shaping the country's land use, have transformed Brazil's landscapes. Together, these sectors now involve nearly 22% of the country's territory, with far reaching implications for the environment, economy, and rural livelihoods. Brazil is now the world's largest beef exporter, and one of the top producers of soy, with both commodities mainly concentrated in the Central-West and South regions. Soy farming is particularly prevalent in the states of Mato Grosso, Paraná, Rio Grande do Sul, Mato Grosso do Sul, and Goiás, while cattle ranching dominates in Pará, Mato Grosso, Minas Gerais, Bahía and Goiás.

While technological advances have boosted productivity, land speculation, weak governance and policies that reward deforestation continue to drive land clearing. In many frontier regions, deforestation is further used to establish land claims and increase property value. This has fueled widespread land grabbing, in which public lands are illegally occupied, cleared and later sold or titled through loopholes in land tenure laws. Violent conflict over land and encroachment into the territories of indigenous peoples and other traditional communities also occur. Based on data analysis and a review of the latest literature, this report summarizes how deeply intertwined soy and cattle expansion dynamics are, and how they interact with the processes of land grabbing and land speculation to reshape Brazil's agricultural frontiers, reinforcing speculative clearing and contributing to one of the highest deforestation rates in the world.

1. Cattle ranching

Brazil's ranching sector is made up of a huge variety of types of production systems, including smallholders and largeholders, and those in frontier areas and consolidated areas, which affects access to resources, production strategies, and the underlying motivations of production by these different types of producers (Pacheco & Poccard-Chapuis 2012; Pereira et al., 2016) This enormous variability is in production systems is a fundamental underlying reason that this sector has proven so challenging to govern.

Brazil has nearly 147 Mha of pasture, a 170% increase from the 84 Mha of pasture that there was in1985. Nearly all of this pasture is planted, and therefore exists at the expense of native vegetation (including forests and non-forest vegetation). The scale and speed of pasture expansion have varied by biome (**Figure 1.1**). In the Cerrado, pasture growth has mirrored the national pattern, rising from 28 Mha to 44 Mha – about 30% of the country's current pasture area– during the 1985-2023 period. Meanwhile, pasture growth in the Amazon followed a much sharper trajectory. There, pastureland more than quadrupled, growing from just 12 Mha in 1985 to over 54 Mha in 2023– 37% of Brazil's current pasture area. Beef production in Brazil has more than doubled during this period, mainly via pasture expansion, rather than productivity increases (Martha et al., 2012, **Figure 1.2**), though productivity has increased significantly in some regions and varies considerably from farm to farm.

2. Soy farming

In response to rising food, animal feed and biofuel demands, soybean cultivation has expanded rapidly worldwide, with global production more than doubling in the last 25 years, and most of the expansion area concentrated in Latin America and, specifically, Brazil (Song et al., 2021). Over the past few decades, soy has become one of the country's most dominant crops, both in terms of land use, production volume, and export revenue (**Figure 1.2)**. By 2023, there were nearly 40 Mha planted to soy, a 9-fold increase since 1985 (Mapbiomas, 2025) (**Figure 1.1**).

This growth in area has been accompanied by a transformation in soy production systems. Whereas in the 1980s, soy was planted largely by family farmers who were successfully incorporated into commodity chains by national policies–including PRONAF's credit lines for family farms, rural technical assistance programs such as ATER and seed distribution initiatives (Junior et al., 2021)–today soy production is often industrial in scale, with family farms overall seeing limited gains in soybean areas, accounting for roughly 16% of the national soy output (Grassroots international, 2009). Family farms have benefited from soy-driven rural economic growth—through wage employment, land sales, infrastructure development and upward mobility (Richards, 2015)–-however, the majority still face marginalization and have limited access to resources to expand their production, given even operations that are run by families often need the latest technologies such as precision-farming and may involve thousands of hectares of cropland.

The surge in soy production has been especially concentrated in the Cerrado (where 50% of the growth has occurred) and Amazon (15% of the growth) biomes. In the Cerrado, soy area grew more than 15-fold over the past four decades, from just over 1 Mha in 1985 to more than 19 Mha in 2023. The Amazon, though starting from a much smaller base, saw an even more dramatic relative growth: less than 1,500 ha were planted with soy in 1985, compared to nearly 6 Mha in 2023. While productivity has also increased considerably-–by 24% in the last decade alone (Maranhão et al., 2019)–-this rapid expansion has intensified pressure on native vegetation, including both forests and savannahs, and displaced pasture to frontier regions.

Indeed, soy expansion has served as both a direct and an indirect driver of deforestation in the Amazon and the Cerrado over the past several decades, though its balance in these two roles has changed somewhat over time (Moffette and Gibbs 2021). When acting as an indirect driver, soy tends to replace cattle pasture, which then may be "displaced" into forests or other native vegetation, resulting in deforestation as much as 2.7 to 6.4 times greater than the expansion of soy itself (Arima et al., 2011). On average, soy replaced forest 3 years after initial clearing in the Cerrado, and 5 years after clearing in the Amazon, positioning soy as a key direct driver of deforestation in the Cerrado, while it acts as a latent driver in the Amazon (Song et al., 2021).

Changes in technology and supply chain policies are among the reasons for these shifts. For example, in the 1980s, newly deforested lands in the Amazon required the planting of rice for a few years before soybeans could be planted; eventually, soybean varieties suited for the acidic soils of the Amazon were developed, allowing for soybean to expand directly into newly cleared lands. However, following a campaign by the environmental non-governmental organization, Greenpeace, in 2006, the majority of soy buyers signed an agreement known as the Amazon Soy Moratorium to prohibit the purchase of soybeans from recently deforested areas. This created a major disincentive for soybean to directly cause deforestation, while possibly increasing the indirect pressure on forests from soybean. Indeed, following the Soy Moratorium nearly all soybean expansion has occurred over pasture areas (Gibbs et al., 2015). In the state of Mato Grosso, for example, it has been reported that ranchers may use their profits from selling land to soy farmers to buy larger, forested areas in the state of Pará, raising concerns that the policy could contribute to more deforestation than would have resulted had the soy farmers simply continued to expand into newly cleared lands (Berenguer et al., 2025). However, even with this possibility, research has shown that the Amazon Soy Moratorium has contributed to an overall slowdown in deforestation, likely due to reducing the market for lands cleared after the policy's cut-off date of 2008 (Heilmayr et al., 2020).

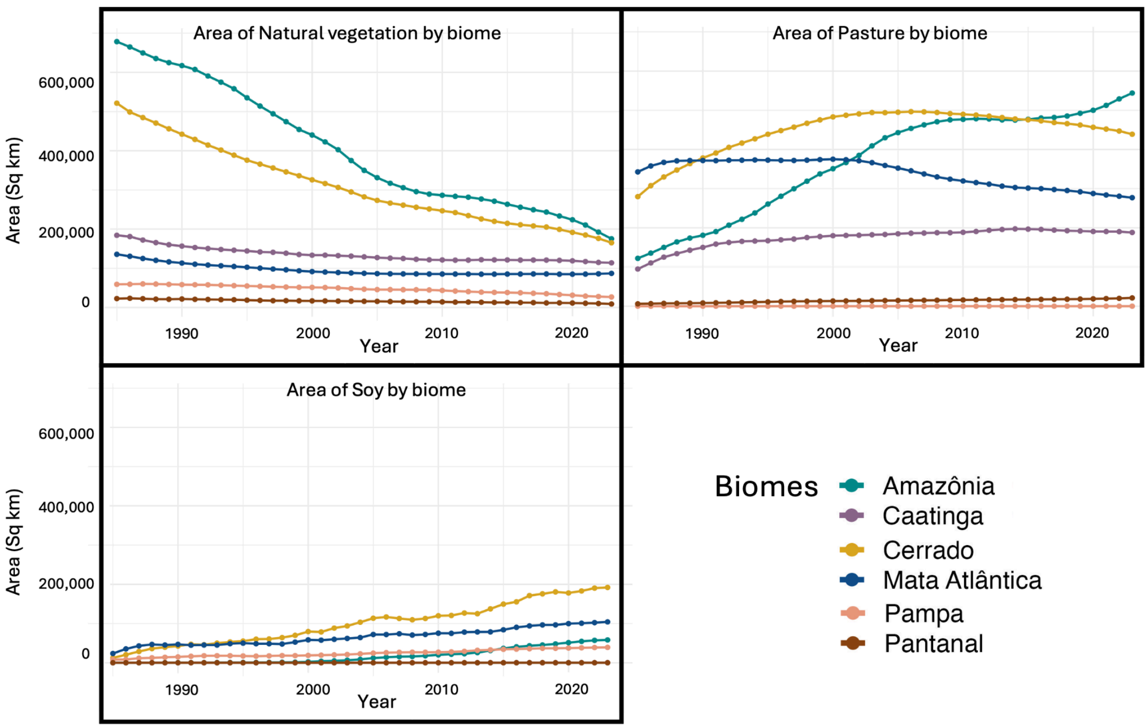


Figure 1.1. Brazil land cover area trends for natural vegetation, pasture and soy per biome, based on Mapbiomas 9.0 land use and PRODES deforestation.

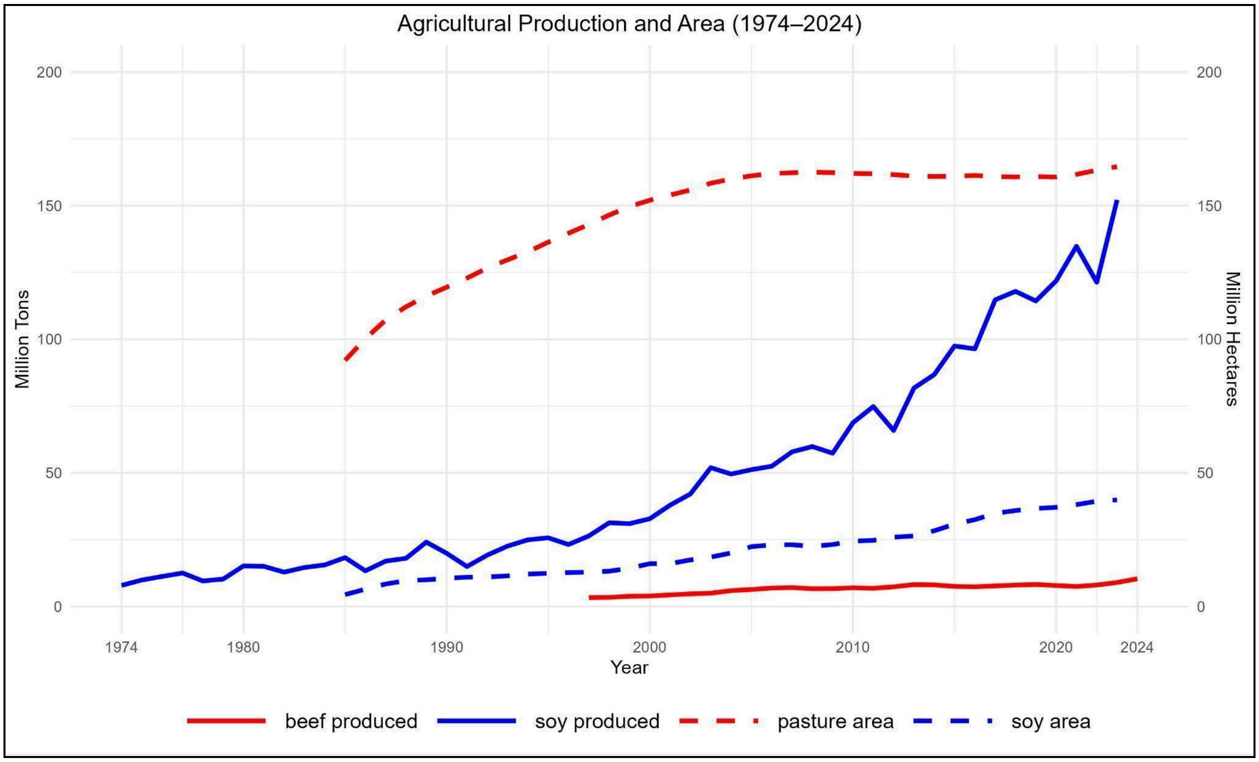


Figure 1.2. Soy and Beef production through time, compared with soy and pasture area through time, across Brazil, based on estimates of production from IBGE and Mapbiomas 9.0 land use.

3. Soy and cattle spatial patterns

Starting in the 1960s, Brazil intensified its agricultural expansion project, enacting multiple policies aimed at incentivizing migration of farmers into the Amazon to achieve economic growth and territorial security. This resulted in high rates of deforestation as soy farming and cattle ranching spread from the South of the country towards the North and the Midwest (Seixas et al., 2025).

The epicenter of cattle ranching production has continuously moved Northwest since the 1990s, propelled mainly by land speculation and short lasting productivity due to poor land management (Maranhão et al., 2019)(**Figure 1.3**; see section 6.3 of this chapter for more discussion of land speculation).

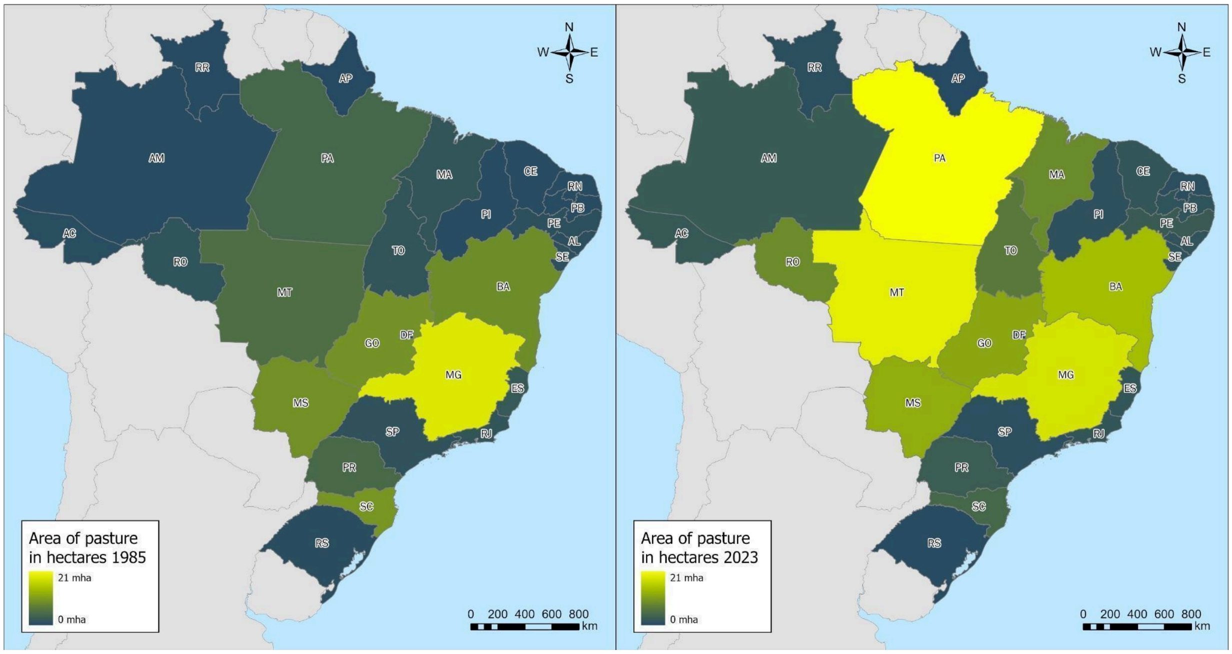


Figure 1.3. Density of pasture area by state in 1985 and 2023.

Since the Amazon Soy Moratorium was implemented in 2006, soy farming lands have continued to expand for feed and biofuels, leading soy to exert increasing displacement pressure on cattle ranching, and pasture has been expanding towards the Southern border of the Amazon, causing pastureland epicenter in the Amazon to move a total of 165 km with a Western direction since 1985, while remaining within the limits of the expansive municipality of Altamira, in Pará (**Figure 1.4**).

In the Cerrado, pasture has moved a total of 277 km northward, from the municipality of Bom Jesus de Goiás to Guaraíta, both in the state of Goiás. The states with the biggest herds have gone from being mostly located in the Center and South (Mato Grosso do Sul, Minas Gerais, Rio Grande do Sul and Goiás) to being mostly located in the Amazon biome (Pará, Rondônia) (Maranhão et al., 2019)(**Figure 1.2**).

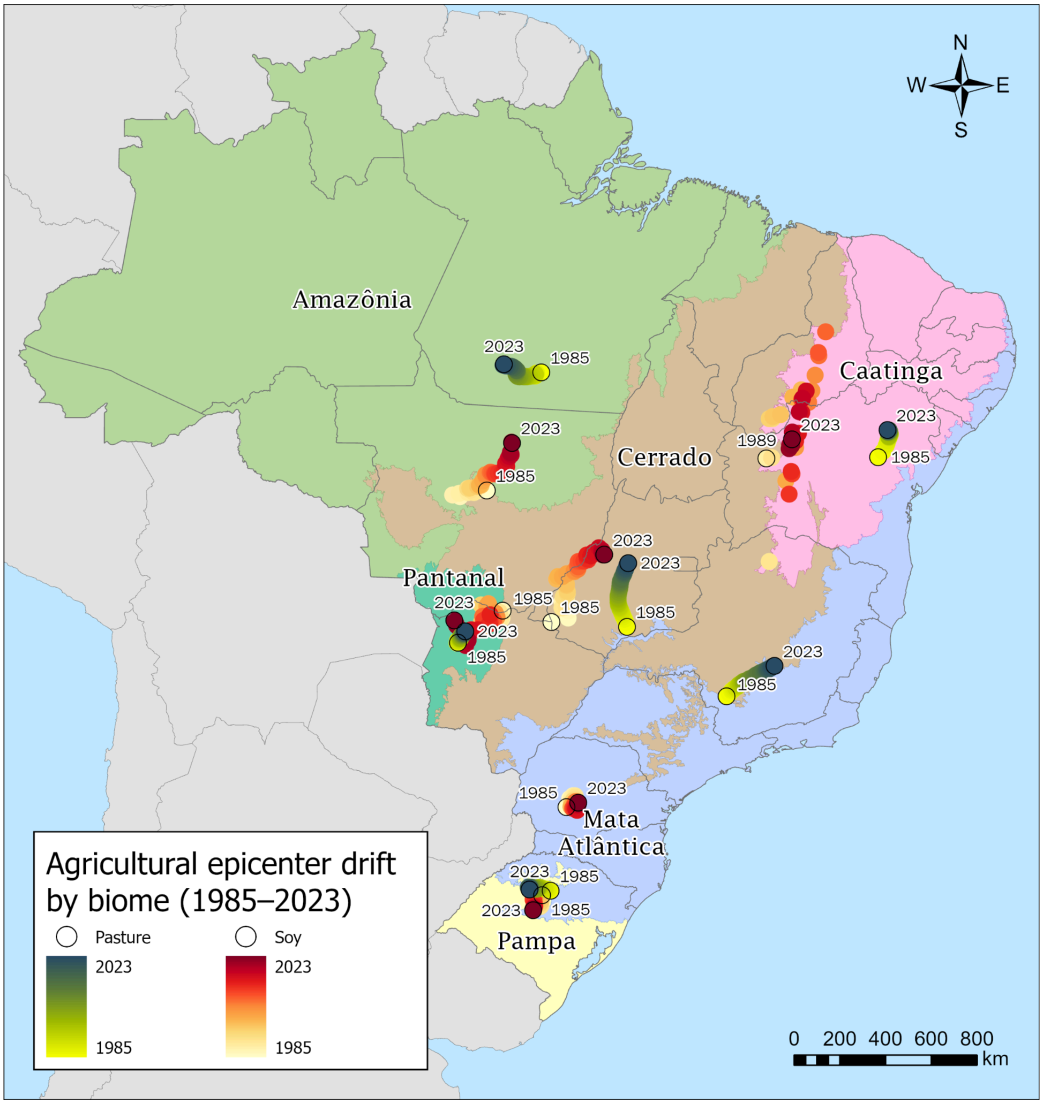


Figure 1.4. Soy and pasture biome epicenter (weighted mean center) migration for the 1985-2023 period. Based on Mapbiomas 9.0 land use and PRODES deforestation.

Since the 1990s, soy production has been expanding more markedly and continuously. The states with the greatest increase in soy area since 1985, and the largest soy production areas as of 2023, are Mato Grosso, Rio Grande do Sul, Parana, and Goiás (**Figure 1.5)**.

In the South this expansion has been mostly towards higher altitudes, while in most other regions it has expanded towards the North (**Figure 1.5**). Nationwide, the epicenter of soy farming has moved from the South to the center of Brazil (Maranhão et al., 2019), reaching its northern point in 2005 before moving South after the Soy Moratorium was signed in 2006 (**Figure 1.4**).

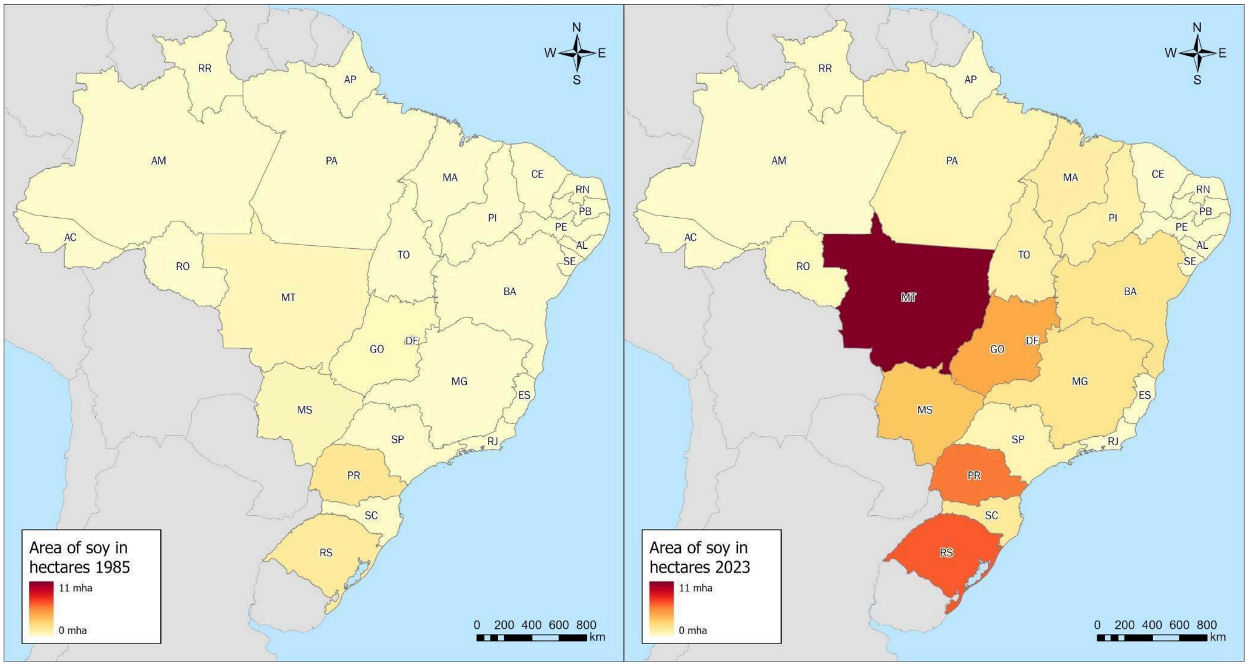


Figure 1.5. Density of soy crop area by state in 1985 and 2023.

In the Amazon biome, soy has expanded at the expense of forest, both primary (32%) and non-primary (17%), and pasture (51%) (Song et al., 2021). This expansion has had a North-Northeast direction; the epicenter of all soy farming land in the Amazon biome moved 235 km in this direction during the 1985-2023 period, going from the municipality of Sorriso to Marcelândia in Mato Grosso (**Figure 1.4**).

In the Cerrado, 20% of all new soy farming land has replaced native vegetation. Soy expansion in the Cerrado has also had a Northeast direction, moving a total of 367 km during our study period, from the municipality of Mineiros to Britânia, both in Goias (**Figure 1.4**). Soy driven deforestation has decreased in Mato Grosso since the Soy Moratorium, but has increased in Pará, where there are more soy companies operating that do not adhere to the Moratorium, and the Matopiba region, where the Moratorium does not apply.

The expansion of soy cultivation and cattle ranching across the Amazon and Cerrado biomes has been closely linked to increasing land conflicts, displacements and struggles over territorial rights, particularly affecting indigenous groups and local communities. Research shows that soy expansion in previously informally accessible land triggered a rise in land occupation, as locals tried to secure or reclaim land tenure in the face of agribusiness encroachment (Falcone & Rosenberg, 2022). Rapid growth in cattle ranching and soy farming in Rondônia for example, has resulted in widespread deforestation, invasions into protected areas and indigenous lands, and violence (Greenpeace, 2021). In Matopiba and other areas of the Cerrado, soy-driven land appropriation and speculation have displaced traditional peoples, undermined local food systems and increased land inequalities (Bastos Lima & Persson, 2020)

4. Cattle stocks and soy yields through time

During the period from 1990 to 2009, the cattle herd in Brazil increased by 33% (McManus et al., 2016). Cattle heads in the Amazon have steadily increased in the last 40 years, from 15M heads in 1985 to 96M heads in 2023, which represents over a 500% increase (**Table 1.1, Figure 1.6**). The cattle herd has also increased in the Cerrado overall, but this happened at a much slower pace, from 92M heads in 1985 and 144M heads in 2023, a 56% increase.

Beef production in Brazil increased 6-fold during the 1950-2006 period (Martha et al., 2012), mostly via the expansion of pastures, while beef productivity remains well under the average estimated carrying capacity of 2 AU/ha (Feltran-Barbieri & Féres, 2021). Overall, stocking rates in Brazil went from 0.51 animal units per hectare (AU/ha) in 1975 to 1.08 in 2006 (Silva & Moran, 2015). By 2010, stocking rates were 1.48 AU/ha in the Amazon biome and 1.53 AU/ha in the Cerrado biome (Dias et al., 2016; Silva & Moran, 2015). There is considerable variation, though, across different regions and at the producer level, as some ranches persist with little to no investment in pasture quality or improved production systems, while others employ the latest technologies and have production levels well above average (Moffette and Gibbs 2021).

Soy area has expanded substantially in both the Amazon and Cerrado biomes. The expansion was most significant in the Amazon, where there were just 1.3 Mha planted with soy in 1988 to 14.9 Mha in 2023 (an over 1,000% increase), while in the Cerrado the area increased from 6.7 Mha in 1988 to 33 Mha in 2023 (a ~400% increase) (**Table 1.2, Figure 1.6)**. Soy yields increased at a much higher rate during our study period in both biomes. Soy tons produced increased from 1.7M to 54M (more than 3,000% increase) in the Amazon, and from 12M to 126.8M (over 1,000% increase) in the Cerrado biome (**Table 1.3, Figure 1.6**).

While land area used to grow soy has grown, yields have grown at a much higher rate, reflecting continued intensification. Increases in soy productivity per unit area (kg/ha) have surged by over 500% in the Amazon biome (4,026 kg/ha in 1985 to 26,445 kg/ha in 2023) and of over 100% in the Cerrado biome (16,337 kg/ha in 1985 to 36,849 kg/ha in 2023). The biggest innovation that allowed for this growth was new crop varieties developed for Amazonian soils in the 80s, along with methods such as lime application to decrease soil acidity, phosphate and potassium fertilizers to improve soil fertility and boost yields, and no till farming to help retain soil moisture, reduce erosion and increase productivity.

Table 1.1. Cattle head count per state and totals for Amazon and Cerrado biomes per year (1985-2023). IBGE. *Mato Grosso is included in both biomes averages.

State	1985	1995	2005	2015	2023
Rondônia	764,299	3,928,027	11,349,452	13,397,970	18,162,632
Acre	349,150	471,434	2,313,185	2,916,207	4,908,956
Amazonas	427,504	805,804	1,197,171	1,293,325	2,377,089
Roraima	305,155	282,049	507,000	794,783	1,181,553
Pará	3,378,894	8,058,029	18,063,669	20,271,618	25,040,621
Amapá	48,370	93,349	96,599	89,682	54,842
Maranhão	3,278,340	4,162,059	6,448,948	7,643,128	10,128,610
Mato Grosso*	6,507,632	14,153,541	26,651,500	29,364,042	33,994,004

Total Amazon Biome	**15,059,344**	**31,954,292**	**66,627,524**	**75,770,755**	**95,848,307**
Mato Grosso*	6,507,632	14,153,541	26,651,500	29,364,042	33,994,004
Piauí	1,600,761	2,135,286	1,826,833	1,649,549	1,384,189
Bahia	10,255,844	9,841,237	10,463,098	10,758,372	13,290,719
Minas Gerais	19,847,770	20,146,402	21,403,680	23,768,959	22,498,415
São Paulo	11,260,601	13,148,133	13,420,780	10,468,135	10,768,360
Paraná	8,046,780	9,389,200	10,153,375	9,314,908	8,774,410
Mato Grosso do Sul	14,991,356	22,292,330	24,504,098	21,357,398	18,891,916
Goiás	19,551,110	1,8492,318	20,726,586	21,887,720	23,729,878
Distrito Federal	76,389	123,110	102,320	96,576	83,061
Tocantins	-	5,544,400	7,961,926	8,412,404	11,313,309
Total Cerrado Biome	**92,138,243**	**115,265,957**	**137,214,196**	**137,078,063**	**144,728,261**

Table 1.2. Soy crop area (ha) by state and totals for Amazon and Cerrado biomes per year (1988-2023). IBGE. *Mato Grosso is included in both biomes averages.

State	1988	1995	2005	2015	2023
Rondônia	4,620	4,500	75,275	233,605	589,983
Acre	-	-	55	-	12,010
Amazonas	-	-	2,256	-	8,237
Roraima	-	-	13,000	23,820	128,197
Pará	-	-	68,410	337,056	1,007,539
Amapá	-	-	-	11,365	7,350
Maranhão	14,365	87,690	372,074	761,225	1,190,047
Mato Grosso*	1,329,816	2,338,926	6,121,724	8,983,683	11,981,285
Total Amazon Biome	**1,348,801**	**2,431,116**	**6,652,794**	**10,350,754**	**14,924,648**
Mato Grosso*	1,329,816	2,338,926	6,121,724	8,983,683	11,981,285
Bahia	243,349	470,575	870,000	1,440,135	192,3627
Minas Gerais	486,674	603,773	1,118,867	1,328,641	2,214,362
São Paulo	512,500	530,000	781,210	792,081	1,360,285
Paraná	2,128,498	2,206,249	4,154,667	5,240,402	5,762,069
Mato Grosso do Sul	1,178,363	1,044,779	2,038,176	2,350,927	3,884,468
Goiás	774,480	1,126,511	2,663,646	3,263,118	4,590,730
Distrito Federal	42,778	43,831	59,020	68,862	85,000
Tocantins	-	20,237	355,300	83,0031	1,331,484
Total Cerrado Biome	**6,696,458**	**8,384,881**	**18,162,610**	**24,297,880**	**33,133,310**

Table 1.3. Census soy yields (tons) by state and totals for Amazon and Cerrado biomes per year (1985-2023). IBGE *Mato Grosso is included in both biomes averages.

State	1985	1995	2005	2015	2023

Rondônia	677	10,800	233,281	748,429	2,131,535
Acre	-	-	114	-	45,732
Amazonas	-	-	5,136	-	23,455
Roraima	-	-	36,400	55,795	445,076
Pará	-	-	204,302	1,022,677	3,156,487
Amapá	-	-	-	29,370	19,536
Maranhão	9,013	162,375	996,909	2,099,507	3,821,792
Mato Grosso*	1,656,039	5,491,426	17,761,444	27,850,954	44,425,783
Total Amazon Biome	**1,665,729**	**5,664,601**	**19,237,586**	**31,806,732**	**54,069,396**
Mato Grosso*	1,656,039	5,491,426	17,761,444	27,850,954	44,425,783
Piauí	875	20,199	559,545	1,772,722	3,389,142
Bahia	75,600	1,072,911	2,401,872	4,513,633	7,776,560
Minas Gerais	879,727	1,199,666	2,937,243	3,524,055	8,459,161
São Paulo	960,386	1,185,500	1,703,660	2,406,262	4,962,226
Paraná	4,413,000	5,694,427	9,492,153	17,229,378	21,553,541
Mato Grosso do Sul	2,558,720	2,283,546	3,718,514	7,305,608	14,193,250
Goiás	1,356,240	2,146,926	6,983,860	8,606,210	17,405,060
Distrito Federal	91,787	86,212	188,746	180,832	306,000
Tocantins	-	36,471	905,328	2,418,367	4,340,578
Total Cerrado Biome	**1,199,274**	**19,217,284**	**46,652,365**	**75,808,021**	**126,811,301**

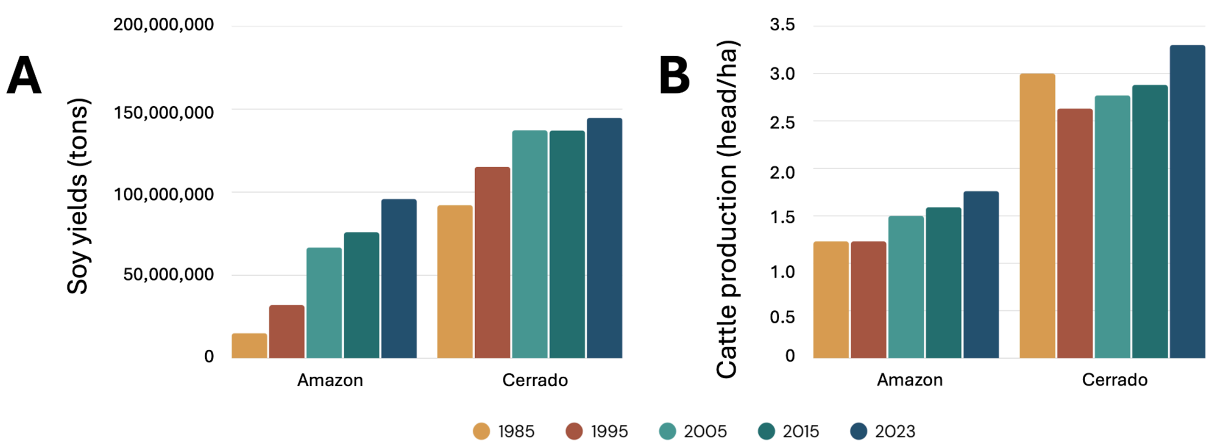


Figure 1.6 (A) Soy yields (tons) and **(B)** cattle production (heads/ha) for the Amazon and Cerrado biomes over time based on IBGE census data and Mapbiomas 2024 pasture estimates.

5. Land Values

Land prices in the Amazon have been increasing, mainly due to higher availability of rural credit lines, increased market prices for agricultural commodities, and increased infrastructure and connectivity resulting in lower transportation costs (Perz et al., 2008). Paving of official roads leads to increased land prices due to improved access and decreasing transportation prices to producers; it also leads to the development of a network of unofficial roads that cascades into more capital that leads to deforestation and additional roads (Perz et al., 2008). Land that can be used for productive purposes ("improved" land), or land that may be used this way in the future, is worth more, while environmental law enforcement tends to decrease the value of forest lands.

Multiple studies have shown consistent increases in land prices across Brazil's major agricultural states. For example, a study by Scot Consultoria shows that agricultural and pastureland prices rose 113% and 116%, respectively, over the last five years in Brazil's top grain- and cattle-producing states. The average price of agricultural land per hectare increased from R$14,818 in 2019 to R$31,609 in 2024, and from R$8,267 to R$17,886 for pastureland for the same period (nominal values). Consequently, land acquisition is one of the surest ways to make a profit in Brazil, which undoubtedly incentivizes land speculation (Beledeli, 2025).

Land prices in the agricultural frontier area both in the Amazon and in the Matopiba region of the Cerrado increased faster than in other regions, in part due to the relative scarcity of suitable agricultural lands in these regions compared to the pressure from markets for expansion resulting from high global commodity prices and a weak Brazilian currency (Richards et al., 2014).

6. Land Grabbing, Deforestation, and Land Tenure

The link between land grabbing and deforestation in the Brazilian Amazon is well documented in the scientific literature. In Brazil, "land grabbing" (*grilagem*) primarily refers to the illegal appropriation of large areas of public land, typically in the Amazon rainforest, often through the falsification of ownership documents. Unlike other global contexts—where the term may refer to legal land acquisitions by foreign investors—in Brazil, *grilagem* denotes the unlawful occupation of public lands without defined land tenure, typically for agricultural expansion or real estate speculation (Oliveira et al., 2021). Undesignated public lands have historically been particularly vulnerable to this type of activity (Azevedo-Ramos et al., 2020).

Land grabbing is a major immediate driver of deforestation in the region. Deforestation is not only a byproduct of illegal occupation but also a deliberate strategy to assert informal land claims. Clearing vegetation serves as a visible sign of possession and is often followed by parceling and selling of the land. In some cases, land is sold at a discount on the condition that the new occupant clears the forest, thereby reinforcing possession. This process aims to convert forested landscapes into open areas—*faits accomplis*—that can later be used to justify land regularization of large, illegally occupied tracts.

Those engaged in these activities are commonly referred to as *grileiros*, a term that originates from an old practice: forged documents were stored in drawers with crickets (*grilos*) to artificially age the paper and simulate authenticity.

The existing literature indicates that land grabbing– driven by legal incentives, low prices and the possibility of value appreciation– is a major factor in the loss of forest and its replacement with pasture in the Amazon. While pasture expansion is often recognized as the primary land use following deforestation, it is frequently used as a means to land titling, especially on public and undesignated land. However, clearing for pasture is a more complicated and dynamic process, and should not be reduced to a mere speculative one. In many cases, especially among smallholders, pasture also serves as a critical source of income and stability, making it hard to disentangle whether deforestation is driven by opportunistic land speculation, subsistence needs or, more likely, a combination of both.

6.1 Agricultural Expansion and Indirect Drivers of Deforestation

Agriculture, especially large-scale production of soybeans, contributes to Amazonian deforestation both directly—through land clearance for crops—and indirectly, through displacement of pastures and market-driven land appreciation. During 2000–2005, Brazil's soy production in Brazil grew by approximately 60%, with Mato Grosso, the leading soy producing state in the Amazon, doubling its soy cultivation area during this period. Only 6% of the land cleared during that time was directly used for soy (P. Richards, 2015), though studies have estimated that indirect effects from soybean expansion may have accounted for more than 30% of all Amazon deforestation (Richards et al., 2014).

The acceleration of soy expansion in the Amazon is itself the result of another type of indirect pressure on forests, known as the "price effect," in which rising biofuel demand in the EU and US resulted in the displacement of soy by corn, drove up its price and incentivized expansion of this crop in other regions like Brazil (Searchinger et al., 2008; Gibbs et al., 2008). These effects often lead to soy displacing pasture, which in turn pushes cattle ranching further into forested areas—a chain reaction of land use displacement.

6.2. Idle Pasture and Land Underutilization

Cattle ranching in the Amazon is characterized by low productivity and low levels of investment. Additionally, a significant portion of deforested land in the Amazon remains unused for extended periods after being cleared. Previous research shows that 16% of land cleared for pasture in the Amazon, Cerrado and Atlantic Forest biomes between 2000-2017 was not actively used for cattle ranching for at least 5 years after clearing (zu Ermgassen et al., 2020). This suggests that deforestation often at least partially serves speculative purposes, particularly to assert land tenure claims, rather than being a means to boost agricultural productivity. Furthermore, the low average cattle stocking rate in Brazil, ranging from 0.5–1 head per hectare, highlights the low productivity of these pastures, reinforcing the notion that land is cleared primarily to establish ownership rather than for economic use.

6.3. Land Appreciation and Speculative Gains

Land values in the Amazon increase markedly after deforestation, even if the land is unproductive. Richards et al. (2014) found that simply clearing forest for pasture leads to a significant rise in land prices, creating strong speculative incentives for deforestation. This is compounded by policies such as Law 13,465 of 2017, widely known as the "Land Grabbing Law, which fixed prices for new land claims at 10-50% of INCRA's assessed land values, which is already below market prices effectively subsidizing speculative clearing. Land owners can later resell these lands for profit, encouraging a cycle of clearing and profit extraction.

Brazil risks incurring massive financial losses if all unallocated lands are sold below market value. Additionally, the ongoing failure to address these structural issues ensures the continued use of deforestation as an instrument for land control and profit generation.

6.4. Pasture as a Livelihood: Economic Realities in the Amazon and Cerrado

While pasture expansion in Brazil is frequently associated with speculative land use and deforestation, it’s important to acknowledge that cattle ranching also serves as a primary source of income for many in the Amazon and Cerrado regions. Approximately 70% of deforested land in the Amazon is utilized for cattle ranching, underscoring its significance in the region’s economy (Lima Filho et al., 2021).

Smallholders have increasingly adopted cattle ranching as a viable livelihood strategy. Studies indicate that even traditional extractivist communities, such as rubber tappers, have transitioned to cattle ranching as their primary source of income due to its economic benefits. This shift is often driven by the need for income security, the availability of government subsidies and loans for cattle raising, and the challenges associated with other forms of agriculture in these regions (Ubiali & Alexiades, 2022).

However, the profitability of cattle ranching varies. Research has shown that while ranching provides a steady income, it often yields lower returns per hectare compared to other agricultural activities, especially for low intensity pastures. For instance, in the eastern Amazon state of Pará, cattle ranching generates approximately $250 per hectare annually, whereas fruit and horticultural production can yield up to $3,300 per hectare. Despite this, many farmers continue to engage in cattle ranching due to factors such as market accessibility, cultural practices, and the relative ease of cattle management compared to more labor-intensive crops (Garrett & Ferreira, 2017).

In the Cerrado biome, cattle ranching has similarly played a fundamental role in land occupation and economic development. The region’s vast pastures support extensive livestock operations, which are integral to both local economies and Brazil’s position as a leading global beef exporter. Yet, this expansion has also led to significant environmental impacts, including soil degradation and biodiversity loss (Oliveira et al., 2020).

7. Conclusion

The trends presented here highlight that cattle ranching, soy farming, and land grabbing each play a distinct but interrelated role in driving deforestation in the Brazilian Amazon and Cerrado, with cattle and land grabbing emerging as the most immediate and extensive drivers, and soy functioning increasingly as a powerful, though indirect force.

Cattle ranching has been the most visible and widespread proximate cause of deforestation over the past 35 years, with pasture expansion accounting for the majority of cleared forest, especially in the Amazon and Cerrado biomes. Its role, however, is complex: while often linked to low-productivity and speculative land use, cattle ranching is also a key livelihood for many smallholders. Despite its economic importance, much of this expansion occurs with low stocking rates and underutilization, suggesting that in many cases, pasture serves as a placeholder for land claims more than productive intent.

Soy cultivation, on the contrary, contributes more subtly to forest loss. Direct soy-driven deforestation remains limited compared to pasture, particularly after policy interventions like the Amazon Soy Moratorium. However, soy acts as a major indirect driver by displacing pasture, which in turn pushes cattle deeper into forest frontiers—a dynamic known as the displacement effect. This process has accelerated land use change in key regions such as Pará and Matopiba, indicating that soy, while not the primary front-line cause of deforestation in the Amazon, plays a significant role in perpetuating and intensifying land conversion patterns.

Finally, land grabbing emerges as a structural and often under-acknowledged driver of deforestation. Legal loopholes, weak enforcement, and speculative incentives have made forest clearing a low-risk, high-reward strategy for acquiring land titles, particularly on public and undesignated lands. This creates a feedback loop where deforestation becomes the currency of land speculation, fueling both pasture expansion and, eventually, crop production.

Changing Uses of Deforested Land in the Brazilian Amazon and Cerrado

Land use change in Brazil is often complex and dynamic, featuring simultaneous processes of expansion, with conversion of native vegetation due to pasture or crops; abandonment, which usually entails regrowth of secondary forest; and intensification, such as low productivity pasture replacement by high productivity crops (Caballero et al., 2023). Patterns of land use following deforestation in Brazil provides critical insights into the economic, political, and territorial dynamics driving this environmental change. A growing body of research, supported by long-term satellite data such as MapBiomas and PRODES, shows that deforestation in the Amazon and Cerrado biomes is rarely a one-time, static event. Instead, it initiates a sequence of land transitions that vary across time, space, and scale. These land use trajectories —whether forest is replaced by and maintained as pasture, converted to crops, or eventually abandoned— not only reflect evolving market demands and infrastructure expansion, but also shifts in governance, land tenure, and investment strategies. The synthesis below draws from multiple studies and our own data analysis to examine how deforested land is used over time, what these patterns reveal about why land is cleared, and how such transitions differ between new and old deforestation fronts and across biomes.

1. Trajectories of Land Use After Deforestation

Since the 1960s, deforestation in the Brazilian Amazon has followed a dominant trajectory: forests are cleared for cattle pasture, and then, often years later, sometimes converted to agriculture—especially soy cultivation (Seixas et al., 2025). This pasture-first pathway remains the most common sequence, although direct conversion from forest to cropland (particularly soy) does occur, albeit less frequently (Gibbs et al., 2015). Between 1985 and 2023, over 60 million hectares (Mha) of forest were converted to agriculture in the Amazon biome, but only about 9% of these transitions were direct conversions to crops without an intermediate pasture phase (Seixas et al., 2025).This pattern is partly explained by the low-capital requirements of cattle ranching, which allow for rapid land occupation following deforestation, often as a speculative strategy to secure land tenure or enable future land sales (Bowman et al., 2012). Moreover, cleared forest lands are often initially unsuitable for mechanized cropping due to poor soils and lack of infrastructure, and it often takes up to three years to prepare land for soy crops, requiring a period of pasture use to stabilize land use or build capital (Walker et al., 2009; Richards et al., 2014).

The lag between deforestation and agricultural establishment however, has decreased over time. In the earliest period for which we have data available (1985–1995), conversion from forest to agriculture typically took more than 10 years (Seixas et al., 2025). However, by the early 2000s, this transition had accelerated markedly. In the peak deforestation year of 2003, nearly half of the transitions occurred within just two years (Seixas et al., 2025). This faster turnover indicates increasingly deliberate and economically motivated deforestation, driven by high commodity prices and enabled by infrastructure expansion.

The intensity of land use change is linked both to population growth in rural areas and to the market demands for different agricultural products. In Brazil, the accelerated rates of land conversion over the last few decades have been strongly tied to international trading prices of soy and beef, specifically influenced by China along with increasing demand for biofuels in Europe (Espírito-Santo et al., 2016).

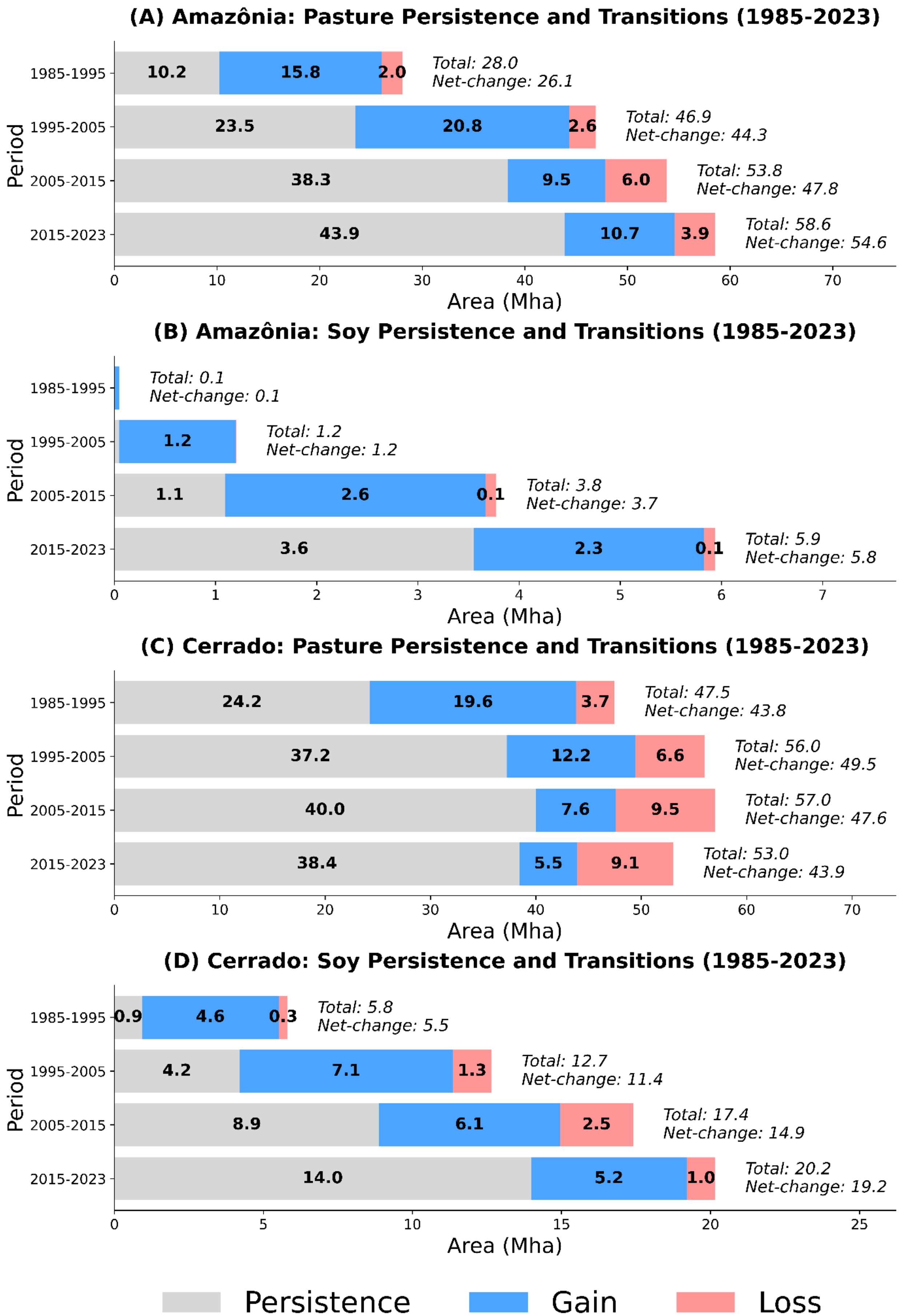
2. Patterns of Land Use Change: First, Second, and Third Uses

First use: Most deforested land is initially converted to **pasture**. MapBiomas and Landsat data (one of the world's most comprehensive satellite imagery archives) have both been used to identify pasture as the dominant first land use, responsible for over 60 Mha of forest loss since 1985. This land use transition is widespread across all biomes but particularly concentrated in the Amazon and Cerrado.

However, pasture is not always a stable long-term land use: some pastures persist for decades, especially in remote or poorly connected regions, while others are rapidly converted to cropland particularly in the Amazon-Cerrado transition and southern Mato Grosso (**Figure 2.1**). Still others are abandoned, often due to remoteness, economic marginalization or policy enforcement, leading to secondary vegetation growth (Alves et al., 2003).

Second use: Over time, some pasturelands transition to **croplands**, especially in regions like southern Mato Grosso and the Amazon-Cerrado border. The most common crop in these transitions is **soy**, which frequently replaces degraded or underutilized pasture. In the Cerrado, this often forms part of a double-crop regime (e.g., soy-corn). Soy tends to be a stable land use category (**Figure 2.1**); once an area is converted to soy, it almost always persists as soy for at least the next 5 years.

Third use: Other temporary crops are less stable when compared to soy, with over 50% of them transitioning to soy and 15% to pasture within the first 5 years (Seixas et al., 2025). Additionally, some previously cleared lands are **abandoned** and undergo natural or assisted reforestation. Degraded pastures that are no longer productive and policy enforcement targeted at stopping primary forest loss, have been shown to result in regrowth of **secondary forest** (Assunção et al., 2017). Between 1985 and 2020, a quarter of all cleared land in the Amazon was re-vegetated with secondary forests. This regrowth is especially notable in the northeastern Amazon, and to a lesser extent in the Cerrado. Secondary forest has also shown increasing deforestation trends, although at a much lower rate than primary forest (Caballero et al., 2023).



(A) Amazônia: Pasture Persistence and Transitions (1985-2023)
1985-1995
10.2
15.8
2.0
Total: 28.0
Net-change: 26.1
1995-2005
23.5
20.8
2.6
Total: 46.9
Net-change: 44.3
2005-2015
38.3
9.5
6.0
Total: 53.8
Net-change: 47.8
2015-2023
43.9
10.7
3.9
Total: 58.6
Net-change: 54.6
Period
Area (Mha)
0
10
20
30
40
50
60
70
(B) Amazônia: Soy Persistence and Transitions (1985-2023)
1985-1995
Total: 0.1
Net-change: 0.1
1995-2005
1.2
Total: 1.2
Net-change: 1.2
2005-2015
1.1
2.6
0.1
Total: 3.8
Net-change: 3.7
2015-2023
3.6
2.3
0.1
Total: 5.9
Net-change: 5.8
Period
Area (Mha)
0
1
2
3
4
5
6
7
(C) Cerrado: Pasture Persistence and Transitions (1985-2023)
1985-1995
24.2
19.6
3.7
Total: 47.5
Net-change: 43.8
1995-2005
37.2
12.2
6.6
Total: 56.0
Net-change: 49.5
2005-2015
40.0
7.6
9.5
Total: 57.0
Net-change: 47.6
2015-2023
38.4
5.5
9.1
Total: 53.0
Net-change: 43.9
Period
Area (Mha)
0
10
20
30
40
50
60
70
(D) Cerrado: Soy Persistence and Transitions (1985-2023)
1985-1995
0.9
4.6
0.3
Total: 5.8
Net-change: 5.5
1995-2005
4.2
7.1
1.3
Total: 12.7
Net-change: 11.4
2005-2015
8.9
6.1
2.5
Total: 17.4
Net-change: 14.9
2015-2023
14.0
5.2
1.0
Total: 20.2
Net-change: 19.2
Period
Area (Mha)
0
5
10
15
20
25
Persistence
Gain
Loss

Figure 2.1. Land use persistence and transition in pasture and soybean areas in the Amazon and Cerrado biomes (1985–2023). Panels (A) and (B) show pasture and soybean area transitions in the Amazon biome, respectively; panels (C) and (D) show the same for the Cerrado. Each bar represents a specific period and indicates the area (in million hectares, Mha) that remained stable (gray), expanded (blue), or contracted (pink) for each period. Total and net changes (Total minus losses) are noted for each period.

3. Differences Across Deforestation Front and Biomes

Older fronts of deforestation: The Arc of Deforestation is a region where the agricultural border continually pushes into the forest and where the highest rates of forest loss are located. It now represents nearly 500,000 km2 of land and runs from the East and South of the Brazilian state of Pará towards the West, passing through the states of Mato Grosso, Rondônia, and Acre. In these older fronts of deforestation, forests have been replaced by consolidated zones of agriculture and cattle ranching. These areas saw deforestation peaking before 2010, when there were longer time lags between forest clearing and crop establishment. Conversion here now occurs at a more stable pace, largely due to dramatically reduced forest areas, and often involves established landholders expanding cultivation and ranchlands on their properties and is influenced by proximity to infrastructure and markets.

Newer fronts of deforestation: New frontier areas in central Amazon, south Amazonas, and the center of Pará now exhibit more rapid forest clearing and land turnover as they creep deeper into the forests. These zones, which are typically more remote and may emerge near newly constructed roads or energy infrastructure, are characterized by speculative land acquisition, large-scale cattle operations, and weak governance. Deforestation in these areas often occurs ahead of policy enforcement or formal land titling, making them highly dynamic and vulnerable to illegal activities. Low land prices, compared to those in consolidated fronts, make these areas particularly appealing to speculators (Yanai et al., 2022).

At the municipality level, most deforestation is concentrated in new fronts opening either along areas of infrastructure development, such as highways, dams and ports or in areas where large expanses of forest remain standing (Carrero et al., 2022). Factors that lead to quick land use turnovers are isolation, lack of public policy implementation, lack of formal land titles and of proper infrastructure.

Biome-level variation:

Over the past four decades, widespread habitat loss has occurred across all of Brazil’s biomes. From 1985 to 2006 most land use transitions involved conversion of primary vegetation for pasture: native vegetation loss adds up to a third of all land use change since 1985, ~40% of which occurred in the Amazon and ~34% in the Cerrado. After that, conversion to soy and other agricultural uses, both from pasture and native vegetation, became the primary conversion, representing 31% of all land use change. Between 2004 and 2012—a period of heightened governance as the Brazilian government, the private sector, and civil society sought to address record levels of deforestation, leading to the implementation of policies like the Amazon Soy Moratorium and the 2012 Forest Code—forest-to-pasture conversions slowed, but pasture-to-soy transitions increased. Around 10% of all land use change corresponded to vegetation gain, with 30% taking place in the Cerrado and 25% in the Amazon (Souza et al., 2020). However, after 2012, deforestation once again accelerated, driven by both direct soy expansion (largely outside of the Amazon biome) and indirect pathways via pasture.

The **Amazon biome** leads in overall forest loss and agricultural expansion (4.6% annual growth). Until 2010, most land use change in the Amazon biome corresponded to loss of native vegetation for the expansion of pasture (**Figure 2.2**) along the Southern-Eastern borders of the biome, known as the Arc of Deforestation. This area, although still expanding, is now largely consolidated agricultural and cattle ranching land. Starting in 2013, new fronts of deforestation moved towards the center of the biome, where a few dozen municipalities are responsible for 90% of the Amazon deforestation. These municipalities can be characterized as either being sites for the development of new infrastructure, such as roads and dams, or for having smallholder settlements where agriculture was expanding (Carrero et al., 2022). Rural settlement agriculture has become a substantial deforestation driver in Brazil's Amazon, propelled by insecure tenure, lot consolidation, inadequate planning, and credit policies favoring pasture. Unlike agribusiness—which clears vast tracts for soy or cattle—settler-driven deforestation is more fragmented, often initiated prematurely to establish land claims, and frequently transitions into parcel consolidation and cattle pasture. Since 2022, forest loss has also been elevated in the center of Pará, along the BR-163 and in the South of Amazonas state (Souza et al., 2023).

Pasture transition to crops and pasture abandonment also takes place in this biome but are still quite minimal when compared to forest conversion to pasture (**Table 2.1**). While over 46 Mha of forest were cleared for pasture over the last four decades, 2 Mha of pasture were abandoned and only 27,000 were converted to crops (Souza et al., 2023). Additionally, over 120,000 ha have transitioned directly from forest to crops. Out of these, 600 ha were abandoned with the subsequent regrowth of secondary forest, and 28,000 were later converted to pasture.

There was a notable rise in the abandonment of pasture and conversion to crops between 1998 and 2004 (by 1.5 and 20-fold respectively). During this time, farmers also increasingly cleared forest directly for crops, and some croplands were later abandoned as well (5-fold and 2-fold). In the following years after 2004, the pace of deforestation slowed. More pastureland was being turned into cropland than the reverse, and a significant amount of previously cleared land—both pasture and cropland—began to regenerate naturally, becoming secondary forest, adding up to nearly 3 Mha. However, starting 2013, forest loss increased again, driven largely by expanding pasture (~1.4 Mha annually) with cropland also contributing to forest loss, though to a lesser extent (44,000 ha annually)(Souza et al., 2023).

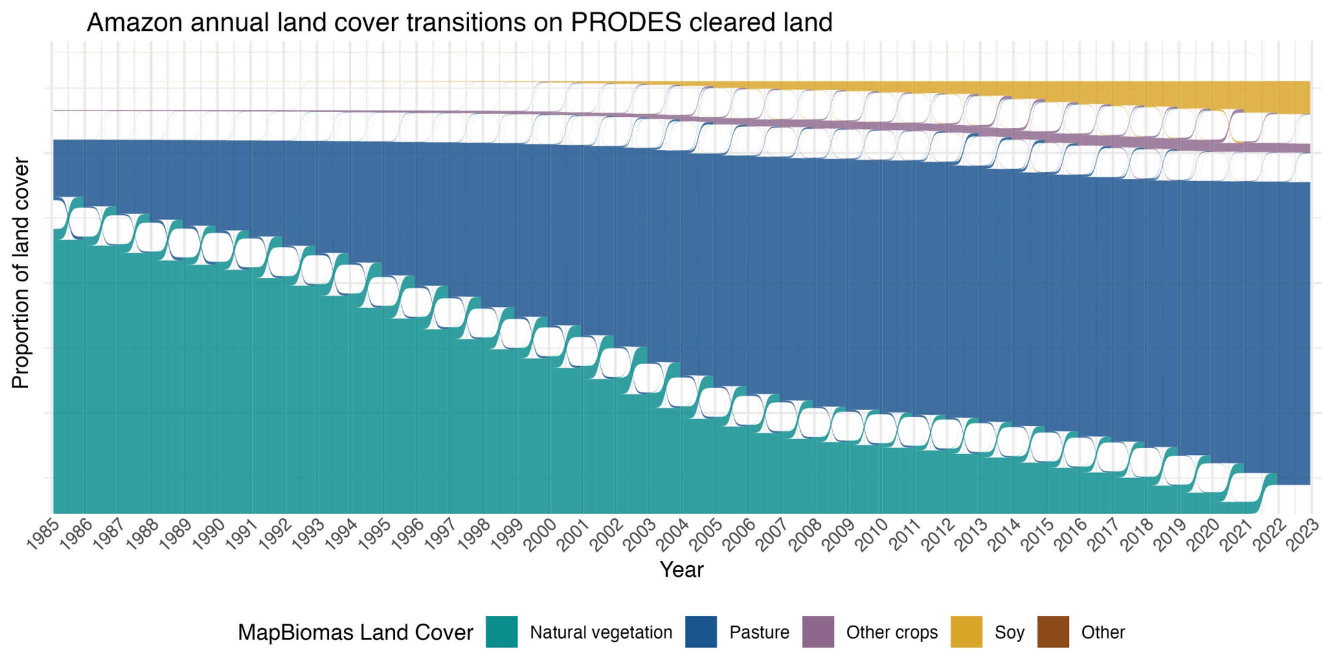


Figure 2.2. Sankey flow showing land use transitions between different land cover types in the Amazon biome, from 1985 to 2023.

Table 2.1. Percentages of land use transitions between different land cover types in PRODES cleared areas for the Amazon biome, from 1985 to 2023, based on Mapbiomas 9.0.

From class	To class	1985-1995	1995-2005	2005-2015	2015-2023
Natural vegetation	Natural vegetation	58.2	26.7	13.5	0
Natural vegetation	Pasture	23.6	31.1	13.7	14.8
Natural vegetation	Other crops	0.3	1.1	0.4	0.2
Natural vegetation	Soy	0.1	1.1	0.4	0.3
Natural vegetation	Other	0	0	0	0
Pasture	Natural vegetation	1.9	1.3	1.7	0
Pasture	Pasture	15.5	36.5	61.3	72.3
Pasture	Other crops	0.2	0.7	2.1	1
Pasture	Soy	0	0.6	2.7	1.9
Pasture	Other	0	0	0	0
Other crops	Natural vegetation	0	0	0	0
Other crops	Pasture	0.1	0.1	0.2	0.4
Other crops	Other crops	0.1	0.4	0.8	1.5
Other crops	Soy	0	0.2	1.2	1.6
Other crops	Other	0	0	0	0
Soy	Natural vegetation	0	0	0	0
Soy	Pasture	0	0	0.1	0
Soy	Other crops	0	0	0.1	0.2
Soy	Soy	0	0.1	1.8	5.9

From class	To class	1985-1995	1995-2005	2005-2015	2015-2023
Soy	Other	0	0	0	0
Other	Natural vegetation	0	0	0	0
Other	Pasture	0	0	0	0
Other	Other crops	0	0	0	0
Other	Soy	0	0	0	0
Other	Other	0	0	0	0

The **Cerrado biome** has been subject to even higher land-change pressure than the Amazon biome. Despite lower annual areas of deforestation, the Cerrado has experienced high forest conversion rates (0.6% per year) and the most conversion to intensive agriculture, with pasture frequently converted to soy (**Figure 2.3**). Like the Amazon, native vegetation to pasture was the most widespread transition in the Cerrado during our study period, however, both pasture and native vegetation conversion to soy have progressively increased (**Table 2.2**).

Native vegetation regeneration, from abandoned pastures and croplands, happened at a much smaller rate, but was still significant during this period. Over 60% of all pasture in the Cerrado has been catalogued as degraded. While most degraded pasture tends to be abandoned and results in regrowth, a quarter of all cleared land since 1985 had been regrown as secondary forest by 2020 (Caballero et al., 2023), some areas have been degraded to the point of desertification and cannot naturally regenerate (Espírito-Santo et al., 2016).

The Cerrado is currently responsible for nearly 50% of Brazil’s grain production and has approximately 27 Mha of native vegetation areas that could be legally cleared for agriculture if demand keeps rising. Unlike the Amazon, where around 30% of the area is protected, only 7% of the Cerrado area is currently protected land (Polizel et al., 2021).

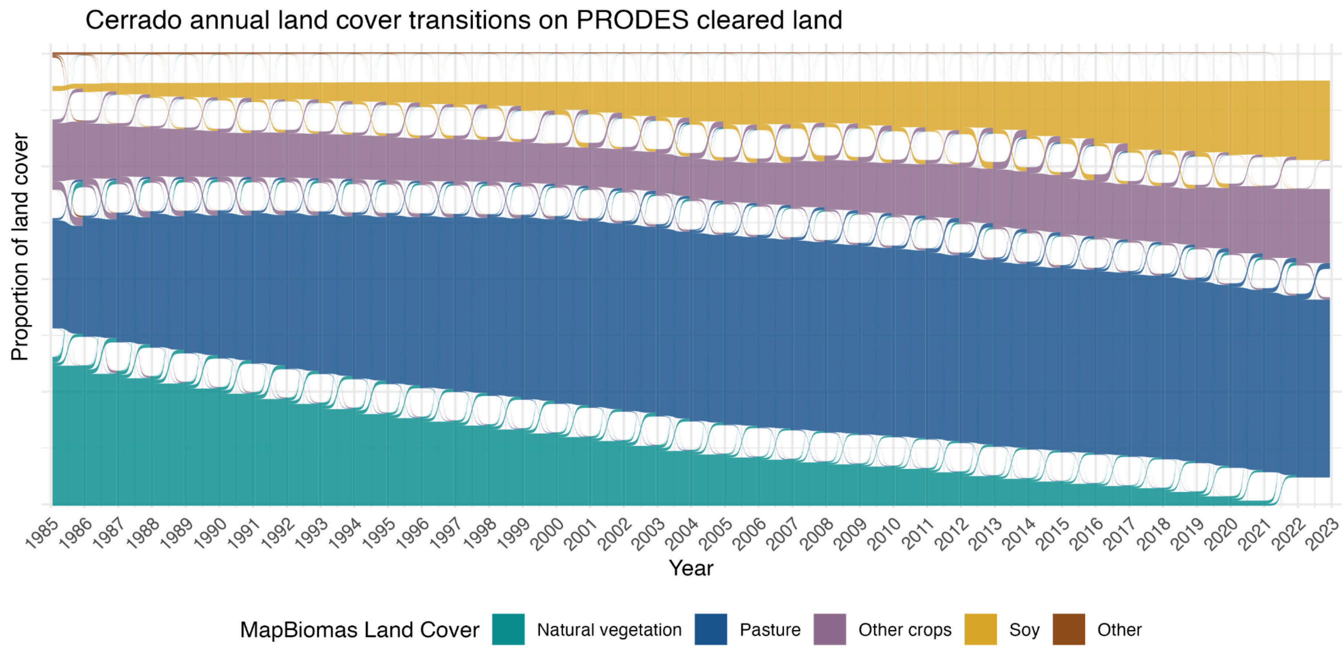


Figure 2.3. Sankey flow showing land use transitions between different land cover types in PRODES cleared areas for the Cerrado biome, from 1985 to 2023.

Table 2.2. Percentages of land use transitions between different land cover types in PRODES cleared areas for the Cerrado biome, from 1985 to 2023.

From class	To class	1985-1995	1995-2005	2005-2015	2015-2023
Natural vegetation	Natural vegetation	25.0	13.9	6.2	0.0
Natural vegetation	Pasture	12.2	8.4	5.1	4.0
Natural vegetation	Other crops	4.7	2.4	2.1	2.9
Natural vegetation	Soy	1.6	2.6	1.8	0.5
Natural vegetation	Other	0.2	0.2	0.1	0.0
Pasture	Natural vegetation	0.7	0.8	0.8	0.0
Pasture	Pasture	28.5	43.5	47.2	46.9
Pasture	Other crops	2.4	3.5	6.3	6.7
Pasture	Soy	0.8	2.4	2.2	1.5
Pasture	Other	0.0	0.1	0.1	0.0
Other crops	Natural vegetation	1.6	0.7	0.3	0.0
Other crops	Pasture	8.7	4.2	2.2	1.8
Other crops	Other crops	7.2	6.6	8.0	12.8
Other crops	Soy	3.0	3.5	3.3	4.3
Other crops	Other	0.1	0.0	0.0	0.0
Soy	Natural vegetation	0.0	0.0	0.0	0.0
Soy	Pasture	0.1	0.3	0.5	0.1
Soy	Other crops	0.3	1.3	2.4	1.1

From class	To class	1985-1995	1995-2005	2005-2015	2015-2023
Soy	Soy	1.1	5.1	10.9	17.2
Soy	Other	0.0	0.0	0.0	0.0
Other	Natural vegetation	0.1	0.0	0.0	0.0
Other	Pasture	0.9	0.2	0.1	0.1
Other	Other crops	0.3	0.1	0.1	0.1
Other	Soy	0.1	0.1	0.1	0.1
Other	Other	0.1	0.1	0.0	0.0

4. Secondary Use Evolution and Factors Determining Land Fate

Evolving Secondary Use:

- **Soy stability**: Soy plantations tend to be persistent, reflecting the level of investment required to prepare fields for soy production; about 80% of soy-covered land remained in soy use for at least five years.

- **Other temporary crops**: Crops such as corn and cotton tend to be shorter-term land uses —over half transition to soy within five years, and 15% revert to pasture.

- **Abandoned pastures**: Regeneration of secondary forest is more common in marginal lands or where policy enforcement is stronger.

Determinants of Land Use Fate:

- **Persistence of pasture**: Linked to remoteness, lack of infrastructure, poor soil quality, and speculative landholding.

- **Conversion to crops**: More likely to occur where there is access to infrastructure (e.g., roads, ports), capital, and proximity to agro-industrial hubs.

- **Reforestation**: More common in abandoned lands, areas of legal enforcement (e.g., protected areas), or in places with unsuitable conditions for agriculture.

5. Conclusion

Land use change in the Amazon and Cerrado follows distinct but evolving patterns that reflect both historical trajectories and contemporary policy and market dynamics. While soy transitions have attracted considerable attention and expanded rapidly, particularly in regions with infrastructure and market access, and attract considerable attention, pasture remains by far the dominant land use transition in both biomes. Indeed, the scale of pasture expansion dwarfs that of soy, especially in the Amazon biome. Between 1985 and 2023, over 60 Mha of forest were converted to agriculture in the Amazon biome, with over 76% of it being cleared for pasture, compared to less than 1% directly converted to crops. In the Cerrado, although deforestation rates are lower, pasture replacement for intensified crops has been more pronounced. However, native vegetation conversion to pasture remained the most frequent land use transition here as well.

These transitions however are not static; in the Amazon, the time lag between forest clearing and cropland establishment has shortened considerably, which suggests a shift towards more intentional, economically driven deforestation. At the same time, an increase in land abandonment and regrowth in some areas offers glimpses of recovery but remains limited and unable to reverse the border pattern of land conversion.

Understanding these patterns—particularly the sequence and timing of land uses—is essential for designing effective conservation policies and addressing the deeper structural drivers of deforestation. Policies should target not just the final land use, but also the intermediate phases of land use transition. Coordinated land use planning, improved governance in frontier regions, and enforcement of legal frameworks are essential to curb continued deforestation and manage already-cleared lands more sustainably.

Social insights: Understanding farmers' decisions and motivations to clear forest

1. **Rural population social profile**

The population of the Brazilian Amazon is highly urbanized, with around 24 million of the nearly 30 million people who reside there living in cities (Margolis, 2024). The Cerrado is even more urbanized, while it has 4 times the population of the Amazon biome, it only has twice as many rural residents there. The rural population in both biomes is made up largely of households that participate in the agricultural sector. Both regions have seen massive influxes of migrants from other parts of Brazil over the last four decades, as the agricultural sector and other economic sectors have grown in importance in these regions. We used 2010 and 2017 census data (the most recent available) to profile this population. Around 6.6% of the rural residents in the Amazon have less than 10 years of residency in the state they currently reside in, with Maranhão (20.3%) and Roraima (9.5%) having the highest rates of recent arrivals (**Table 3.1**). Around 4.4% of Cerrado rural residents have less than 10 years of residency in the state where they currently reside. The Cerrado states with the highest rates of recent arrivals were the Distrito Federal (20.8%) and Mato Grosso (13%). Rural migration, either to other rural areas or to urban centers, will likely become increasingly common due to climate change reshaping farming and pasture suitability in certain regions. Lower income men are usually more prone to migrate in these cases (Salerno et al., 2024).

The rural population in the Amazon and Cerrado biomes is predominantly male (IBGE, 2010). Cattle ranchers were 84% male in the Amazon, and 82% in the Cerrado, while temporary crop farmers were 79% and 80% male in the two biomes, respectively (**Figures 3.1 & 3.2**). Cattle ranchers were predominantly middle aged, falling mostly in the 45-65 range, both for men and women in the Amazon (48% and 44%) and the Cerrado (49% and 44%). Indeed, as younger generations have become more involved in family farming, the average age for farmers in Brazil has dropped to 46 years old (Bloomberg, 2024). The same was true for male and female crop farmers in the Cerrado (48% and 43%) while crop farmers in the Amazon skew slightly younger, peaking at the 35-55 range (46% and 44%) (IBGE, 2010).

Table 3.1: Total and percentage of the rural population that has less than 10 years of residency per state for the Amazon (purple) and Cerrado (blue) biomes. Based on the IBGE 2010 census. *Mato Grosso is included in both biomes' averages.

State	Total rural population	Population under 10 years residency	% Population under 10 years residency
Rondônia	413229	25747	6.23%
Acre	201280	5834	2.90%
Amazonas	728495	17256	2.37%
Roraima	105620	9987	9.46%
Pará	2389492	116603	4.88%
Amapá	68490	5087	7.43%
Maranhão	2427640	59628	20.33%
Mato Grosso*	552321	71823	13.00%
Total Amazon Biome	**6886567**	**311965**	**6.56%**
Mato Grosso*	552321	71823	13.00%
Piauí	1067401	34578	1.42%
Bahia	3914430	116350	2.97%

State	Total rural population	Population under 10 years residency	% Population under 10 years residency
Minas Gerais	2882114	104760	3.63%
São Paulo	1676948	106936	6.38%
Paraná	1531834	64759	4.23%
Mato Grosso do Sul	351786	28162	8.01%
Goiás	583074	60398	10.36%
Distrito Federal	87950	18288	20.79%
Tocantins	293339	26372	8.99%
Total Cerrado Biome	**12941197**	**632426**	**4.42%**

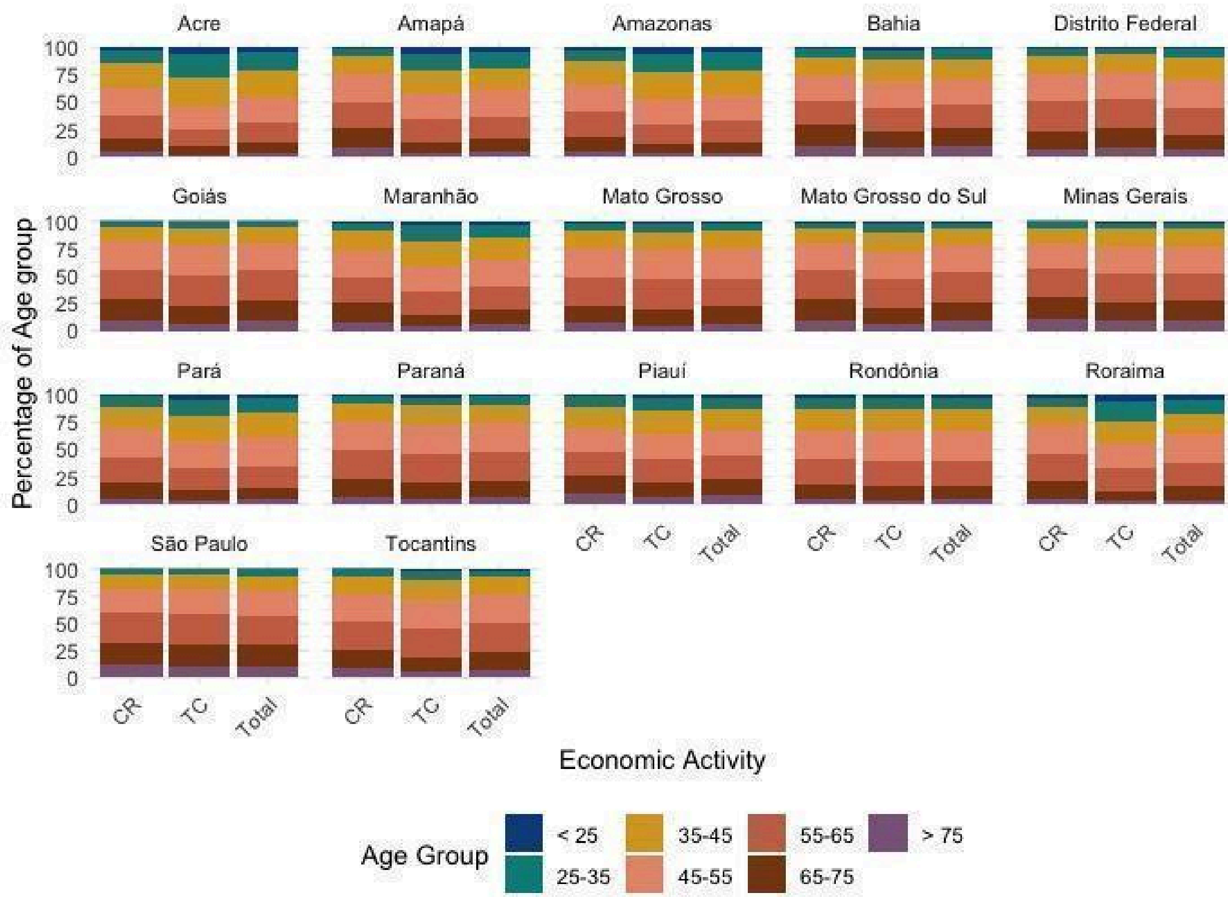


Figure 3.1. Age distribution by economic activity (CR= Cattle ranching; TC= Temporary crops including soy) and state for men in the Amazon and Cerrado biomes. Based on the IBGE 2010 census.

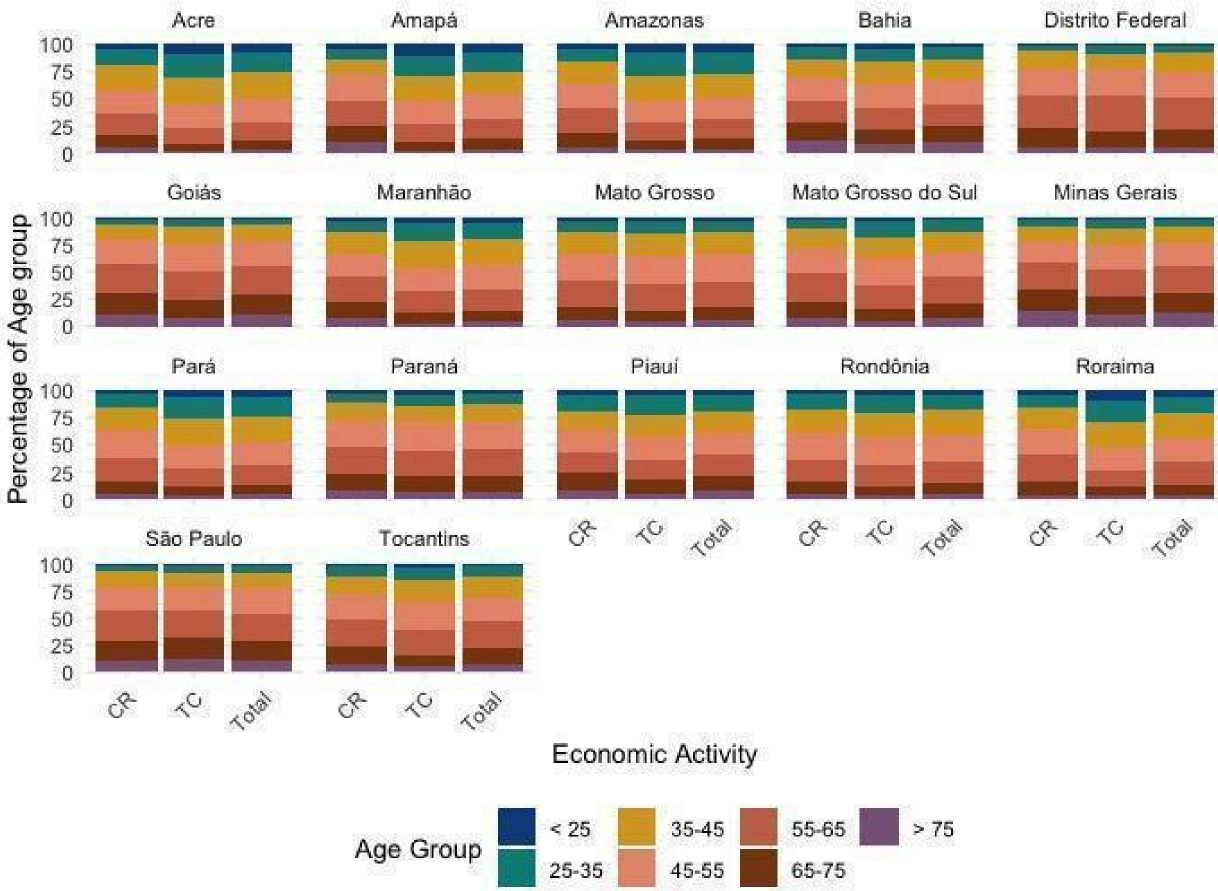


Figure 3.2. Age distribution by economic activity (CR= Cattle ranching; TC= Temporary crops including soy) and state for women in the Amazon and Cerrado biomes. Based on the IBGE 2017 census.

Families tend to be large in the Amazon biome compared to the country wide trends, with nearly a fifth of all households having 3 or more children, though a third have no children at all (**Figure 3.3**), while over 40% of the overall population have no children and only 10% have 3 or more. Larger households are often associated with subsistence production and agrarian reform settlements, in which lower income families are offered access to land and technical assistance to support subsistence farming and other rural economic activities (de Sherbinin et al., 2008; Schneider & Peres, 2015). In these contexts, families typically rely on family labor for agricultural land, making family size an important asset. These households are commonly located in settlement projects established through federal land reform programs, such as INCRA. Only 10% of families in the Cerrado biome had 3 or more children, while nearly 40% had no children at all.

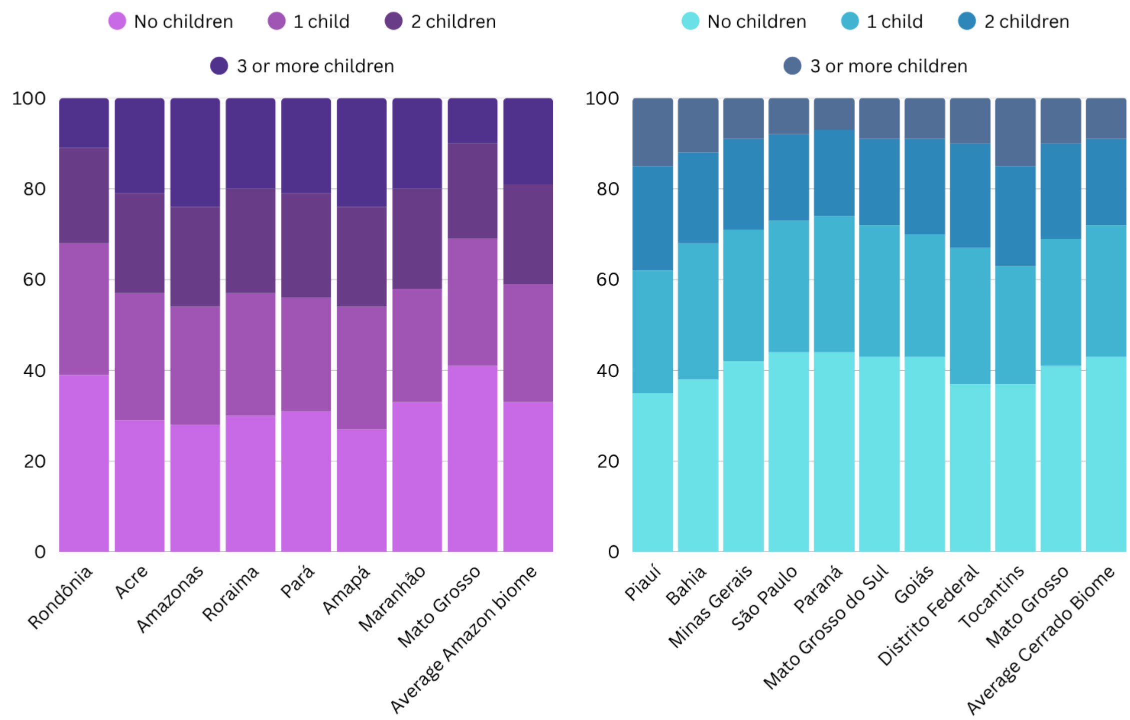


Figure 3.3. Average number of children per family per state for the Amazon (purple) and Cerrado (blue) biomes. Based on the IBGE 2010 census.

The education level for the rural population is low across both biomes (**Figure 3.4**), but the Cerrado shows slightly higher indicators, especially in the Southern and Southeastern states. Illiteracy rates were as high as 30% in the Amazon and 28% in the Cerrado; only 7% of rural residents have finished high school in the Amazon, with twice as many having finished high school in the Cerrado. Both are lower than the average in Brazil, where roughly half of people above the age of 25 years have high school diplomas.

Rural incomes were lower in the Amazon biome than in the Cerrado biome, averaging R$620/month in the Amazon, as of 2017, and R$790/month in the Cerrado. Rural incomes were substantially lower than urban incomes and overall incomes in both biomes (**Table 3.2**). Soy-dominated regions, like the municipality of Sorriso, can have very high GDPs, which can mask considerable inequality (Mongabay, 2024). In general, incomes for soy farmers, as well as for more capitalized ranchers, can be very high, while large portions of rural populations may persist based on subsistence activities and have very low incomes.

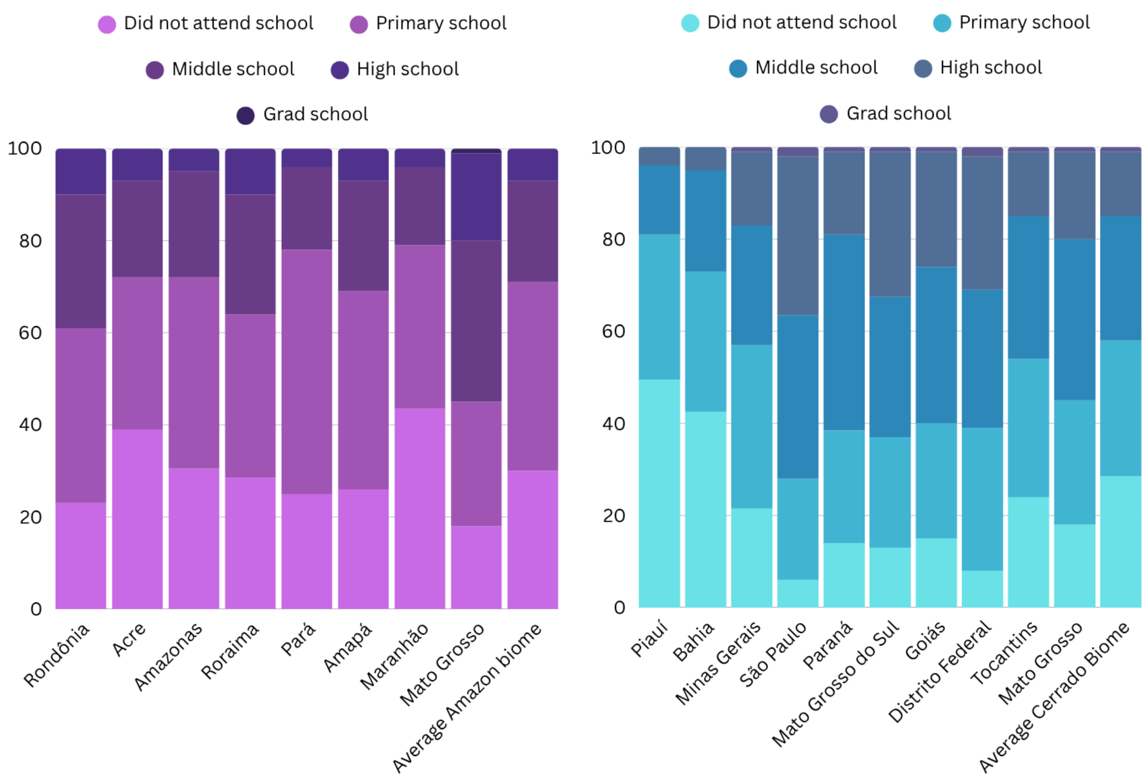


Figure 3.4. Education level of rural population per state for the Amazon (purple) and Cerrado (blue) biomes. Based on the IBGE 2017 census.

Table 3.2. Average income of the general and rural population per state for the Amazon (purple) and Cerrado (blue) biomes. Based on the IBGE 2010 census.
*Mato Grosso is included in both biomes' averages.

State	Average total population income	Average rural population income
Rondônia	1181.12	744.27
Acre	1092.49	570.49
Amazonas	1166.76	485.62
Roraima	1234.76	644.78
Pará	926.54	526.56
Amapá	1238.01	663.67
Maranhão	747.32	436.43
Mato Grosso*	1304.97	887.98
Average Amazon Biome	**1111.5**	**619.98**
Mato Grosso*	1304.97	887.98
Piauí	797.81	403.21
Bahia	897.82	428.07
Minas Gerais	1212.73	670.72
São Paulo	1721.96	974.96
Paraná	1397.98	831.09
Mato Grosso do Sul	1327.57	804.4

State	Average total population income	Average rural population income
Goiás	1311.86	910.51
Distrito Federal	2793.89	1395.83
Tocantins	1077.28	596.18
Average Cerrado Biome	**1384.39**	**790.3**

Land inequality in Brazil, and specifically in the Amazon and the Cerrado, is substantial. In general, there are many more small properties than large properties, though most land is concentrated on large properties. In the Amazon states, there are fewer properties overall, compared to the Cerrado, with most of them in small and mid-size categories, and with few large producers (**Figure 3.6**). The holdings of cattle ranchers, the dominant group by activity, largely define these trends; cattle ranchers are mostly smallholders, with the dominant property size being 20-50 ha[1]. Nearly three quarters of cattle properties are under 100 ha, and there are just a small number of ranches larger than 500 ha (2.5% of cattle ranches). Farms with temporary crop production in the Amazon were more mixed in size, but overall smaller than cattle ranches, with 90% of all farms being less than 100 ha; however, soybean production tends to be more prevalent on larger landholdings (> 300 ha) due to the investment required and the benefits of economies of scale in this sector (P. Pacheco, 2012; Brown et al 2008).

Cerrado states have smaller cattle properties than Amazon states, on average (181 ha in the Amazon vs 119 ha in the Cerrado), but larger temporary crops properties, including soy (38 ha in the Amazon vs 105 ha in the Cerrado) (**Figure 3.5**). There are generally more larger farms (>2500 ha) in the Cerrado, both cattle ranches and farms planting temporary crops, in some regions, notably Mato Grosso and Mato Grosso do Sul, where soy farming is particularly prevalent.

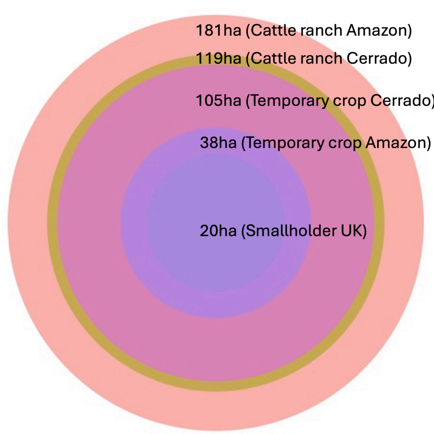


Figure 3.5. Nested diagram with average farm sizes in the Amazon and Cerrado biome and the UK for reference.

1 For reference in the UK, a smallholder farm is legally defined as 20 ha or less, and the average farm size is 82 ha (Gov.uk, 2024).

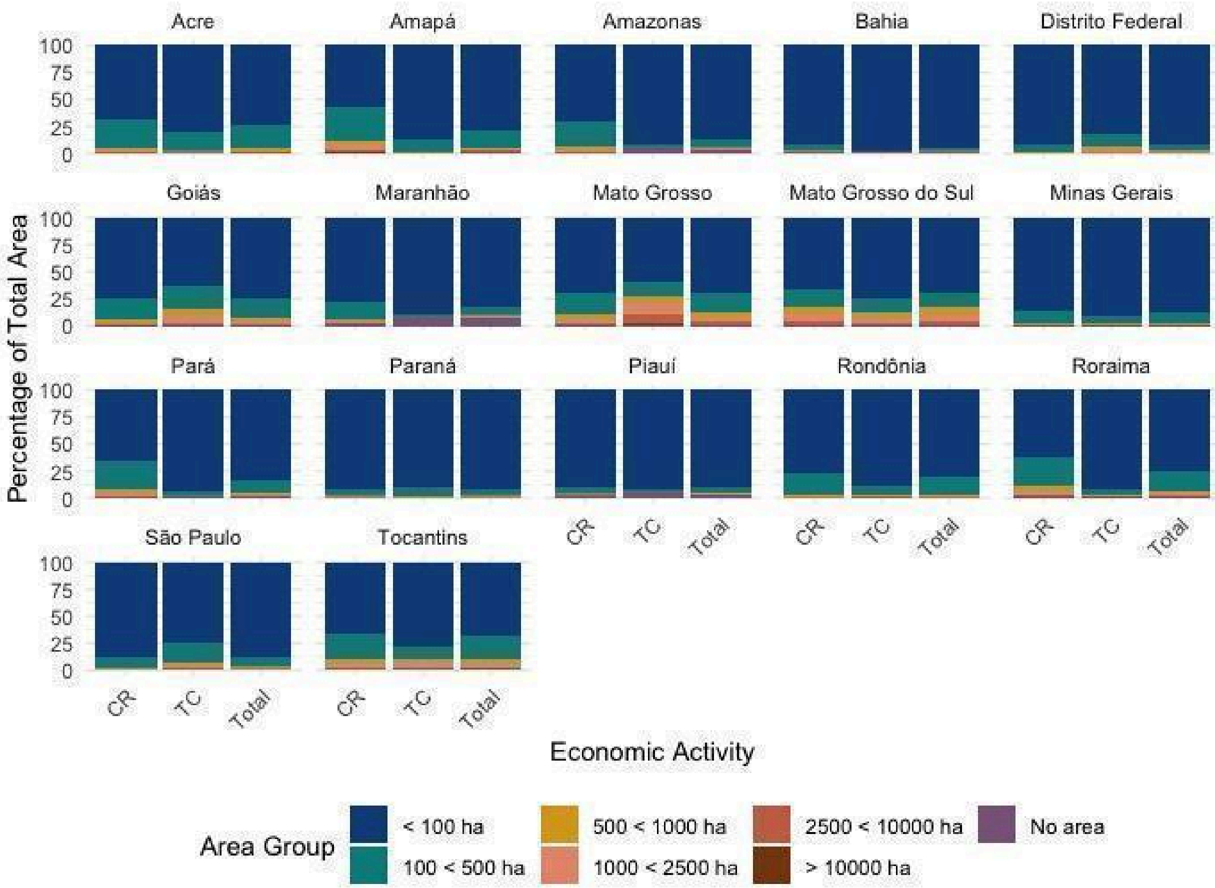


Figure 3.6. Property Area distribution by economic activity (CR= cattle ranching; TC= temporary crops including soy) and state for all Amazon and Cerrado biome states. Based on the IBGE 2017 census.

2. Political alignments of the agricultural sector

The agricultural sector is closely aligned with conservative politics in Brazil. Congressional representatives and senators from conservative parties have developed a voting bloc known as the Ruralist Bloc (*Bancada Ruralista*), which generally seeks to support policies that promote economic development and reduce environmental protection and land reform progress (Killeen, 2025). This alignment of the agricultural sector with conservative politics is particularly strong for producers associated with industrial agriculture activities, like soy and most beef production in the Amazon and the Cerrado; of course, smallholder and subsistence agricultural producers may align less completely with these conservative politics which in some cases (especially in the case of land reform positions) may be against their interests. The dominance of urban populations, even in the agricultural heartlands of the Amazon and the Cerrado, also ensures some variation in the voting choices of residents of these regions.

High deforestation counties, such as those across the Arc of Deforestation in the southern and eastern Amazon, tend to vote for conservative candidates like Jair Bolsonaro (Social Liberal Party, president from 2019-2023) (**Figure 3.7**) (Peres et al., 2023). For example, these trends are prevalent in rural areas in Mato Grosso and Rondônia, and becoming increasingly prevalent in Southern and Eastern Pará, Northern Tocantins and Roraima, which are well consolidated agricultural areas where soy has been replacing cattle pasture. These counties, largely populated by migrants that moved to the Amazon in the last 50 years, also tend to have few employment opportunities, low-income averages and high rates of illegal activities and land grabbing. Most Amazon regions that voted for Lula in the last election, tend to have more remaining forest and to be populated with traditional and native peoples that have more recently experienced encroachment by new settlers (Peres et al., 2023); voting preferences for Lula in the Northeast, including in Cerrado regions dominated by soy such as Matopiba (portions of the states of Maranhão, Tocantins, Piauí and Bahia) can largely be explained by the presence of large urban centers that have traditionally voted for liberal candidates.

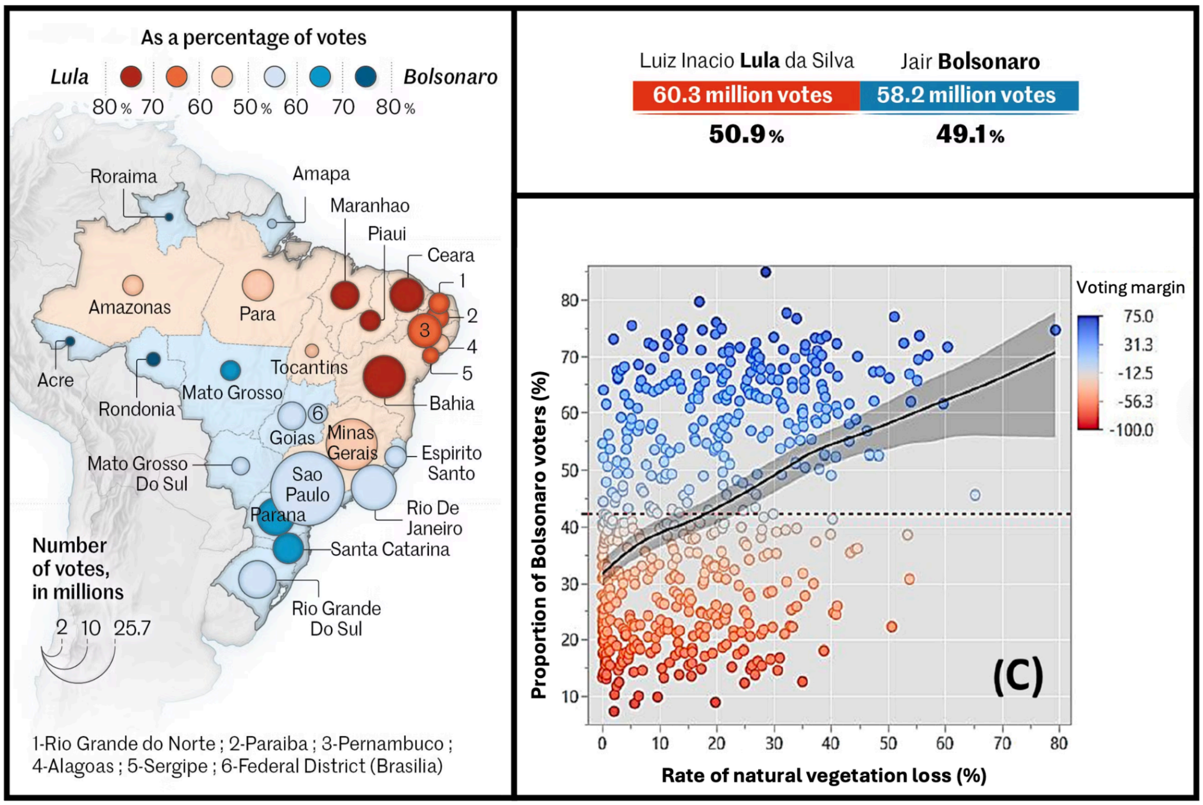


Figure 3.7. Results from the 2022 Brazil second round of presidential elections and positive relationship between county-scale proportion of pro-Bolsonaro votes and cumulative deforestation rates (modified from Le Monde, 2022 and Peres, Campo-Silva & Ritter, 2023)

The relationship between political activity and deforestation can also be explained by other types of links to the agricultural sector. Studies have shown that deforestation tends to increase during the governments of local politicians that have previously worked in the agricultural sector (Rocha & Bragança, n.d.).

3. Production practices and deforestation tendencies

Farmers' decisions to clear forest are shaped by a complex interplay of economic incentives, policy landscapes, and sociocultural factors. While motivations and outcomes vary widely depending on region, property size, and land tenure status, a number of consistent patterns emerge. These patterns offer insights into the drivers of deforestation across Brazil's diverse socio-environmental contexts, particularly within the Amazon and Cerrado biomes.

In the Amazon, most deforestation takes place outside of formally recognized production areas of both cattle and soy. These areas are largely frontier zones where deforestation precedes productive agricultural activities, highlighting the speculative component of deforestation in this region. However, a substantial amount of the deforestation, mostly going beyond the legal limit prescribed by the Forest Code, also occurs on active cattle and soy properties, reflecting the overall sense of impunity that has prevailed in the region. Some farmers and ranchers have taken conspicuous positions in favor of reducing deforestation in the sectors and complying with environmental laws (Eisenhammer, 2020); market demands for such production characteristics from the EU and China may be making breakthroughs into the sector and creating important disincentives for being associated with deforestation (Hanbury, 2024).

The following sections outline significant trends shaping land clearing behavior in the Amazon and the Cerrado.

3.1. Economic incentives

The potential for profit is the underlying driver of forest loss and an undercurrent across all trends. Deforestation is relatively low-cost and immediately increases the value of land, making it an important speculative investment tool. International market dynamics and currency fluctuations have also played a key role. For example, between 2001 and 2004, rising beef prices and increased credit availability were linked to a spike in Amazon deforestation. During the 1990s, the devaluation of Brazil’s real boosted commodity exports, resulting in rapid agricultural expansion. One estimate suggests that this currency shift alone may have added 63,000 hectares of soy crops—almost half of it in the Legal Amazon—by 2009 (Richards et al., 2012).

Soy exports from Brazil to the EU tripled between 1996 and 2008, and exports to China increased eightfold. Conversely, when the real began to appreciate again around 2009, deforestation rates and agricultural expansion both declined, underlining the strong link between macroeconomic trends and forest loss.

3.2. Land speculation and land tenure insecurity

Land speculation is another key driver of deforestation, particularly in public and undesignated lands, which make up around 14% of the land in the Brazilian Amazon. In areas such as these, where property rights are ambiguous or unenforced, land is often cleared speculatively to assert ownership through "productive use." This pattern is less common in the Cerrado, where landholdings tend to be more formalized and there are fewer undesignated lands.

Between 1985 and 2018, most deforestation occurred on private and undesignated or untitled lands (A. Pacheco & Meyer, 2022). Research shows that parcels with insecure tenure, such as untitled properties, experienced 12–23% more deforestation compared to similar parcels with secure titles (A. Pacheco & Meyer, 2022). Legislation such as Law 13.465/2017, which enabled the regularization of illegally grabbed lands, has further incentivized speculative deforestation. By rewarding prior illegality with formal land titles, such laws risk encouraging further land grabbing and forest clearing under the expectation of future amnesties.

3.3. Policy context

Government policies—both protective and permissive—have significant effects on deforestation. In the Amazon, the federal Forest Code mandates that 80% of forest cover must be preserved on private land. In contrast, only 20-35% must remain untouched in the Cerrado, incentivizing legal clearance of the remaining 65-80% (Gibbs et al., 2015; Rausch et al. 2019).. However, this policy has been poorly enforced, and illegal deforestation is particularly common in the Amazon.

Federal plans to reduce deforestation in the Amazon, known as Action Plans for the Prevention and Control of Deforestation in the Legal Amazon (Portuguese acronym PPCDAm) have helped shore up Forest Code enforcement and reduce illegal deforestation at different times, though the introduction of improved satellite-based monitoring, the establishment of a “blacklist” of municipalities with high deforestation rates resulting in credit access restriction and increased presence by enforcement agents, and expansion of protected areas. Supply chain policies such as the Cattle Agreements and the Soy Moratorium have also contributed to a reduction in deforestation in the Amazon (Gibbs et al., 2015, Gibbs et al., 2016, Heilmayr et al., 2020; Levy et al., 2023; Nepstad et al., 2014).

On the other hand, reductions in federal spending on enforcement of environmental laws, as happened most recently during Bolsonaro’s presidency, is associated with an increase in deforestation. Similarly, following the relaxation of the Forest Code to include a type of amnesty for illegal deforestation prior to 2008, deforestation rates more than doubled, likely due to the perception that future illegalities would also be forgiven (Rajão et al., 2022).

Rural credit programs, agricultural subsidies, and infrastructure expansion reduce the cost of agricultural expansion and forest clearing. The continued availability of credit without adequate enforcement of environmental regulations exacerbates this trend.

3.4. Cultural norms and values

Cultural perceptions of land and farming play a significant, though often underappreciated, role in deforestation. Forest clearing is widely seen as a way to improve land and increase its value. This notion of land “development” was reinforced by historical government narratives promoting the colonization of the Amazon.

Deforestation is embedded in traditional farming practices, particularly through the use of slash-and-burn cultivation (SBC) and shifting cultivation (SC) by smallholders including indigenous groups (van Vliet et al., 2013). SBC, where forest is permanently converted to agriculture, is more common in established frontiers and linked with cattle production. SC, which allows forest to regrow after temporary cultivation, tends to prevail in remote regions far from markets. While none of these activities are typically used in soy production landscapes, these land use dynamics often precede soy expansion, especially in the Amazon.

Despite the expansion of agricultural exports from the Amazon since 2005, rural incomes and living standards remain low across the region overall. This paradox reflects the complex motivations behind land use decisions. Practices like cattle ranching, though low in economic return, offer non-monetary benefits such as autonomy, low labor input, and social prestige. In remote areas with poor access to machinery or credit, cattle ranching remains a viable, low-risk strategy (Garrett & Ferreira, 2017), and thus is often taken up, at least informally, while establishing claims to land and clearing forest on the frontier.

Land use preferences are further shaped by gender, ethnicity, and community ties (Rosero-Añazco et al., 2025). For example, indigenous farmers tend to maintain more diversified and sustainable land use systems. In high-deforestation regions such as Pará, economic growth and migration have spurred development. In contrast, areas like northern Maranhão show both high forest loss and deep economic stagnation. Meanwhile, regions with limited deforestation often have low economic growth but place higher value on forest conservation (Sathler et al., 2018).

4. Conclusion

The rural population of the Amazon and Cerrado biomes are shaped by decades of migration, shifting land use practices and unequal access to land. While both regions are often framed in terms of their agricultural productivity, their rural communities reflect complex social profiles characterized by relatively low education and income levels, large household sizes (particularly in the Amazon), and demographic patterns dominated by middle-aged men. Migration—driven by economic opportunities and increasingly by climate change—has been a defining feature of the rural landscape, with newer arrivals settling in agricultural frontiers and areas undergoing rapid land transformation.

Land and income inequality are stark: most farms are small, but the majority of land is held by a few large landowners.These dynamics underscore the uneven distribution of economic benefits and land access, often to the detriment of subsistence and land reform families. In both biomes, this inequality is mirrored in political alignment, with industrial agriculture often aligned with conservative forces seeking to roll back environmental protections, while smaller producers and forest-dependent communities are more likely to support progressive policies. Deforestation in these regions reflects a mix of economic incentives, speculative land claims, weak enforcement and cultural norms that valorize land development through clearing.

While policies like the Forest Code, supply chain agreements, and rural credit regulations have had some success in slowing deforestation, enforcement remains uneven. The benefits of agricultural growth have not been equally distributed, and in many areas, economic development continues to come at the cost of social equity and environmental sustainability.

Future Trends in Soy and Cattle Production: Implications for Deforestation and Land Use in Brazil

1. Rising Global Demand for Soy and Beef and Production Outlook

Increasing population and rising incomes are driving demand for soy and beef. Due to its importance as a source of protein, both for human intake and animal feed, and as a biofuel, soy has become the most traded agricultural commodity, and the 4th most traded commodity overall (Barboza Martignone et al., 2024). Soy demand is expected to increase by 50% by 2050. Meeting this demand will require an estimated 20 million hectares (Mha) of land, much of which is expected to come from South America (Song et al., 2021). As a key player, Brazil is poised to expand its soy cultivation area significantly to 57 Mha by 2033/34, a 25% increase in area from 2023/24. This growth is expected to drive a 35% increase in production (in terms of volume) over the same period (MAPA, 2024) equal to a 3.5% annual growth (**Figure 4.1**). Domestic consumption will increase by 1.9% annually in the next 10 years, while soy exports are expected to increase by 41%, from 92 Mton in 2023/24 to 130 Mton in 2033/34 (MAPA, 2024). Already a major economic force valued globally at 155 USD billion, the soy industry is projected to reach USD 278 billion by 2031 (Voora et al., 2024).

Nearly 70% of Brazil's soy is exported (Soterroni et al., 2019), highlighting the critical role of international markets and policy in shaping domestic land use. China will remain the primary export market for both beef and soy, although its slowing economic growth could moderate future demand.

Similarly, Brazil's beef production is forecasted to grow by 1.1% annually in the next 10 years, reaching 11 million tons by 2034 (**Figure 4.1**). Domestic beef consumption will grow modestly (0.6% annually), while exports are expected to surge by 27%, from 3.5 to 4.5 million tons (MAPA, 2024).

Pasture could increase its area between 61 to 77 Mha in a business-as-usual scenario that does not involve intensification, and up to 83 Mha in a severe climate change scenario by 2050, highlighting the risks for further deforestation unless intensification occurs (Barbosa de Souza et al., 2023; Lapola et al., 2011).

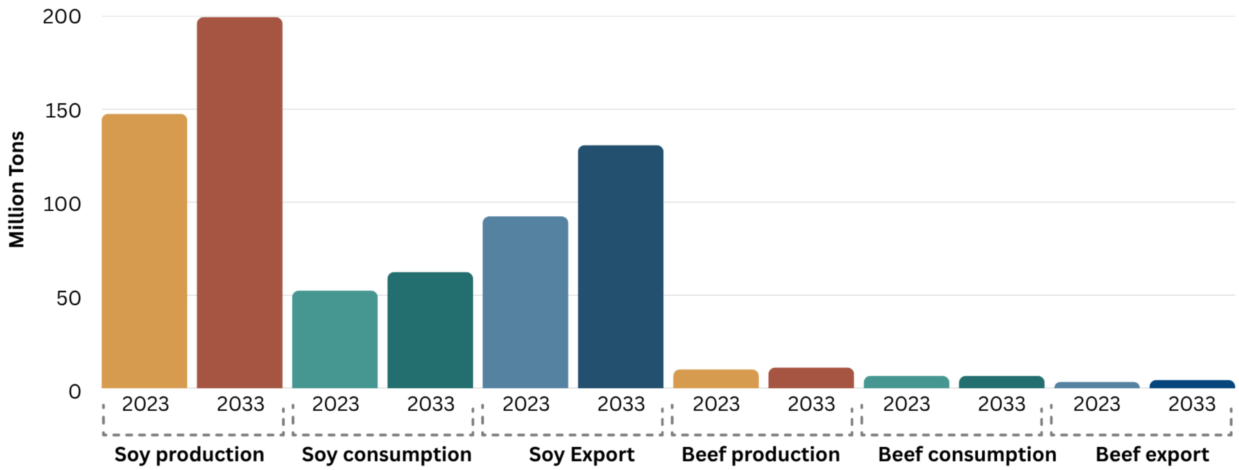


Figure 4.1. Current (2023/24) and projected (2033/34) Brazilian soy and beef production, consumption and export, in million tons. Based on MAPA, 2024.

2. Historical Drivers and Risk Factors for Habitat Conversion

Historically, the expansion of soy agriculture and cattle ranching have been the principal drivers of deforestation in the Amazon and Cerrado biomes. While local subsistence initially dictated land use decisions, the past two decades have seen global demands emerge as the primary drivers of forest loss due to agriculture expansion.

Economic booms in agricultural commodities have repeatedly triggered surges in land conversion. Spikes in soy and beef prices, like those in 2002-2005 and 2011-2014 for instance, were closely followed by sharp increases in deforestation, particularly in areas with infrastructure access and low policy enforcement (da Silva, 2009; Morton et al., 2006). Municipal-level data shows increased soy prices drive immediate forest clearing, while beef prices increase result in deforestation spikes with a one-year lag (da Silva, 2009).

The introduction of the Amazon Soy Moratorium in 2006 followed by the Cattle Agreements in 2009, demonstrated that targeted supply chain governance –via remote sensing, monitoring, embargoes and blacklists and credit restrictions– can significantly reduce direct deforestation by large actors (Macedo et al., 2012; Gibbs et al., 2015; Heilmayr et al., 2020; Rausch & Gibbs, 2021; Levy et al., 2023). However, this success has been uneven and largely concentrated in the Amazon. In the Cerrado, where 90% of the land is privately owned and the Forest Code mandates only 20-35% of properties be set aside in Legal Reserves of native vegetation (vs. 80% in the Amazon), conversion risks remain high. Since 2012, deforestation has steadily increased in this biome, where embargoes and enforcement are limited (Soterroni et al., 2019) and there is much less supply chain pressure to reduce deforestation; with most of this deforestation being legal (Rausch et al., 2019).

Another major historical driver of deforestation is insecure land tenure. In regions where land claims are unclear or disputed, rapid deforestation is often used to assert property rights by demonstrating productive use. This practice is especially observed among smallholders and speculative occupiers. While attention can usually focus on these actors, large and medium landholders are responsible for the bulk of deforestation once they gain ownership. Over 70% of deforestation occurs in less than a third of properties—mostly medium and large landholdings—especially in the Amazon-Cerrado frontier (Song et al., 2021).

Large areas of undesignated public lands—estimated at 118-143 Mha, including 56 Mha of forests—also face intense pressure from speculative deforestation and land grabbing (IPAM, 2025) largely due to insufficient governance. An additional 19.6 Mha of land have already been allocated for privatization, 40% of which have been cleared; if current cattle and soy driven trends continue, this could trigger another 1.1 to 1.6 Mha of new deforestation by 2027 (Brito et al., 2019).

Finally, infrastructure and accessibility also play a critical enabling role in forest loss dynamics. The construction and paving of roads, both official and informal, have historically resulted in forest fragmentation and the opening of new deforestation fronts (Perz et al., 2008). Roads reduce transportation costs for producers and facilitate access to markets and capital (Perz et al., 2008). The impact is particularly noticeable along major highways like BR-163 where deforestation probabilities increase sharply within a 50-km corridor from the road (Perz et al., 2008). At the same time, unofficial roads –usually stemming from official roads– not only lead to higher fragmentation, but tend to initiate cycles of informal road branching, speculative clearing, and increased income, leading to more roads (Perz et al., 2008).

Summary of historical risk factors

1. **Land use sequence**
    - Forest is typically cleared for pasture, then potentially converted to soy when land is no longer fit for pasture or due to increasing land prices
    - Soy expansion can indirectly drive deforestation by displacing cattle deeper into frontier zones
2. **Market fluctuations and profitability**
    - Soy and beef price spikes often correlate with surges in deforestation
3. **Infrastructure and accessibility**
    - Official and unofficial roads catalyze new deforestation fronts and reduce costs for producers
    - Areas within 50km of major paved roads show significantly elevated deforestation risk
4. **Land security and speculation**
    - Undesignated public lands are highly vulnerable to speculative clearing
    - Deforestation is used to establish land ownership
5. **Governance and supply-chain policies**
    - Policies like the Amazon Soy Moratorium and the Cattle Agreements can help to reduce deforestation when enforced
    - Their absence in the Cerrado has resulted in increased risk for that biome

3. Policy and Market Scenarios Shaping the Future

Key Influences on Deforestation Trajectories

- **Policy Scenarios**
    - If Bolsonaro or similar ruralist-backed leadership returns, legal reserves requirements may be weakened again, potentially opening 135 Mha for legal clearing (Brandão Jr et al., 2020).
    - Forest Code enforcement could limit deforestation but covers forests more than savannas like the Cerrado.
- **Soy Moratorium Expansion**
    - Expanding the Soy Moratorium to the Cerrado could prevent 3.6 Mha of deforestation by 2050, even when accounting for leakage (Soterroni et al., 2019) but this seems unlikely given the pressure to end the Moratorium in the Amazon.
    - Without it, business-as-usual could see 12.4 Mha of new soy cropland—10.8 Mha in the Cerrado alone (Soterroni et al., 2019).
- **EUDR and Trade Regulations**
    - The EU Deforestation Regulation (EUDR) targets only tropical forests, leaving savannas like the Cerrado unprotected.
    - The weakening or collapse of EUDR would increase deforestation risk, especially in the Cerrado, where companies are already pressuring to dismantle deforestation-free initiatives.
- **Market-Based Commitments**
    - Zero Deforestation Commitments (ZDCs) currently cover 82% of Brazilian beef and 90% of soy exports from the Amazon (Levy et al., 2023).
- **Consumption and Tax Scenarios**
    - Scenarios simulating a 40% reduction in beef consumption by 2050—either via cultural shifts or taxes—show minor reductions in deforestation (~1.1%) but increases in crop land use (Parzianello & Carvalho, 2024).
    - In contrast, continued high meat consumption and export trends will reinforce demand for pasture and grains, risking further conversion of native vegetation.

4. Future Deforestation Hotspots and Expansion Zones

To estimate future deforestation and identify the regions most likely to experience expansion in the coming years, we conducted a projection exercise considering both the quantity and the spatial distribution of potential deforestation.

We developed three distinct scenarios for the year 2050, both covering the Amazon and Cerrado biomes. based on high, business-as-usual, and low deforestation rates. These rates were derived from historical PRODES data for each biome, assuming that observed trends would continue from 2025 to 2050.

For the spatial allocation, we overlaid the 2023 land cover data from MapBiomas with the agricultural suitability dataset developed by Brandão Jr. et al. (2018). This allowed us to identify both (i) already-cleared areas suitable for soy expansion without requiring new deforestation, and (ii) native vegetation most vulnerable to future conversion.

As part of this spatial analysis, we also developed a deforestation risk model, producing a probability map to estimate which remaining patches of native vegetation are most susceptible to future deforestation pressure.

4.1. Estimating deforestation scenarios through 2050 in the Amazon and Cerrado

Based on historical deforestation data from PRODES for the Amazon and Cerrado biomes, we developed three simplified projection scenarios through the year 2050. The Business-as-Usual (BAU) scenario assumes a linear continuation of the average annual deforestation rates observed from 2008 to 2024. The Low Deforestation scenario reflects the average rates recorded during periods of stronger environmental enforcement in each biome, particularly following 2022, when deforestation began to show signs of decline. The High Deforestation scenario is based on the average annual deforestation rates observed during the Bolsonaro administration (2019 to 2022), a period marked by the weakening of environmental policies. This scenario assumes that these elevated rates would continue from 2025 to 2050 in the absence of effective forest governance. It is important to note that none of the scenarios consider forest regrowth.

We compared these projections with the ecological tipping points described in the scientific literature, thresholds beyond which ecosystems lose their resilience and may irreversibly shift into new environmental states. For the Amazon, Lovejoy and Nobre (2018) estimated that this tipping point occurs when deforestation reaches between 20% and 25% of the biome's original extent. In the case of the Cerrado, no specific tipping point was found in the literature, but we used 60% of total biome conversion as a reference for comparison.

In the Amazon biome, PRODES data show that by 2024, approximately 782,507 km² had been deforested, equivalent to 18.6% of the Brazilian Amazon's area. According to our projections, the deforested area could reach between 18.76% and 28% of the Amazon by 2050, depending on the scenario (**Figure 4.2**). This means that even under moderate control efforts (Scenario BAU), deforestation in the Amazon could approach or surpass the 25% tipping point within the next few decades, potentially triggering large-scale ecological disruptions.

In the Cerrado, more than half of the biome –over 1 million km²– has already been converted. Our projections indicate that this figure could rise to between 51.33% and 73.43% by 2050 (**Figure 4.2**). Although no defined tipping point has been established for the Cerrado, the continued advance of deforestation suggests a high risk of ecological degradation. This could have serious consequences for local climate regulation, biodiversity, and environmental stability across Brazil.

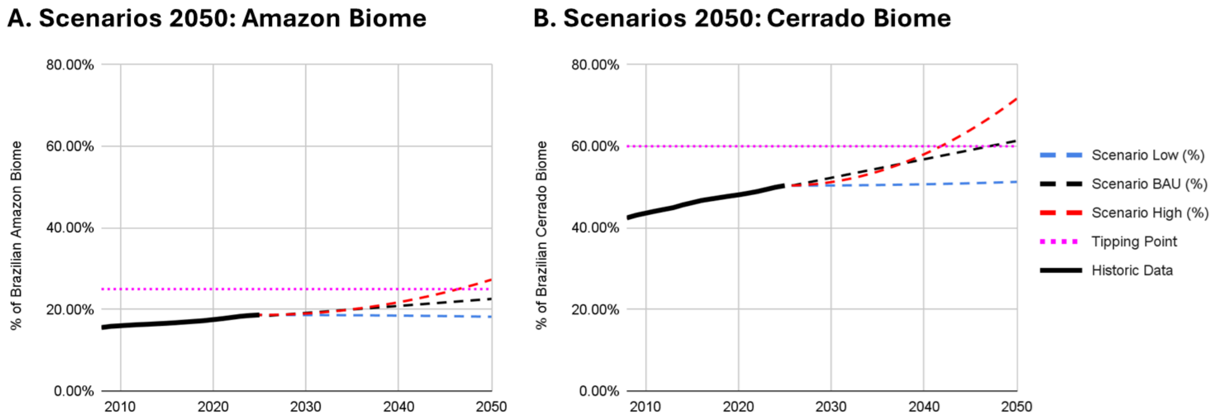


Figure 4.2. Projected land conversion in the Amazon (A) and Cerrado (B) biomes under three scenarios through 2050: Low deforestation (blue), Business-as-Usual (BAU, black), and High deforestation (red). The black line shows historical data, and the dotted pink line indicates estimated ecological tipping points for each biome.

4.2. Where Expansion is Likely to Occur

Multiple studies project that most future expansion of soybean cultivation and cattle ranching will take place in the Cerrado biome, where private lands cover 90% of the area. Expansion is projected to be especially high in the Matopiba region, comprising the states of Maranhão, Tocantins, Piauí, and Bahia (Colman et al., 2024; Soterroni et al., 2019). This aligns with the location of soy suitable areas (**Figure 4.3**) and high-risk deforestation areas (**Figure 4.4**) from our models. Although 90% of the Cerrado consists of private lands, only 8.3% of this area is legally protected. The Matopiba region alone contains an estimated 17.2 Mha of surplus native vegetation that can still be legally cleared (Pompeu, 2022). At the current forest loss rate, as much as 40.3 Mha of native vegetation could be legally deforested in the Cerrado by 2050 (Soares-Filho et al., 2014). Even with full compliance with the Forest Code, projected vegetation loss remains substantial—26.5 million hectares by 2050 and 30.6 million hectares by 2070 (Colman et al., 2024). Deforestation is likely to be concentrated on large properties in Matopiba due to the expansion of large-scale soy production in this region, Mato Grosso, and Mato Grosso do Sul, while medium-sized properties are projected to drive vegetation loss in other states where large properties are less common (Colman et al., 2024).

By contrast, remaining deforestation in the Amazon is likely to concentrate in undesignated public lands and protected areas, particularly in northern Pará (Song et al., 2021). Without strengthened governance, states like Mato Grosso and Rondônia could retain little forest cover outside protected areas by 2050 (Rosa et al., 2013). Our models also show regions already experiencing significant forest loss, such as the AMACRO zone (encompassing Amazonas, Acre, and Rondônia), northwestern Mato Grosso, and the BR-163 corridor in Pará, are projected to remain deforestation hotspots in the coming decades.

New deforestation frontiers may also emerge. Our models highlight a key area of concern, along the BR-319 corridor in Amazonas. Political pressure (Barboza Martignone et al., 2024) to connect Porto Velho and Manaus could increase deforestation risks across central Amazonia, accelerating the opening of intact forest areas.

Our analysis based on MapBiomas land cover data and soybean suitability maps revealed distinct land use patterns across the Amazon and Cerrado biomes, which together span approximately 621 million hectares in 2023. By that year, 4% of this area (25 Mha) had already been converted to soybean. An additional 12% (76 Mha) consisted of cleared pasturelands suitable for soy expansion, while 8% (47 Mha) comprised pasturelands deemed unsuitable for soy (**Figure 4.2**). Native vegetation accounted for 39% (240 Mha) of land classified as suitable for future soy expansion and 33% (206 Mha) as unsuitable. Spatially, suitable pastures are concentrated along the deforestation arc in the Amazon and in the southern Cerrado, whereas unsuitable pastures are more prevalent along the Transamazon Highway in Pará and parts of the northern Cerrado. Suitable native vegetation areas are primarily found in the southwestern Amazon and central-eastern Cerrado. In contrast, unsuitable native areas are often located along river corridors, rocky outcrops in Pará, and in the Matopiba region.

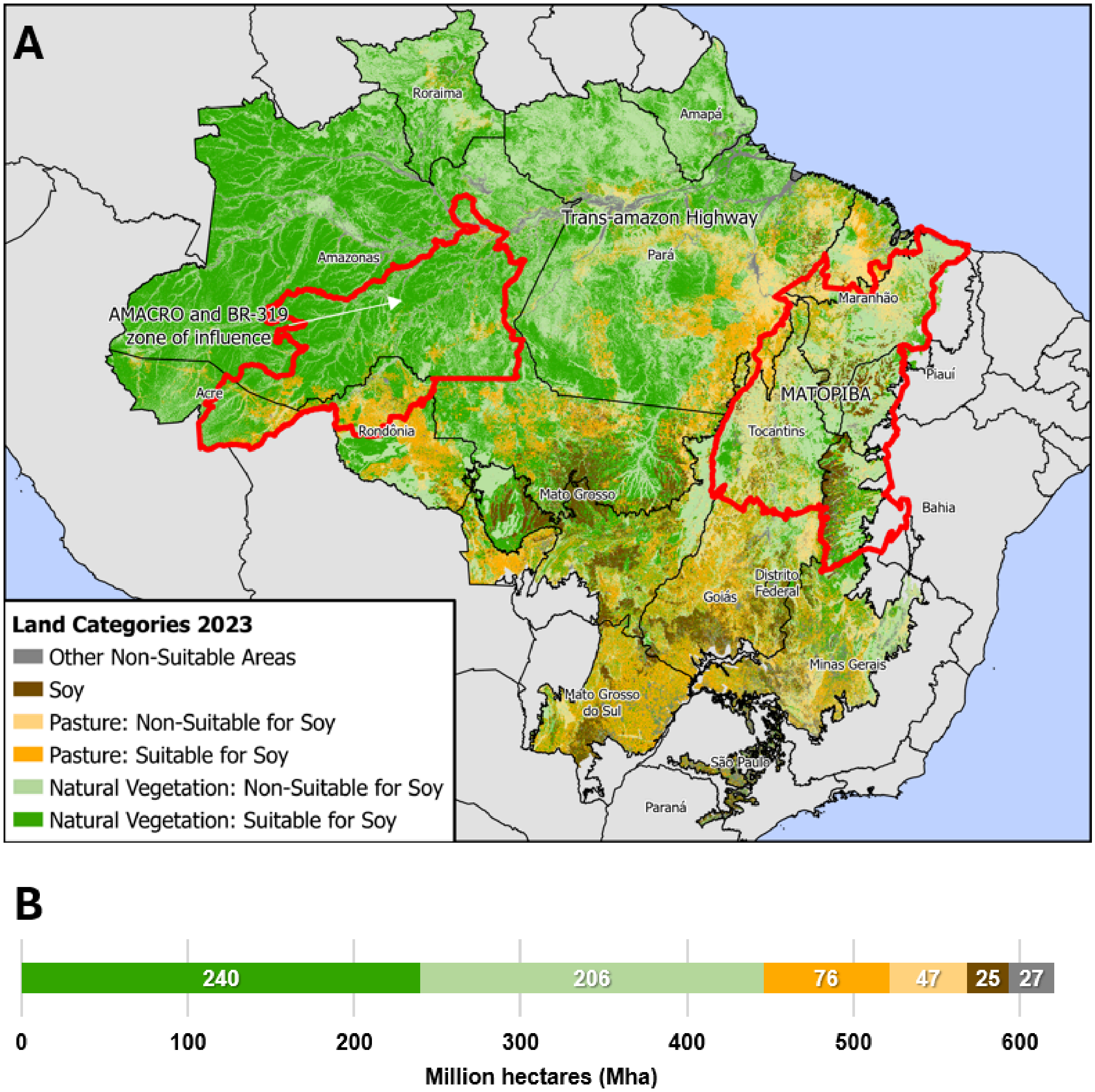


Figure 4.3. Land categories in 2023 across the Amazon and Cerrado biomes based on land cover and soybean suitability. Panel A shows the spatial distribution of areas by land type and soy suitability. Panel B summarizes the total area of each category.

We developed a deforestation risk model to estimate areas with varying probabilities of future deforestation (**Figure 4.4**). The model incorporated multiple explanatory variables, including distance to recent deforestation, rural settlements, embargos, slaughterhouses, navigable rivers, indigenous lands, conservation units, and both paved and unpaved roads, as well as topographic features such as slope and elevation.

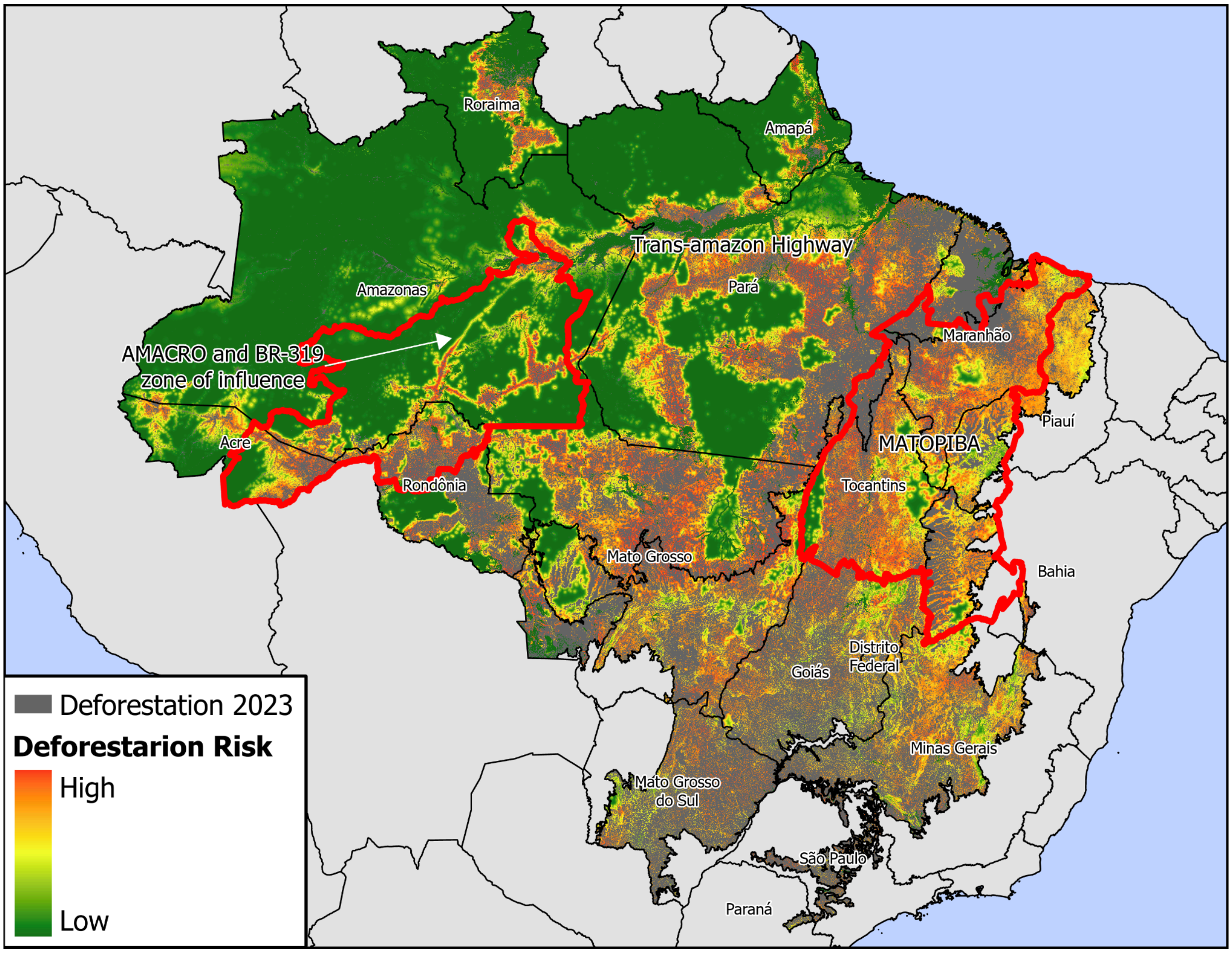


Figure 4.4. Modeled deforestation risk after 2023 across the Amazon and Cerrado biomes.

5. Climate Change Impacts: Agricultural Viability at Risk

Rising deforestation is deeply interconnected with the climate impacts projected in the scientific literature. While many studies emphasize that climate change results from deforestation—particularly through forest clearing, fire use, and greenhouse gas emissions from cattle production—others highlight a more complex feedback loop. Increasingly, climate change itself is becoming a direct driver of environmental degradation, by making forests more susceptible to fire and shrinking the area suitable for agriculture. This is largely due to disrupted rainfall patterns and the growing frequency of extreme weather events. These converging pressures place Brazil's agribusiness sector—currently the country's main economic engine—under growing threat. Farmers and ranchers may soon face significantly higher costs to sustain productivity, whether through technological inputs, fertilizers, or expanded irrigation systems such as reservoirs to manage recurring droughts.

Climate change is expected to reshape the geography and viability of agricultural production in Brazil. Projections suggest that by 2060, nearly 74% of the country's agricultural land could lie outside the optimal climate zone for rainfed crops, potentially causing food production losses of up to 14 billion reais by 2070 (Embrapa, 2008). This transformation is largely driven by intensifying water shortages and rising vapor pressure deficits (VPD)—a key indicator of atmospheric dryness that reflects how much effort plants must exert to retain moisture (Rattis et al., 2021).

Soybean production, one of the pillars of Brazil's agricultural economy, is especially vulnerable. Under high-emissions scenarios triggering a cascade of climate change related impacts, soy yields could fall by up to 40% (Embrapa, 2008), particularly in Southern Brazil and the Matopiba region, where agricultural expansion has surged in recent decades. Climate change not only lowers average yields but also increases their variability, making agricultural outcomes more uncertain and financial returns more volatile.

Pasturelands, which sustain Brazil's large cattle industry, are also expected to suffer. Rising temperatures and decreasing rainfall could reduce pasture carrying capacity by as much as 25% in key regions (Embrapa, 2008), especially in areas already facing soil degradation or marginal productivity. As native grasses lose nutritional value and biomass, ranchers may need to invest more in supplemental feeds—primarily soy and corn—or adopt more intensive livestock systems. Both options entail higher production costs and greater logistical burdens, particularly in remote frontier zones.

Together, these stressors are likely to trigger a process of agricultural de-intensification in parts of Brazil, especially in the Matopiba region (Rattis et al., 2021). De-intensification refers to the retreat from previously intensified farming systems—such as double-cropping—toward lower-yield, less productive practices. In Matopiba, there is already evidence that double-cropping systems, where soy is followed by a second cash crop like corn, are being phased out due to erratic rainfall and shorter growing seasons. Similarly, in the southern Amazon and northern Cerrado, some ranchers are reportedly scaling back rotational grazing and pasture restoration programs, citing rising input costs and growing climate unpredictability. These shifts could lead to declining land productivity, reduced agricultural output, and even land abandonment in the most vulnerable areas.

Ecological models suggest that converting forests into pastureland significantly reduces evapotranspiration, prolongs dry seasons, and disrupts regional rainfall cycles. These impacts are compounded by widespread fire use, deforestation, and global warming. Studies indicate that a 4 °C rise in global temperatures could, by itself, push vast areas of the Amazon toward a degraded savanna state. Based on a wide body of evidence, Lovejoy and Nobre argue that the Amazon's hydrological tipping point could be triggered by the loss of just 20% to 25% of its forest cover, especially in the eastern, southern, and central parts of the biome. The extreme climatic events witnessed over the past two decades—severe droughts (2005, 2010, 2015–16) and exceptional floods (2009, 2012, 2014)—suggest the system may already be nearing this critical threshold.

6. Conclusion

The future of soy and cattle production in Brazil is deeply intertwined with global market forces and growing demands for protein, domestic land use policy, and climate conditions. Brazil is poised for significant growth in both sectors: soy production is expected to expand by 25% in area and 35% in volume by 2034, while beef exports are set to increase by 27%. While there is significant room to expand production without clearing more forests—through intensification and use of degraded lands—current policy gaps and weak enforcement, especially in the Cerrado, make deforestation likely under business-as-usual conditions.

Key interventions like the expansion of the Soy Moratorium, stricter enforcement of the Forest Code, and international trade regulations like the EUDR could alter these trajectories. However, many of these measures currently lack political support or do not apply to non-forest biomes like the Cerrado. Without major systemic shifts in governance, credit access, land titling and supply chain accountability, more than 30 Mha of native vegetation could be legally cleared in the Cerrado alone by 2050. The Amazon also faces growing pressure from infrastructure expansion and land grabbing in undesignated public lands.

Climate change adds another layer of risk. Altered rainfall patterns, fire frequency and rising temperatures are already impacting agricultural productivity and narrowing the climatic window for rainfed crops and pasture. Projections suggest that more than 70% of Brazil's agricultural land could fall outside optimal climate conditions by 2060, threatening both soy and pasture suitability. In regions like Matopiba, signs of de-intensification are already emerging due to erratic weather and rising costs.

In this context, the future of Brazil's agricultural frontier hinges on a delicate balance: meeting growing demand while avoiding ecological collapse. Without coordinated efforts to strengthen environmental regulation, reform land governance and support climate adaptation, continued soy and beef production will likely come at the expense of Brazil's remaining native vegetation, particularly in the Cerrado.

References

Baseline statistics:

Andrade, M. B., Ferrante, L., & Fearnside, P. M. (2021). Brazil's Highway BR-319 demonstrates a crucial lack of environmental governance in Amazonia. *Environmental Conservation*, *48*(3), 161–164. https://doi.org/10.1017/S0376892921000084

Azevedo-Ramos, C., Moutinho, P., Arruda, V. L. da S., Stabile, M. C. C., Alencar, A., Castro, I., & Ribeiro, J. P. (2020). Lawless land in no man's land: The undesignated public forests in the Brazilian Amazon. *Land Use Policy*, *99*, 104863. https://doi.org/10.1016/j.landusepol.2020.104863

Bastos Lima, M.G., & Persson, U.M., 2020. Commodity-centric landscape governance as a double-edge sword: The case of soy and the Cerrado working group in Brazil. *Frontiers in forests and global change*, 3, 27.

Beledeli, M. (2025, January 14). *Agricultural land prices more than double in five years*. Valor Internacional. https://valorinternational.globo.com/agribusiness/news/2025/01/14/agricultural-land-prices-more-than-double-in-five-years.ghtml

Berenguer, E., Armenteras, D., Lees, A. C., Fearnside, P. M., Alencar, A., Almeida, C., Aragão, L., Barlow, J., Bilbao, B., Brando, P., Bynoe, P., Finer, M., Flores, B. M., Jenkins, C. N., Silva Jr, C., Smith, C., Souza, C., García-Vilacorta, R., & Nascimento, N. (2025). Drivers and ecological impacts of deforestation and forest degradation in the Amazon. *Acta Amazonica*, *54*, e54es22342. https://doi.org/10.1590/1809-4392202203420

Brito, B., Barreto, P., Brandão, A., Baima, S., & Gomes, P. H. (2019). Stimulus for land grabbing and deforestation in the Brazilian Amazon. *Environmental Research Letters*, *14*(6), 064018.

Brown, D. S., Brown, J. C., & Brown, C. (2016). Land occupations and deforestation in the Brazilian Amazon. *Land Use Policy*, *54*, 331–338. https://doi.org/10.1016/j.landusepol.2016.02.003

Camara, G., Simoes, R., Ruivo, H. M., Andrade, P. R., Soterroni, A. C., Ramos, F. M., Ramos, R. G., Scarabello, M., Almeida, C., Sanches, I., Maurano, L., Coutinho, A., Esquerdo, J., Antunes, J., Venturieri, A., & Adami, M. (2023). Impact of land tenure on deforestation control and forest restoration in Brazilian Amazonia. *Environmental Research Letters*, *18*(6), 065005. https://doi.org/10.1088/1748-9326/acd20a

Campbell, J. (2014). Speculative Accumulation: Property-Making in the Brazilian Amazon. *The Journal of Latin American and Caribbean Anthropology*. https://anthrosource.onlinelibrary.wiley.com/doi/full/10.1111/jlca.12078

Carrero, G. C., Walker, R. T., Simmons, C. S., & Fearnside, P. M. (2022). Land grabbing in the Brazilian Amazon: Stealing public land with government approval. *Land Use Policy*, *120*, 106133. https://doi.org/10.1016/j.landusepol.2022.106133

De Albuquerque, A., Assunção, J., Castro, P., Hoover el Rashidi, N. & de Miranda, G. (2023). Smallholders in the Caatinga and the Cerrado: A baseline analysis for a rural just transition in Brazil. Climate Policy Initiative.

Dias, L. C. P., Pimenta, F. M., Santos, A. B., Costa, M. H., & Ladle, R. J. (2016). Patterns of land use, extensification, and intensification of Brazilian agriculture. *Global Change Biology*, *22*(8), 2887–2903. https://doi.org/10.1111/gcb.13314

Falcone, S., & Rosenberg, M., 2022. Agricultural modernization and land conflict. *BSE, Barcelona School of Economics*.

Fearnside, P. M. (2022). Amazon environmental services: Why Brazil's Highway BR-319 is so damaging. *Ambio*, *51*(6), 1367–1370. https://doi.org/10.1007/s13280-022-01718-y

Feltran-Barbieri, R., & Féres, J. G. (2021). Degraded pastures in Brazil: Improving livestock production and forest restoration. *Royal Society Open Science*, *8*(7), 201854. https://doi.org/10.1098/rsos.201854

Ferrante, L., Andrade, M. B. T., & Fearnside, P. M. (2021). Land grabbing on Brazil's Highway BR-319 as a spearhead for Amazonian deforestation. *Land Use Policy*, *108*, 105559. https://doi.org/10.1016/j.landusepol.2021.105559

Garrett, R., & Ferreira, J. (2017, October 29). Cattle Ranchers in the Amazon Could Earn More Farming. But They Wouldn't Be Happy. *Brazzil*. https://www.brazzil.com/cattle-ranchers-in-the-amazon-could-earn-more-farming-but-they-wouldnt-be-happy/

Gibbs, H.K., M. Johnston, J.A. Foley, T. Holloway. C. Monfreda, N. Ramankutty, D. Zaks. 2008. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. Environmental Research Letters 3 (3):034001. doi: 10.1088/1748-9326/3/3/034001.

Grassroots International (2009) https://grassrootsonline.org/learning_hub/family-farmers-feed-brazil

Greenpeace international, 26 Oct 2021. https://www.greenpeace.org/international/press-release/50164/meat-soy-deforestation-karipuna-amazon-brazil

Heilmayr, R., Rausch, L. L., Munger, J., & Gibbs, H. K. (2020). Brazil's Amazon Soy Moratorium reduced deforestation. *Nature Food*, *1*(12), 801–810. https://doi.org/10.1038/s43016-020-00194-5

Junior, V.J.W., Piras, S., Grisa, C. & Ghinoi, S. (2021). Assessing Brazilian agri-food policies: what impact on family farms? arXiv preprint arXiv:2105.14996.

Lima Filho, F. L., Bragança, A., & Assunção, J. (2021). The Economics of Cattle Ranching in the Amazon: Land Grabbing or Pushing the Agricultural Frontier? *CPI*. https://www.climatepolicyinitiative.org/publication/the-economics-of-cattle-ranching-in-the-amazon-land-grabbing-or-pushing-the-agricultural-frontier/

Maranhão, R. L. A., de Carvalho Júnior, O. A., Hermuche, P. M., Gomes, R. A. T., McManus Pimentel, C. M., & Guimarães, R. F. (2019). The Spatiotemporal Dynamics of Soybean and Cattle Production in Brazil. *Sustainability*, *11*(7), Article 7. https://doi.org/10.3390/su11072150

Martha, G. B., Alves, E., & Contini, E. (2012). Land-saving approaches and beef production growth in Brazil. *Agricultural Systems*, *110*, 173–177. https://doi.org/10.1016/j.agsy.2012.03.001

Moffette, F., H.K. Gibbs. 2021. Agricultural displacement and deforestation leakage in the Brazilian Amazon. Land Economics Journal 97 (1):155-179. https://doi.org/10.3368/le.97.1.040219-0045R.

Oliveira, E. R. de, Silva, J. R., Baumann, L. R. F., Miziara, F., Ferreira, L. G., & Merelles, L. R. de O. (2020). Tecnologia e degradação de pastagens na pecuária no Cerrado brasileiro. *Sociedade & Natureza*, *32*, 626–638. https://doi.org/10.14393/SN-v32-2020-55795

Oliveira, G. de L. T., McKay, B. M., & Liu, J. (2021). Beyond land grabs: New insights on land struggles and global agrarian change. In *Beyond the Global Land Grab*. Routledge.

Pacheco, P., R. Poccard-Chapuis. (2012). The Complex Evolution of Cattle Ranching Development Amid Market Integration and Policy Shifts in the Brazilian Amazon. *Annals of the Association of American Geographers,* 102:6, 1366-1390, DOI: 10.1080/00045608.2012.678040.

Pereira, R., C.S. Simmons, R. Walker (2016). Smallholders, Agrarian Reform, and Globalization in the Brazilian Amazon: Cattle versus the Environment. *Land*, 5(3), 24; https://doi.org/10.3390/land5030024

Perz, S., Brilhante, S., Brown, F., Caldas, M., Ikeda, S., Mendoza, E., Overdevest, C., Reis, V., Reyes, J. F., Rojas, D., Schmink, M., Souza, C., & Walker, R. (2008). Road building, land use and climate change: Prospects for environmental governance in the Amazon. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1498), 1889–1895. https://doi.org/10.1098/rstb.2007.0017

Probst, B., BenYishay, A., Kontoleon, A., & dos Reis, T. N. P. (2020). Impacts of a large-scale titling initiative on deforestation in the Brazilian Amazon. *Nature Sustainability*, *3*(12), 1019–1026. https://doi.org/10.1038/s41893-020-0537-2

Richards, P. (2015). What Drives Indirect Land Use Change? How Brazil's Agriculture Sector Influences Frontier Deforestation. *Annals of the Association of American Geographers*, *105*(5), 1026–1040. https://doi.org/10.1080/00045608.2015.1060924

Richards, P. D., Walker, R. T., & Arima, E. Y. (2014). Spatially complex land change: The Indirect effect of Brazil's agricultural sector on land use in Amazonia. *Global Environmental Change*, *29*, 1–9. https://doi.org/10.1016/j.gloenvcha.2014.06.011

Santos, A. D., & Galeão, P. (2018). *The Rural Environmental Registry (CAR) and the land grabbing strategies in the Brazilian Amazon*. VI Conference of BRICS Initiative of Critical Agrarian Studies.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D. and Yu, T.H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science, 319(5867), pp.1238-1240.

Seixas, H. T., Silveira, H. L. F. da, Mendes, A. P. da S. F., Soares, F. D. S., & da Silva, R. F. B. (2025). Conversion from Forest to Agriculture in the Brazilian Amazon from 1985 to 2021. *Land*, *14*(2), Article 2. https://doi.org/10.3390/land14020300

Silva, R., & Moran, D. (2015). Where's the beef? Re-examining the nexus of livestock, deforestation and greenhouse gas emissions in Brazil. *Table*. https://www.tabledebates.org/essay/wheres-beef-re-examining-nexus-livestock-deforestation-and-greenhouse-gas-emissions-brazil

Song, X.-P., Hansen, M. C., Potapov, P., Adusei, B., Pickering, J., Adami, M., Lima, A., Zalles, V., Stehman, S. V., Di Bella, C. M., Conde, M. C., Copati, E. J., Fernandes, L. B., Hernandez-Serna, A., Jantz, S. M., Pickens, A. H., Turubanova, S., & Tyukavina, A. (2021). Massive soybean expansion in South America since 2000 and implications for conservation. *Nature Sustainability*, *4*(9), 784–792. https://doi.org/10.1038/s41893-021-00729-z

Ubiali, B., & Alexiades, M. (2022). Forests, Fields, and Pastures: Unequal Access to Brazil Nuts and Livelihood Strategies in an Extractive Reserve, Brazilian Amazon. *Land*, *11*(7), Article 7. https://doi.org/10.3390/land11070967

zu Ermgassen, E. K. H. J., Godar, J., Lathuillière, M. J., Löfgren, P., Gardner, T., Vasconcelos, A., & Meyfroidt, P. (2020). The origin, supply chain, and deforestation risk of Brazil's beef exports. *Proceedings of the National Academy of Sciences*, *117*(50), 31770–31779. https://doi.org/10.1073/pnas.2003270117

Land use change:

Alves, D. S., Escada, M. I. S., Pereira, J. L. G., & de Albuquerque Linhares, C. (2003). Land use intensification and abandonment in Rondônia, Brazilian Amazônia. *International Journal of Remote Sensing*, *24*(4), 899–903.

Assunção, J., Gandour, C., Pessoa, P., & Rocha, R. (2017). Property-level assessment of change in forest clearing patterns: The need for tailoring policy in the Amazon. *Land Use Policy*, *66*, 18–27. https://doi.org/10.1016/j.landusepol.2017.04.022

Bowman, M. S., Soares-Filho, B., Merry, F. D., Nepstad, D., Rodrigues, H. & Almeida, O. T. (2012) Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production. *Land Use Policy,* 29(3), 558:568.

Caballero, C. B., Biggs, T. W., Vergopolan, N., West, T. A. P., & Ruhoff, A. (2023). Transformation of Brazil's biomes: The dynamics and fate of agriculture and pasture expansion into native vegetation. *Science of The Total Environment*, *896*, 166323. https://doi.org/10.1016/j.scitotenv.2023.166323

Carrero, G. C., Walker, R. T., Simmons, C. S., & Fearnside, P. M. (2022). Land grabbing in the Brazilian Amazon: Stealing public land with government approval. *Land Use Policy*, *120*, 106133. https://doi.org/10.1016/j.landusepol.2022.106133

Espírito-Santo, M. M., Leite, M. E., Silva, J. O., Barbosa, R. S., Rocha, A. M., Anaya, F. C., & Dupin, M. G. V. (2016). Understanding patterns of land-cover change in the Brazilian Cerrado from 2000 to 2015. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1703), 20150435. https://doi.org/10.1098/rstb.2015.0435

Gibbs, H. K., Rausch, L., Munger, J., Schelly, I., Morton, D. C., Noojipady, P., Soares-Filho, B., Barreto, P., Micol, L., & Walker, N. F. (2015). Brazil's Soy Moratorium. *Science*, *347*(6220), 377–378. https://doi.org/10.1126/science.aaa0181

Polizel, S. P., Vieira, R. M. da S. P., Pompeu, J., Ferreira, Y. da C., Sousa-Neto, E. R. de, Barbosa, A. A., & Ometto, J. P. H. B. (2021). Analysing the dynamics of land use in the context of current conservation policies and land tenure in the Cerrado – MATOPIBA region (Brazil). *Land Use Policy*, *109*, 105713. https://doi.org/10.1016/j.landusepol.2021.105713

Seixas, H. T., Silveira, H. L. F. da, Mendes, A. P. da S. F., Soares, F. D. S., & da Silva, R. F. B. (2025). Conversion from Forest to Agriculture in the Brazilian Amazon from 1985 to 2021. *Land*, *14*(2), Article 2. https://doi.org/10.3390/land14020300

Souza, C. M., Oliveira, L. A., de Souza Filho, J. S., Ferreira, B. G., Fonseca, A. V., & Siqueira, J. V. (2023). Landsat sub-pixel land cover dynamics in the Brazilian Amazon. *Frontiers in Forests and Global Change*, *Volume 6-2023*. https://www.frontiersin.org/journals/forests-and-global-change/articles/10.3389/ffgc.2023.1294552

Souza, C. M., Z. Shimbo, J., Rosa, M. R., Parente, L. L., A. Alencar, A., Rudorff, B. F. T., Hasenack, H., Matsumoto, M., G. Ferreira, L., Souza-Filho, P. W. M., de Oliveira, S. W., Rocha, W. F., Fonseca, A. V., Marques, C. B., Diniz, C. G., Costa, D., Monteiro, D., Rosa, E. R., Vélez-Martin, E., … Azevedo, T. (2020). Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. *Remote Sensing*, *12*(17). https://doi.org/10.3390/rs12172735

Walker, R., Browder, J., Arima, E., Simmons, C., Pereira, R., Caldas, M., Shirota, R. and De Zen, S., 2009. Ranching and the new global range: Amazônia in the 21st century. *Geoforum,* 40(5), pp.732-745.

Yanai, A. M., de Alencastro Graça, P. M. L., Ziccardi, L. G., Escada, M. I. S., & Fearnside, P. M. (2022). Brazil's Amazonian deforestation: The role of landholdings in undesignated public lands. *Regional Environmental Change*, *22*(1), 30. https://doi.org/10.1007/s10113-022-01897-0

Social insights:

Brown, J.C., Koeppe, M., Coles, B. & Price, K. P. (2005). *Soybean production and conversion of tropical forest in the Brazilian Amazon: The case of Vilhena, Rondônia. AMBIO: A Journal of the Human Environment, 34(6), 462-46*. 10.1579/0044-7447-34.6.462

Couto, C., Sousa, D. and Hirtzer, M. (2024, July 25). Brazil, where a new generation is outpacing the US. *Bloomberg.*

de Sherbinin, A., VanWey, L., McSweeney, K., Aggarwal, R., Barbieri, A., Henry, S., Hunter, L. M., & Twine, W. (2008). Rural Household Demographics, Livelihoods and the Environment. *Global Environmental Change : Human and Policy Dimensions*, *18*(1), 38–53. https://doi.org/10.1016/j.gloenvcha.2007.05.005

Eisenhammer, S. (2020). *Special Report: One Brazilian farmer tried – and failed – to ranch more responsibly in the Amazon | Reuters*. https://www.reuters.com/article/us-brazil-deforestation-cattle-specialre/special-report-one-brazilian-farmer-tried-and-failed-to-ranch-more-responsibly-in-the-amazon-idUKKBN25O1QB/?edition-redirect=uk

Garrett, R., & Ferreira, J. (2017, October 29). Cattle Ranchers in the Amazon Could Earn More Farming. But They Wouldn't Be Happy. *Brazzil*. https://www.brazzil.com/cattle-ranchers-in-the-amazon-could-earn-more-farming-but-they-wouldnt-be-happy/

Hanbury, S. (2024, November 15). Brazil to adopt full beef traceability by 2032 amid China, EU pressure. *Mongabay Environmental News*. https://news.mongabay.com/short-article/2024/11/brazil-to-adopt-full-beef-traceability-by-2032-amid-china-eu-pressure/

Heilmayr, R., Rausch, L. L., Munger, J., & Gibbs, H. K. (2020). Brazil's Amazon Soy Moratorium reduced deforestation. *Nature Food*, *1*(12), 801–810. https://doi.org/10.1038/s43016-020-00194-5

Killeen, T. (2025, January 16). Vested interests and social tribes in the Pan Amazon. *Mongabay Environmental News*. https://news.mongabay.com/2025/01/vested-interests-and-social-tribes-in-the-pan-amazon/

Levy, S. A., Cammelli, F., Munger, J., Gibbs, H. K., & Garrett, R. D. (2023). Deforestation in the Brazilian Amazon could be halved by scaling up the implementation of zero-deforestation cattle commitments. *Global Environmental Change*, *80*, 102671. https://doi.org/10.1016/j.gloenvcha.2023.102671

Margolis, M. (2024). *The Amazon Rainforest Is Urban, Too*. Pulitzer Center. https://pulitzercenter.org/stories/amazon-rainforest-urban-too

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*(6188), 1118–1123. https://doi.org/10.1126/science.1248525

Pacheco, A., & Meyer, C. (2022). Land tenure drives Brazil's deforestation rates across socio-environmental contexts. *Nature Communications*, *13*(1), 5759. https://doi.org/10.1038/s41467-022-33398-3

Pacheco, P. (2012). Actor and frontier types in the Brazilian Amazon: Assessing interactions and outcomes associated with frontier expansion. *Geoforum*, *43*(4), 864–874. https://doi.org/10.1016/j.geoforum.2012.02.003

Peres, C. A., Campos-Silva, J., & Ritter, C. D. (2023). Environmental policy at a critical junction in the Brazilian Amazon. *Trends in Ecology & Evolution*, *38*(2), 113–116.

Rajão, R., Nobre, A. D., Cunha, E. L. T. P., Duarte, T. R., Marcolino, C., Soares-Filho, B., Sparovek, G., Rodrigues, R. R., Valera, C., Bustamante, M., Nobre, C., & Santos de Lima, L. (2022). The risk of fake controversies for Brazilian environmental policies. *Biological Conservation*, *266*, 109447. https://doi.org/10.1016/j.biocon.2021.109447

Richards, P. D., Myers, R. J., Swinton, S. M., & Walker, R. T. (2012). Exchange rates, soybean supply response, and deforestation in South America. *Global Environmental Change*, *22*(2), 454–462. https://doi.org/10.1016/j.gloenvcha.2012.01.004

Rocha, R., & Bragança, A. (n.d.). *Eco-annoying or unscrupulous ruralist? The role of parties ideology on deforestation in the Amazon1*.
Rosero-Añazco, P., Zhu, A. L., Cuesta, F., Speelman, E. N., & Hofstede, G. J. (2025). What is behind land use change in tropical forests? From local relations to global mining concessions. *Ecology and Society*, *30*(1). https://doi.org/10.5751/ES-15646-300129
Salerno, J., Gaughan, A. E., Warrier, R., Boone, R., Stevens, F. R., Keys, P. W., Mangewa, L. J., Mombo, F. M., de Sherbinin, A., Hartter, J., & Hunter, L. (2024). Rural migration under climate and land systems change. *Nature Sustainability*, *7*(9), 1092–1101. https://doi.org/10.1038/s41893-024-01396-6
Sathler, D., Adamo, S. B., & Lima, E. E. C. (2018). Deforestation and local sustainable development in Brazilian Legal Amazonia: An exploratory analysis. *Ecology and Society*, *23*(2). https://www.jstor.org/stable/26799094
Schneider, M., & Peres, C. A. (2015). Environmental Costs of Government-Sponsored Agrarian Settlements in Brazilian Amazonia. *PLoS ONE*, *10*(8), e0134016. https://doi.org/10.1371/journal.pone.0134016
van Vliet, N., Adams ,Cristina, Vieira ,Ima Célia Guimarães, & and Mertz, O. (2013). "Slash and Burn" and "Shifting" Cultivation Systems in Forest Agriculture Frontiers from the Brazilian Amazon. *Society & Natural Resources*, *26*(12), 1454–1467. https://doi.org/10.1080/08941920.2013.820813

Future projections:

Barbosa de Souza, K., Rosa dos Santos, A., Macedo Pezzopane, J. E., Machado Dias, H., Ferrari, J. L., Machado de Oliveira Peluzio, T., Toledo, J. V., Freire Carvalho, R. de C., Rizzo Moreira, T., & França Araújo, E. (2023). Modeling Dynamics in Land Use and Land Cover and Its Future Projection for the Amazon Biome. *Forests*, *14*(7), 1281.
Barboza Martignone, G. M., Ghosh, B., Papadas, D., & Behrendt, K. (2024). The rise of Soybean in international commodity markets: A quantile investigation. *Heliyon*, *10*(15), e34669. https://doi.org/10.1016/j.heliyon.2024.e34669
Brandão Jr, A., Rausch, L., Paz Durán, A., Costa Jr, C., Spawn, S. A., & Gibbs, H. K. (2020). Estimating the potential for conservation and farming in the Amazon and Cerrado under four policy scenarios. *Sustainability*, *12*(3), 1277.
Brito, B., Barreto, P., Brandão, A., Baima, S., & Gomes, P. H. (2019). Stimulus for land grabbing and deforestation in the Brazilian Amazon. *Environmental Research Letters*, *14*(6), 064018.
Colman, C. B., Guerra, A., Almagro, A., de Oliveira Roque, F., Rosa, I. M. D., Fernandes, G. W., & Oliveira, P. T. S. (2024). Modeling the Brazilian Cerrado land use change highlights the need to account for private property sizes for biodiversity conservation. *Scientific Reports*, *14*(1), 4559. https://doi.org/10.1038/s41598-024-55207-1
da Silva, J. H. G. (2009). *Economic Causes of Deforestation in the Brazilian Amazon: An Empirical Analysis of the 2000s*. IPEA – Instituto de Pesquisa Econômica Aplicada.
Gibbs, H. K., Rausch, L., Munger, J., Schelly, I., Morton, D. C., Noojipady, P., Soares-Filho, B., Barreto, P., Micol, L., & Walker, N. F. (2015). Brazil's Soy Moratorium. *Science*, *347*(6220), 377–378. https://doi.org/10.1126/science.aaa0181
Gibbs, H. K., Munger, J., L'Roe, J., Barreto, P., Pereira, R., Christie, M., ... & Walker, N. F. (2016). Did ranchers and slaughterhouses respond to zero‐deforestation agreements in the Brazilian Amazon?. Conservation letters, 9(1), 32-42.
Heilmayr, R., Rausch, L. L., Munger, J., & Gibbs, H. K. (2020). Brazil's Amazon Soy Moratorium reduced deforestation. *Nature Food*, *1*(12), 801–810. https://doi.org/10.1038/s43016-020-00194-5
Lapola, D. M., Schaldach, R., Alcamo, J., Bondeau, A., Msangi, S., Priess, J. A., Silvestrini, R., & Soares-Filho, B. S. (2011). Impacts of climate change and the end of deforestation on land use in the Brazilian Legal Amazon. *Earth Interactions*, *15*(16), 1–29.
Levy, S. A., Cammelli, F., Munger, J., Gibbs, H. K., & Garrett, R. D. (2023). Deforestation in the Brazilian Amazon could be halved by scaling up the implementation of zero-deforestation cattle commitments. *Global Environmental Change*, *80*, 102671. https://doi.org/10.1016/j.gloenvcha.2023.102671
Macedo, M. N., DeFries, R. S., Morton, D. C., Stickler, C. M., Galford, G. L., & Shimabukuro, Y. E. (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *Proceedings of the National Academy of Sciences*, *109*(4), 1341–1346. https://doi.org/10.1073/pnas.1111374109
Morton, D. C., DeFries, R. S., Shimabukuro, Y. E., Anderson, L. O., Arai, E., del Bon Espirito-Santo, F., Freitas, R., & Morisette, J. (2006). Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *103*(39), 14637–14641. https://doi.org/10.1073/pnas.0606377103
Parzianello, L., & Carvalho, T. S. (2024). What if Brazilians reduce their beef consumption? *Ecological Economics*, *219*, 108132. https://doi.org/10.1016/j.ecolecon.2024.108132
Perz, S., Brilhante, S., Brown, F., Caldas, M., Ikeda, S., Mendoza, E., Overdevest, C., Reis, V., Reyes, J. F., Rojas, D., Schmink, M., Souza, C., & Walker, R. (2008). Road building, land use and climate change: Prospects for environmental governance in the Amazon. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1498), 1889–1895. https://doi.org/10.1098/rstb.2007.0017
Pompeu, J. (2022). Legal deforestation can jeopardize plant diversity conservation in an agricultural frontier in the brazilian Cerrado: A spatial explicit contribution to Santana and Simon (2022). *Biodiversity and Conservation*, *31*(11), 2899–2903. https://doi.org/10.1007/s10531-022-02455-0

Rattis, L., Brando, P. M., Macedo, M. N., Spera, S. A., Castanho, A. D. A., Marques, E. Q., Costa, N. Q., Silverio, D. V., & Coe, M. T. (2021). Climatic limit for agriculture in Brazil. *Nature Climate Change*, *11*(12), 1098–1104. https://doi.org/10.1038/s41558-021-01214-3

Rausch, L. L., & Gibbs, H. K. (2021). The low opportunity costs of the Amazon soy moratorium. *Frontiers in Forests and Global Change*, *4*, 621685.

Rausch, L. L., Gibbs, H. K., Schelly, I., Brandão Jr, A., Morton, D. C., Filho, A. C., Strassburg, B., Walker, N., Noojipady, P., Barreto, P., & Meyer, D. (2019). Soy expansion in Brazil's Cerrado. *Conservation Letters*, *12*(6), e12671. https://doi.org/10.1111/conl.12671

Rosa, I. M. D., Purves, D., Jr, C. S., & Ewers, R. M. (2013). Predictive Modelling of Contagious Deforestation in the Brazilian Amazon. *PLOS ONE*, *8*(10), e77231. https://doi.org/10.1371/journal.pone.0077231

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*(6182), 363–364. https://doi.org/10.1126/science.1246663

Song, X.-P., Hansen, M. C., Potapov, P., Adusei, B., Pickering, J., Adami, M., Lima, A., Zalles, V., Stehman, S. V., Di Bella, C. M., Conde, M. C., Copati, E. J., Fernandes, L. B., Hernandez-Serna, A., Jantz, S. M., Pickens, A. H., Turubanova, S., & Tyukavina, A. (2021). Massive soybean expansion in South America since 2000 and implications for conservation. *Nature Sustainability*, *4*(9), 784–792. https://doi.org/10.1038/s41893-021-00729-z

Soterroni, A. C., Ramos, F. M., Mosnier, A., Fargione, J., Andrade, P. R., Baumgarten, L., Pirker, J., Obersteiner, M., Kraxner, F., Câmara, G., Carvalho, A. X. Y., & Polasky, S. (2019). Expanding the Soy Moratorium to Brazil's Cerrado. *Science Advances*, *5*(7), eaav7336. https://doi.org/10.1126/sciadv.aav7336

Voora, V., Bermudez, S., Le, H., Larrea, C., & Luna, E. (2024). Global Market Report | Soybean prices and sustainability. *The International Institute for Sustainable Development*.