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Livestock Changes in Brazil and Sustainable Intensification Challenges

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Abstract: The increasing global demand for animal products has impacted Brazilian cattle farming. This study aims to offer references for developing more sustainable livestock farming in Brazil. It analyzes the numbers of pasture areas, cattle herds, and stocking rates from 1970 to 2017, based on agricultural census data. Additionally, it compares pasture conditions using agricultural census data and satellite imagery for the years 2006 and 2017. The key findings include the following: (1) a 119.7% increase in cattle herds, with migration from the South and Southeast to the North and Central–West regions, which have lower land prices; (2) a 2.6% decrease in the pasture area for cattle (except in the North region); (3) a 3.8% decrease in areas in poor condition; and (4) a 125.5% increase in the stocking rate. Despite technological advancements improving productivity, most pastures (59.6%) are still underperforming, indicating potential for reducing the pressure on native vegetation. This study concludes that production areas are shifting between regions in Brazil, with livestock farming intensifying, marked by a decrease in pasture areas and degraded pastures, alongside an increase in cattle numbers and stocking rates. However, these changes are heterogeneous across the country. This analysis provides an overview of beef cattle nationwide, which is relevant for addressing production sustainability challenges.

Keywords: agricultural censuses; beef cattle; pasture area; pasture conditions; stocking rate

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1. Introduction

The current food and farming systems are failing to reconcile key issues like food security and environmental sustainability. While these systems have delivered substantial quantities of food to global markets, they have also caused numerous adverse effects: extensive degradation of land, water, and ecosystems; significant greenhouse gas emissions (GHG); and a decline in biodiversity [1]. These adverse effects continue to threaten the capacity of natural resources to meet the rising demand for food, particularly animal protein, driven by increasing individual wealth and by population growth [2]. As animal production is of great importance to global food security [3], there are increasing public awareness of and concerns over the environmental effects of beef production [4,5], especially in Brazil, which is among the largest producers and suppliers of beef [6].

The growing global demand for animal products has led to increased meat production and cattle herds in Brazil [7]. In 2022, the Brazilian cattle herd was 227 million head, with a production of 8674 thousand tons and an export of 3018 thousand tons of beef [8]. As a leading beef producer, and with vast natural resources and biodiversity, Brazil faces significant environmental responsibilities, particularly because the Brazilian cattle sector

accounts for approximately 21% of the total GHG emissions in Brazil [9]. Therefore, to maintain its environmental leadership, Brazil must focus on the sustainable intensification of its pasture-based animal production systems [4,10].

Investments in promoting and expanding the livestock sector increased in the 1960s through incentives for developing livestock activity and pasture management. However, the expansion of agricultural and forestry crops, as well as urban expansion, displaced Brazilian cattle farming to agricultural frontier regions, especially those with extensive production systems, while already-established areas were converted to agriculture uses [11,12]. This extensive-grazing practice is often characterized by low livestock productivity, leading to pasture and soil degradation [12,13]. Pasture restoration is recognized as fundamental to Brazil's internal policy of encouraging low-carbon agriculture and is an important component of the country's Nationally Determined Contributions (INDCs) for emissions mitigation. Therefore, it plays a crucial role in the country's overall strategy for sustainable agriculture intensification [14]. Further, the natural pasture areas have been reduced in Brazil [15,16]. However, these areas still maintain an important role in regions where livestock have a strong cultural–historical identity, such as the Pampa biome and Pantanal biome. The preservation of such high-biodiversity pastures is extremely important due to the numerous ecosystem services they provide [17–19].

A few studies, such as that by Barona et al. [20], conducted for the Brazilian Legal Amazon, have analyzed the efficiency of beef cattle nationwide. This analysis is particularly relevant because Brazil, with its increasing participation in the global beef market, has faced challenges from the international market related to production sustainability [21,22]. Livestock management in a sustainable manner is crucial for preventing the degradation and erosion of pasture areas, thereby maintaining high biodiversity levels and the provision of ecosystem services [23]. Efforts by trade blocs, as well as measures voluntarily adopted by large buyers, aim to establish international barriers that prevent the commercialization of commodities originating from deforested areas or those produced under environmental and social inequalities. Forested areas in the tropics are among the most important regulators of regional and global climate, natural carbon sinks, and the most significant repositories of terrestrial biomass. They hold immeasurable value for biodiversity, ecosystem services, social and cultural identities, livelihoods, and climate change adaptation and mitigation [24]. Although there are still no widely recognized criteria for sustainable international trade [25], sustainable practices tend to be established and to become permanent, requiring producer countries to adjust to their requirements. For instance, technological advancements have introduced new production techniques, such as integrated crop–livestock systems, which can improve soil fertility and reduce the need for further agricultural expansion [12]. However, these systems are still in the process of expansion in Brazil [26].

Aiming to provide national and regional references for the development of more sustainable livestock farming in Brazil, this study investigated recent changes in the dynamics of pasture areas, as well as the quality of these areas, cattle herds, and stocking rates. We hypothesize that competition for land by other activities, especially grain crops, and environmental pressures to reduce deforestation have led to intensified cattle production across various regions. We discussed whether this intensification may have been achieved through technological advancements in herd and pasture management, which allowed more bovine head per pasture area, or by expanding planted pasture areas, particularly in agricultural frontier regions and the Amazon.

2. Materials and Methods

2.1. Study Area

The spatiotemporal dynamics of pasture use, as well as the herd and stocking rates of cattle in Brazil, were analyzed across the country's different geographical divisions: North, Northeast, Southeast, South, and Central–West (Figure 1). A description of the livestock farms considered in the Agricultural Census (AC) is provided in Table 1.

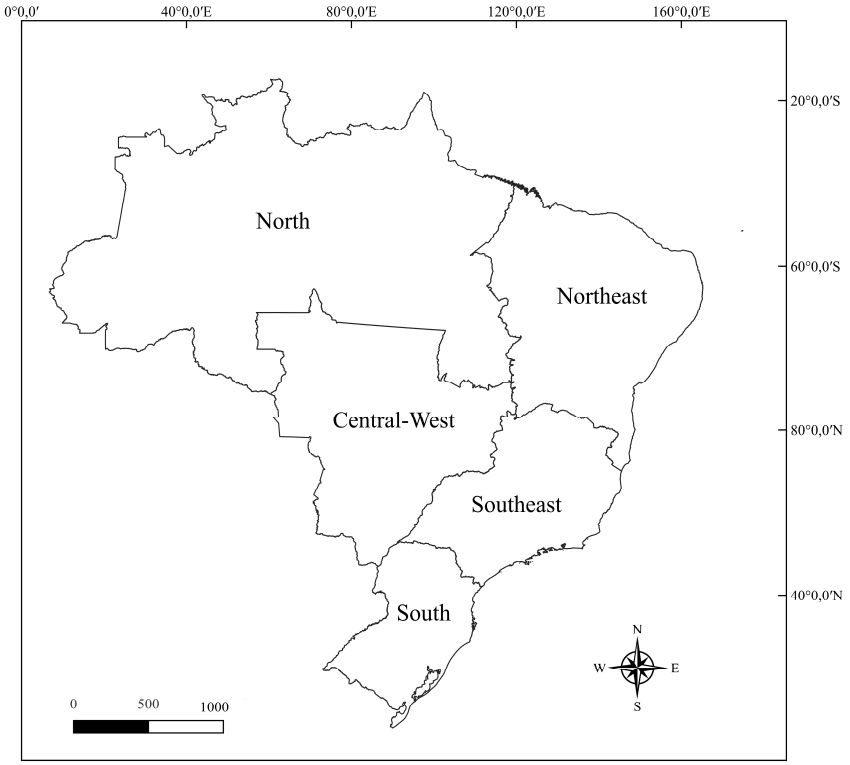


Figure 1. Study area: Brazil and its five major regions (North, Northeast, Central–West, Southeast, and South).

Table 1. Number and average area of agricultural farms in the economic activity groups of *livestock and breeding of other animals* in 2017, in Brazil and its major regions. Data from the 2017 Agricultural Census (AC), Brazilian Institute of Geography and Statistics (IBGE).

Brazil and Its Major Regions	Predominant Biomes	Number of Farms (Units)	Average Size of Farms (ha)	Average Bovine Herd Size per Farm (Head)
Brazil		2,476,629	90.3	68.5
North	Amazon	253,355	195.9	131.5
Northeast	Atlantic Forest, Caatinga, Cerrado	1,089,602	41.3	24.9
Southeast	Atlantic Forest, Cerrado	514,782	65.6	57.0
South	Atlantic Forest, Pampa	342,436	47.8	42.0
Central-West	Amazon, Cerrado, Pantanal	276,454	285.5	223.3

2.2. Data Source and Processing

To analyze the dynamics of pasture use (both natural and planted) and the herd and stocking rates of cattle in Brazil, data from the AC of the Brazilian Institute of Geography and Statistics (IBGE), conducted between 1970 and 2017, were used. The AC publishes information on agricultural farms and activities, which is available for the five different geographical divisions of Brazil (Figure 1). The AC was conducted every 10 years until 1970. Between 1970 and 1985, it was conducted every 5 years. After 1985, due to IBGE's difficulties in performing the survey, the AC was conducted irregularly in 1996, 2006, and 2017. In this study, data from the AC conducted in 1970, 1975, 1980, 1985, 1995, 2006, and 2017 were used (see summary in Table 2).

The data on the number of cattle (in millions of heads) and the pasture area occupied by cattle (in millions of ha) were also obtained using IBGE microdata. These microdata are derived from special calculations generated by IBGE, based on an institutional cooperation agreement with the Rural Development Institute of Paraná—IAPAR-EMATER (IDR-Paraná), at the request of the authors. The results were organized at the national and regional levels. In the AC data, it is not possible to identify the purpose of cattle production

for all farms [27]; therefore, a cattle herd includes animals intended for both beef and milk production.

Table 2. Data used in the current study. Data are from the agricultural censuses of the Brazilian Institute of Geography and Statistics (IBGE) and the Brazilian Project for Annual Mapping of Land Use and Cover (MapBiomas).

Years	Source and Description of the Data
1970, 1975, 1980, and 1985	IBGE's Agricultural Census data: bovine herd and pasture areas with bovines
1995, 2006, and 2017	IBGE's special tabulations of Agricultural census (microdata): bovine herds and pasture areas occupied with bovines
2006 and 2017	IBGE's agricultural censuses: conditions of the planted pastures; MapBiomas: conditions of the pastures.

Natural pasture, according to the AC, is defined as "area occupied with natural fields, *faxinal*, and other", referring to "areas of unplanted pastures, even if they are cleaned, graded, or otherwise managed and used or destined for the grazing of animals existing in the area". In addition, information on the conditions of the planted pastures was used, and these microdata were collected in the 2006 and 2017 ACs, according to the definitions and terminology presented in Table 3. This information was used to analyze pasture degradation. For comparison, in 2006 and 2017, information was obtained on the areas and conditions of the pastures using data from the Brazilian Project for Annual Mapping of Land Use and Coverage (MapBiomas) [28].

Table 3. Definitions adopted by the Brazilian Institute of Geography and Statistics in the 2006 and 2017 agricultural censuses (AC) for classifying the conditions of planted pastures.

Pasture Conditions	Variable Raised in the AC *	Description of the AC Variable **
Pasture in good condition	Pastures planted in good conditions of use (including pastures that are in the process of recovery)	Areas planted or in preparation for planting plant species intended for the grazing of existing animals on farms, which are not degraded, as they receive frequent maintenance. Include pastures that are in the process of recovery.
Pasture in bad condition	Planted pastures degraded by inadequate management or lack of conservation, in poor conditions of use (low productivity, degraded or unused)	Areas planted with plant species intended for grazing animals on farms, considered degraded, in poor condition, or unused by the producers themselves. In general, these are pastures that were initially productive and, due to lack of maintenance or intensive use, have become less productive. In addition, they can present other problems, such as erosion, invasive plants, and termite mounds. These areas do not include those planted with forage for cutting, used in animal feed.

Sources: elaborated based on * questionnaire and ** taker manual from agricultural censuses of the Brazilian Institute of Geography and Statistics.

2.3. Research Methods

The stocking rate was calculated as the ratio between the number of cattle and the pasture area occupied by cattle in hectares [29]. However, our methodological procedure differs from the one adopted by Martha et al. [30], which does not use the area occupied exclusively by cattle, but rather the area occupied by all livestock herds (cattle, horses, buffaloes, sheep, goats, and others). The stocking rate calculation adopted in the current study expressed the intensity of pasture use only by bovine cattle. In other words, in our study, the stocking rate is the number of animals per unit of pasture area in a given period, calculated as the ratio between the number of bovine cattle and the pasture area occupied by bovines, expressed in terms of total head of bovines per hectare (i.e., animal units at a specific time per unit of land area currently grazed [29]).

3. Results

3.1. Herd Changes, Total Area Occupied by Pastures, and Cattle Stocking Rate

The analysis of the AC data indicates that the number of cattle in Brazil increased by 119.7%, from 78.6 million head in 1970 to 172.7 million in 2017 (Figure 2a). This growth was mainly due to the more intense expansion of the cattle herd in the North and Central-West regions, which grew by 1947.1% and 253.2%, respectively. In contrast, the growth rates in the other regions were 57.2% in the Northeast, 24.2% in the South, and 17.5% in the Southeast (Figure 3a). Even with a small decrease (1.9%) in the number of cattle in Brazil between 2006 and 2017, from 176.1 million to 172.7 million head, there was an increase in the number of cattle in the North (6.8%) and Central–West (2.5%) regions during the same period.

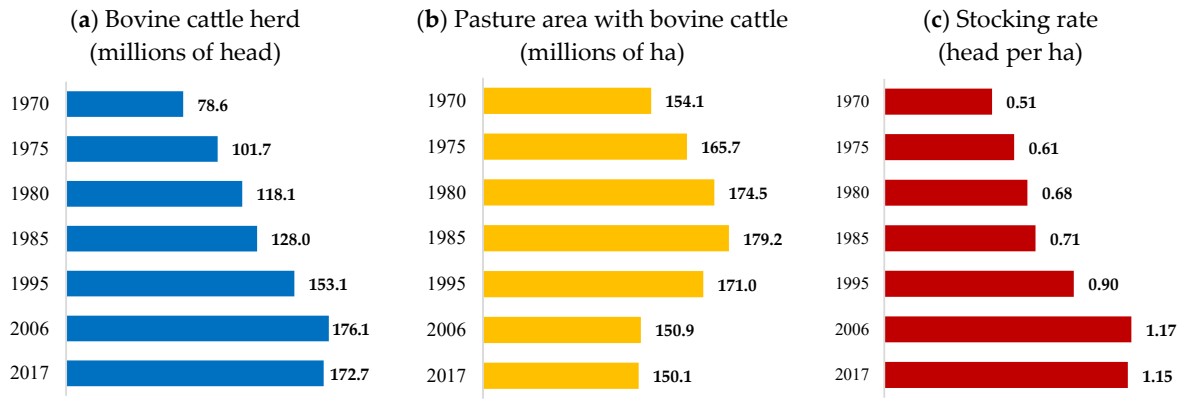


Figure 2. Changes in Brazil from 1970 to 2017: (**a**) bovine cattle herds, (**b**) pasture areas with bovine cattle, and (**c**) cattle stocking rates, based on data from the agricultural censuses (1970 to 1985) and special tabulations of the agricultural censuses (census years 1995, 2006, and 2017) of the Brazilian Institute of Geography and Statistics.

In relation to the total area occupied by pastures in Brazil (both planted and natural), considering the beginning and end of the period, there was a decrease of 2.6%, from 154.1 million ha (Mha) in 1970 to 150.1 Mha in 2017 (Figure 2b). However, when analyzing its change between the census periods, it was observed that the area of pasture increased between 1970 and 1985, reaching a maximum of 179.2 Mha, and then decreased to its smallest area in 2017, 150.1 Mha, showing a stability trend, as it remained practically the same as in 2006.

Between 1970 and 2017, only the North region experienced an increase in pasture area, growing considerably from 4.4 Mha in 1970 to 31.3 Mha in 2017 (an increase of 611.4%, Figure 3b). In the other regions, i.e., the Northeast, Southeast, South, and Central–West, decreases in pasture areas of 14.0%, 42.5%, 33.3%, and 1.3%, respectively, were observed. The regions with the highest total pasture area in Brazil in 2017 were the Central–West region, with 36.5% of the total pasture area, followed by the North region, with 20.9%.

Although there was a 2.6% reduction in pasture area in Brazil from 1970 to 2017, the stocking rate increased, with cattle herd numbers growing substantially at the same time (Figure 2c). There was a continuous increase in the stocking rate throughout the period based on the successive comparison of census data, except from 2006 to 2017, when this indicator decreased slightly (1.7%). The highest stocking rate increases occurred from 1970 to 2017 in the Central–West (251.6%) and North (184.6%) regions (Figure 3c). In turn, the Southeast and South regions experienced increases of 105.0% and 85.2%, respectively, while the Northeast region had the lowest increase in stocking rate, at 82.0%. Although the stocking rate growth in the South region over the entire period was relatively low compared to the North, Central West, and Southeast regions, and almost as low as the growth shown in the Northeast, it maintained the highest absolute stocking rates in all the years of the census series analyzed in this study (Figure 3c).

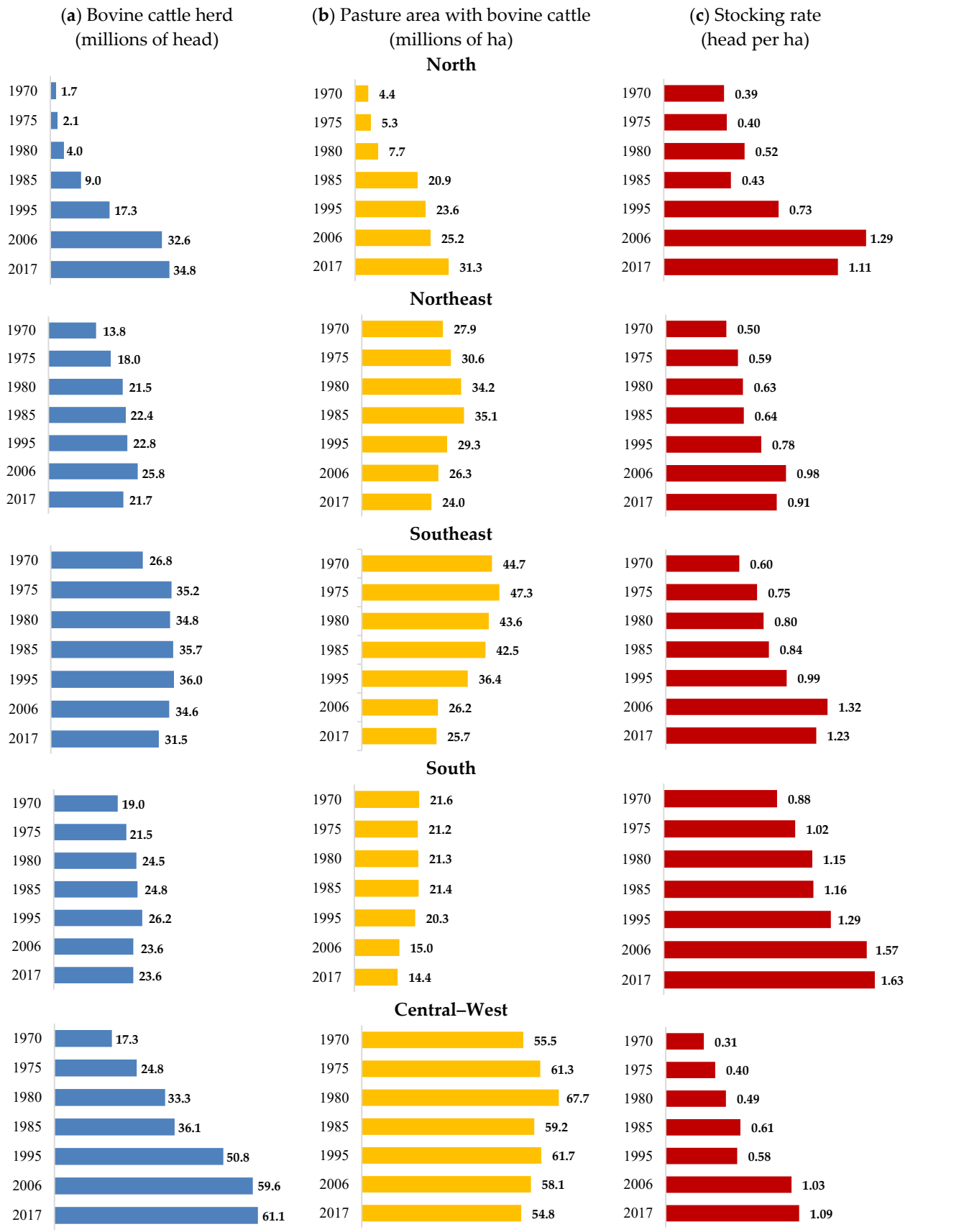
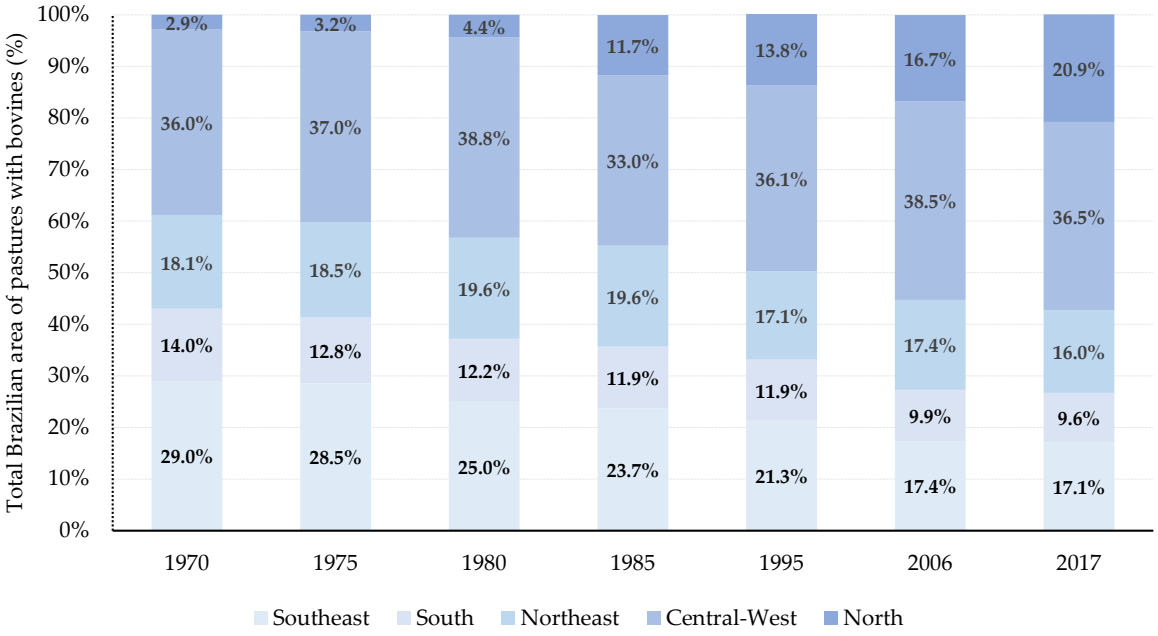


Figure 3. Changes in the major regions of Brazil from 1970 to 2017: (**a**) cattle herds, (**b**) pasture areas, and (**c**) cattle stocking rates based on special tabulations of the agricultural censuses of the Brazilian Institute of Geography and Statistics.

Figure 4 synthesizes the changes in the spatial distribution of cattle herds and pasture areas among the major regions of Brazil. From 1970 to 2017, the North and Central–West regions increased their share of the Brazilian cattle herd from 2.2% and 22% to 20.2% and 35.4%, respectively, while the other regions saw a decrease (Figure 4a). The same trend was observed for pasture areas (Figure 4b).

(**a**) Participation of major regions in the Brazilian area of pastures with bovines



(**b**) Participation of Major Regions in the Brazilian bovine herd

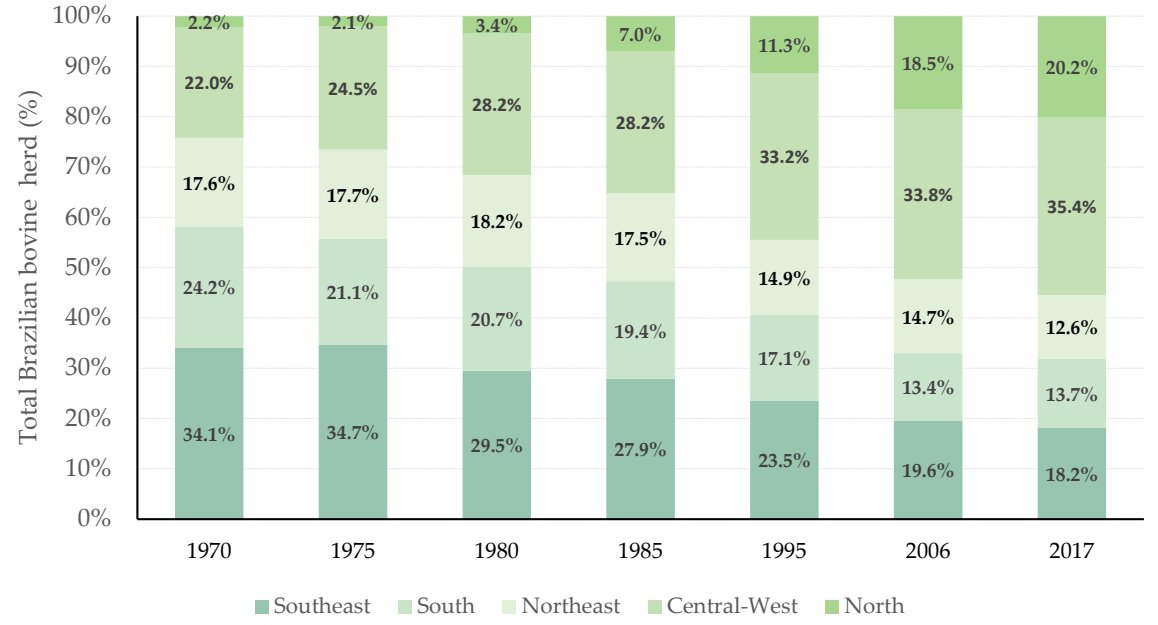


Figure 4. (**a**) Participation of major regions in the Brazilian area of pastures with bovines, and (**b**) participation of major regions in the Brazilian bovine herd from 1970 to 2017, based on data from agricultural censuses (1970 to 1985) and special tabulations of the agricultural censuses (census years 1995, 2006, and 2017) of the Brazilian Institute of Geography and Statistics.

In order to illustrate the dynamics of pasture areas, based on the relative participation of pasture areas in the total area of farms, Figure S1 was prepared using IBGE data from Brazilian microregions published in the agricultural censuses of 1995, 2006, and 2017, as these are the years with information available by microregion in the IBGE System of Automatic Recovery (SIDRA).

3.2. Changes in Pasture Types and Conditions

This section analyzes the changes in pastures according to their classification as natural or planted, as well as the changes in the condition of planted pastures, based on data obtained from producers in the 2006 and 2017 ACs and, for comparison purposes, on georeferenced data obtained from MapBiomas for Brazil and the major Brazilian regions. The purpose was to separate the pastures according to their type (natural or planted) and the condition in which they were found (in good or bad condition/degraded or not degraded).

The natural, planted, and total pasture areas in Brazil and its five major regions surveyed in the ACs from 1970 to 2017 are presented in Table 4.

In general, in Brazil, the analysis shows that in almost all the years of the census series, there was a reduction in natural pastures (except from 1970 to 1975) and an increase in planted pastures. Specifically, the area of natural pastures decreased from 124.4 to 47.3 Mha, while the area of planted pastures increased from 29.7 to 112.2 Mha. These trends of increasing planted pasture area and decreasing natural pasture area observed in Brazil overall also occurred in the major regions, except in the North region, where an increase in natural pasture area from 1970 to 1985 occurred with decreases in the subsequent surveys. The analyzed data show that the growth of the total pasture area from 1970 to 1985 was sustained by the substantial increase in the planted pasture area, which more than offset the reductions in natural pastures, and that the reduction observed in the total pasture area from 1985 was at a smaller scale, in absolute terms, due to the continuous expansion of planted pastures.

The Central–West region had the largest total pasture area in all the years of the census series, with a reduction of 74.8% in natural pasture and an increase of 393.7% in planted pasture area from 1970 to 2017. Another region that experienced a substantial reduction in natural pasture area was the Southeast, where it decreased by 76.5%, while the growth of the planted pasture area in this period was 80.2%. From 1970 to 2017, reductions in natural pasture areas were also observed in the South (47.2%) and Northeast (45.2%) regions, as well as increases in planted pasture areas of 52.8% and 165.5%, respectively. The North region, which had the smallest total pasture area in Brazil in 1970, had the second largest area in 2017. This was the only major Brazilian region that, considering the study period overall, showed growth in both natural pasture areas (55.3%) and planted pasture areas (4450.0%). Although the North region predominantly features forest vegetation, not all of it is part of the Amazon biome. There are typical savanna areas in Roraima. Furthermore, in 1988, the state of Tocantins, which has areas with dominant savanna vegetation, was created and administratively incorporated into the North region, explaining the occurrence of natural pastures. However, two distinct subperiods were identified: in the first, from 1970 to 1985, there was an increase in the natural pasture area (210.5%), while in the second subperiod, from 1985 to 2017, there was a reduction of 50.0% in the natural pasture area. This scenario shows that the same pattern of a downward trend in natural pastures observed in the other major regions also occurred in the North region, even though it started later in the census series (from 1985 onward). The data also reveal that the continuous and high expansion rate of the total pasture area in the North region in the study period was due to the substantial advance of planted pastures.

Table 4. Areas of natural and planted pastures, and total pasture area in Brazil and its major regions from 1970 to 2017 (for bovines from 1970 to 1985 and total livestock in the last three census years, 1995, 2006, and 2017) based on data from the agricultural censuses of the Brazilian Institute of Geography and Statistics.

Brazil and Major Regions	Year	Pasture Area (in Million ha)		
		Natural	Planted	Total
Brazil	1970	124.4	29.7	154.1
	1975	126.0	39.7	165.7
	1980	113.9	60.6	174.5
	1985	105.1	74.1	179.2
	1995	78.0	99.7	177.7
	2006	57.6	102.4	160.0
	2017	47.3	112.2	159.5
North	1970	3.8	0.6	4.4
	1975	3.7	1.6	5.3
	1980	4.0	3.8	7.7
	1985	11.8	9.1	20.9
	1995	9.6	14.8	24.4
	2006	6.0	20.9	26.9
	2017	5.9	27.3	33.2
Northeast	1970	22.1	5.8	27.9
	1975	23.8	6.8	30.6
	1980	23.8	10.3	34.2
	1985	23.3	11.9	35.1
	1995	20.0	12.1	32.1
	2006	16.0	14.6	30.6
	2017	12.1	15.4	27.5
Southeast	1970	34.1	10.6	44.7
	1975	35.7	11.6	47.3
	1980	27.5	16.2	43.6
	1985	25.8	16.7	42.5
	1995	17.3	20.5	37.8
	2006	11.0	16.9	27.8
	2017	8.0	19.1	27.2
South	1970	18.0	3.6	21.6
	1975	16.7	4.4	21.2
	1980	15.7	5.6	21.3
	1985	15.3	6.1	21.4
	1995	13.7	7.0	20.7
	2006	10.8	4.8	15.7
	2017	9.5	5.5	15.0
Central–West	1970	46.4	9.1	55.5
	1975	46.0	15.3	61.3
	1980	43.0	24.7	67.7
	1985	29.0	30.3	59.2
	1995	17.4	45.3	62.8
	2006	13.8	45.2	59.0
	2017	11.7	44.8	56.5

For the 2006 and 2017 ACs, information was collected about the conditions of planted pastures in Brazil, which did not occur in previous surveys. This information, presented in Table 5, was obtained based on information provided by interviewees responsible for rural farms, who indicated that 90.3% in 2006 (equivalent to 92.5 Mha) and 89.4% in 2017 (100.2 Mha) of the total planted pasture area was in good condition. In 2006, the Central–West region had the highest relative percentage of planted pastures declared by farmers to be in good condition, at 92.6%, while in 2017, the highest relative percentage occurred in

the South region, at 95.4%. In absolute terms, for both censuses, the Central–West region had the largest area of planted pastures in good condition, equivalent to 41.9 Mha in 2006 and 41.8 Mha in 2017. The Northeast region had the lowest proportion of pastures in good condition in two census surveys, 84.6% in 2006 and 73.5% in 2017. Despite having the lowest percentages in the country, the Northeast region still had a very high number of pastures in good condition in relation to the total number of planted pastures.

Table 5. Conditions of planted pastures in Brazil and its major regions: total area and percentage in 2006 and 2017, according to data from the agricultural censuses of the Brazilian Institute of Geography and Statistics.

Brazil and Major Region	Year	Area (Million ha)			% of Total Area		
		Good Condition	Bad Condition	Total	Good Condition	Bad Condition	Total
Brazil	2006	92.5	9.9	102.4	90.3	9.7	100
	2017	100.3	11.9	112.2	89.4	10.6	100
North	2006	18.7	2.2	20.9	89.5	10.5	100
	2017	25.1	2.2	27.3	91.9	8.1	100
Northeast	2006	12.3	2.2	14.6	84.6	15.4	100
	2017	11.3	4.1	15.4	73.5	26.5	100
Southeast	2006	15.2	1.7	16.9	90.1	9.9	100
	2017	16.8	2.4	19.1	87.7	12.3	100
South	2006	4.4	0.5	4.8	90.7	9.3	100
	2017	5.2	0.3	5.5	95.4	4.6	100
Central–West	2006	41.9	3.4	45.3	92.6	7.4	100
	2017	41.8	2.9	44.8	93.4	6.6	100

The percentage of planted pasture areas in Brazil declared by farmers to be in poor condition was 9.7% in 2006 and 10.6% in 2017, equivalent to 9.9 Mha and 11.9 Mha, respectively. In absolute terms, the Central–West region had the largest area of planted pasture in poor condition in 2006 (3.4 Mha), and the Northeast region had the largest area in 2017 (4.1 Mha). The Northeast region also had the highest relative percentage of pasture area in poor condition in both census surveys (15.4% in 2006 and 26.5% in 2017). In turn, the South region had the lowest area of planted pasture in poor condition in both absolute terms (0.5 Mha in 2006 and 0.3 Mha in 2017) and percentage terms (9.3% in 2006 and 4.3% in 2017).

The high rates of planted pastures declared to be in good condition in the census survey data attracted our attention as they did not corroborate data from other sources, such as MapBiomas, which is based on image analysis. According to MapBiomas, pasture areas in poor condition (degraded) in Brazil represented 63.4%, in 2006, and 59.6%, in 2017, of the total pasture area. The MapBiomas data for 2017 are like those reported by other sources that also use geoprocessing to determine land use [31]. These findings contrast with the data provided by rural producers during the ACs (Table 5). However, the values of total pasture area in both sources, the ACs (160 and 159.5 Mha in 2006 and 2017, respectively, Table 4) and MapBiomas (166.2 Mha and 158.4 Mha in 2006 and 2017, Table 6), were similar.

According to the analysis of the MapBiomas data, the regions with the highest percentage of pasture degradation were the Central–West (71.6% of the total), in 2006, and the Northeast (71.3% of the total), in 2017, while lower degradation, in relative terms, was observed in the North (49.4%), in 2006, and in the South (31.4%) in 2017. In absolute terms, the largest areas of degraded pasture were found, in both 2006 and 2017, in the Central–West region, at 39.2 and 30.8 Mha, respectively.

Table 6. Conditions of planted pastures in Brazil and its major regions: total area and percentage in 2006 and 2017, according to data from the Brazilian Project for Annual Mapping of Land Use and Cover (MapBiomas).

Brazil and Major Region	Year	Area (Million ha)			% of Total Area		
		Good Condition	Bad Condition	Total	Good Condition	Bad Condition	Total
Brazil	2006	60.8	105.4	166.2	36.6	63.4	100
	2017	64.1	94.3	158.4	40.4	59.6	100
North	2006	19.3	18.8	38.1	50.6	49.4	100
	2017	22.9	19.3	42.2	54.2	45.8	100
Northeast	2006	12.9	20.5	33.4	38.6	61.4	100
	2017	9.7	24.1	33.8	28.7	71.3	100
Southeast	2006	10.7	24.2	34.9	30.7	69.3	100
	2017	10.1	18.8	28.9	34.9	65.1	100
South	2006	2.3	2.6	4.9	46.5	53.5	100
	2017	2.7	1.2	3.9	68.6	31.4	100
Central–West	2006	15.6	39.2	54.8	28.4	71.6	100
	2017	18.7	30.8	49.5	37.8	62.2	100

4. Discussion

4.1. Dynamics of Cattle Raising in Brazil

The expansion of Brazilian cattle herds can be attributed to both the domestic and the international demand for beef, especially from the United States and, more recently, China. Brazilian beef exports increased from 124 thousand tons in 1970 to 1231 thousand tons in 2010 [30], and reached 1534 thousand tons in 2017, of which 1210 thousand tons were in fresh, chilled, and frozen forms [32]. This production growth in Brazil was due to the increase in stocking rates (from 0.51 to 1.15 head ha^{-1}, on average, from 1970 to 2017), especially in the South and Southeast regions, and the increase in pasture area, for example, in the North region of the country.

Under extensive and extractive systems, pasture area expansion has increasingly shifted to the forest areas of the Amazon and Cerrado biomes, as observed by Fearnside [33], Soares-Filho et al. [34], and Pereira et al. [35]. The data from the present study also showed the same result: increased total pasture area and number of cattle in the North and Central–West regions, both of which contain most of the territory covered by these two biomes in Brazil. According to Vinholis et al. [36], this extractive model of cattle production should be reviewed because, in addition to being an aggressive system, it does not fit the current models of sustainable livestock farming or the new sanitary, environmental, and food safety requirements, making such systems unsustainable in the medium and long term. Grasses from the African genus Urochloa (Poaceae) have adapted well to the Brazilian climate and are widely cultivated for cattle, covering approximately 80% of the pasture areas in Brazil. However, this widespread cultivation might have an impact on ecosystem biodiversity [37]. The human impact on natural land (i.e., land use conversion and natural land cover modification) in Brazil increased by 64% between 1985 and 2018 (when achieved around 400 Mha), but whereas the pasture area increased by 42%, the cropland area in Brazil nearly tripled in this period, the latter being sourced primarily (61%) from converted pastures [38].

Such dynamics suggest the migration of beef cattle to regions with lower land prices [39], which are compatible with livestock production in the face of competition for land from other agribusiness activities, especially soybean, corn and sugarcane [13]. This would explain the displacement of cattle herds and the increase in pasture area in, for example, the North region of Brazil. The reduction in pasture areas and the reduction in the number of cattle in the country between 2006 and 2017 may indicate a transition from areas previously

occupied by livestock to crops in the South and Southeast regions. Thus, the expansion of annual cropland in the South and Southeast states seemed to 'push' livestock activity to the agricultural frontier, causing deforestation, with the loss of natural vegetation areas because of the general dynamics of the evolution of Brazilian agriculture. For instance, De Sá et al. [40] showed that planting sugarcane in pasture areas in São Paulo resulted in the displacement of livestock from that state to the Amazon, causing deforestation. Reducing drivers of deforestation on the planet is critical, especially for tropical forests (i.e., forty-five percent of the world's forested areas), since deforestation results in the loss of ecosystems services, biodiversity, and human well-being and enhances the vulnerability of socio-ecological systems to the impacts of climate change [24].

Deforestation in Brazil is strongly associated with land grabbing and speculation [41], with 9 to 13% of the lands in the Amazon being vulnerable to extensive cattle ranching, which occurs through these methods [42]. Rajão et al. [43] highlight that only 2% of properties (which produce soy and beef for export) are responsible for 62% of the area illegally deforested in the Amazon and Cerrado. In addition, according to the authors, parts of the soy and beef produced in Brazil, which are exported annually to the European Union, come from areas of illegal deforestation in the Amazon and Cerrado. The other Brazilian biomes, Atlantic Forest [44], Caatinga [45], Pantanal [46], and Pampa [47], have also experienced vegetation loss related to the expansion of commodity production. The Pampa and Pantanal biomes and specific areas of other biomes, such as the "Campos de Cima da Serra", which is part of the Atlantic Forest [48,49], have important natural pastoral ecosystems, in which beef cattle are essential for their preservation and sustainability. In the Pampa biome, for example, it is possible to considerably expand meat production by improving the conditions of native pastures and by supplementing animal feed, resulting in a lack of need for new open areas.

4.2. Intensity of Pasture Use for Cattle Raising in Brazil

Historically, the use of areas for extensive animal production had a great influence on territorial expansion and occupation in Brazil, according to the economic logic that livestock activity generally has the natural ability to overcome deficiencies in transportation infrastructure when expanding into new regions [50]. This logic explains the change observed in the study, as the North and Central–West regions are the most remote in the country, and due to their extensive area, they are less served by transportation infrastructure. Furthermore, as land-title granting by the Brazilian State at the beginning of colonization was based on the effective use of the land, extensive cattle ranching was also a way of guaranteeing property rights. Until 1985, increasing pasture areas was the main strategy for the expanding Brazilian livestock activity, given the conditions in which ranchers found themselves, with limited financial resources and low technology use. However, even before 1985, a different dynamic was already observed in Brazilian cattle farming, with increased animal density and reductions in pasture area in some regions, which is consistent with the results obtained here, which show the continuity of these trends compared to those in the previous years of agricultural production expansion [20], especially for soybean [51,52] and sugarcane [11,37], as well as for eucalyptus and pine forest production [53], and even the urbanization of original pasture areas.

Improvements to the production process and support by credit from government modernization programs have been recorded since the 1960s, and examples include the National Livestock and Pasture Program. However, due to the need to implement more intensive production systems to compete with countries considered to be more efficient in meat production for the export market, after the 1980s, there was greater intensification of the pasture use in Brazil, a phenomenon that was confirmed by the results of this study, which showed increased stocking rates for cattle, starting in 1985. Initially, this intensification was explained by changes in the use of natural pastures for cultivated pastures, with the increase in productivity due to the application of technologies, mainly through the improvement of animal management techniques, the recovery and management of

pastures, and the use of improved forage cultivars. According to Polaquini et al. [54], improvements in genetics, nutrition, health, and management of herds (e.g., by adjusting the forage allowance, at no cost), factors related to animal performance indices also contributed to the increase in productivity. Such changes of a technological nature explained 79% of the growth in Brazilian beef production from 1950 to 2006 and accounted for an estimated land saving effect of 525 Mha [30]. However, the intensification of livestock farming in Brazil in recent years has not prevented the expansion of the pasture area, predominantly dedicated to beef cattle, in the Amazon biome. In this study, using the census data from 1985 to 2017, a 50% increase in pasture area (plus 10.4 Mha), and a 287% increase in cattle herds (plus 25.8 million heads) were verified in the North region. The advance of Brazilian livestock in this biome was also evaluated by França et al. [55], who noted that the Amazonian pasture area as a percentage of the total pasture area of Brazil increased from 11.86% in 1985 to 29.16% in 2018. This result is corroborated by the results of this study, which show that the pasture area in the North region as a percentage of the total pasture area in the country increased from 11.7% in 1985 to 20.8% in 2017 (Table 4).

According to the data of this study, between 2006 and 2017, only the North region experienced continuous growth in both cattle herds and pasture areas. The stocking rate also increased continuously in the region throughout the entire period analyzed in this study, except between 2006 and 2017, when it fell from 1.29 to 1.11 cattle ha^{-1}. This phenomenon may have been related to extensive livestock farming in the North region being resumed as the agricultural frontier advanced and new areas in the Amazon were occupied because immediately after deforestation, these areas had a low number of animals. In this type of system, where vegetation (in this case, forest) has already been removed, production increases occur, with low investments in pastures and animals. However, Meyer and Rodrigues [27] demonstrated in their study that the production system in the North region has intensified, leading to a consequent increase in the stocking rate, thus alleviating pressure on the forest areas. Additionally, the rise in stocking rates in the North can be attributed to the decision by some major slaughterhouses to avoid purchasing animals from recently deforested areas of the Amazon forest, which covers a significant portion of the region [56].

Although cattle herds predominantly contain beef cattle in all regions, the North and Central–West regions have cattle herds that are specialized in meat production, with 90% of the animals produced for beef. The South and Southeast regions of Brazil indeed have favorable soil and climate conditions for dairy production. These regions contribute significantly to the country's milk production, accounting for more than 60% of the total output [57]. This distribution may be related to the high demand for land areas where beef cattle ranching, based mainly on a system of animals raised on pasture, can still occur. Dairy farming is dominant in less extensive areas, i.e., areas with small and medium-sized farms, especially family farms, where the topography is less conducive to soil mechanization.

The reduction in cattle herds observed between 2006 and 2017 in Brazil was probably due to the seasonality of the price of beef per arroba, which resulted in increased cattle slaughter. According to Gonçalves et al. [58], this disposal of cattle provided an economic balance in livestock production when there were low cattle prices, and the value obtained from the sale of these animals was reduced. Another factor that may explain such dynamics is the political and financial instability that affected large national companies involved in the beef market at the time.

Despite the investments in technologies that promoted changes in land use and improved animal production efficiency, demonstrated by the intensification of cattle farming in Brazil, De Oliveira Silva et al. [14] argue that extensive livestock production, which is related to degraded pastures and low productivity, still occurs in many livestock-producing regions, compromising meat production growth in the country and, concomitantly, food and fiber agricultural production expansion in a scenario of zero deforestation. According to Soares-Filho et al. [59], an effective application of the Forest Code, together with government programs, such as the Low Carbon Agriculture (ABC) plan, can reduce deforestation

and generate environmental gains related to the reduction of greenhouse gas emissions in the country.

A part of livestock farming has become more intensive, as demonstrated by Vale et al. [60], who reported that cattle production in feedlot systems increased by 442% in Brazil between 1990 and 2017, when more than 4 million head existed under this management system, mainly in the Central–West and Southeast regions [27]. The yield of a feedlot, in terms of the production in kg of meat ha^{-1} day^{-1}, is five to thirty-eight times higher than that of a traditional system based on pasture (in which 80% of the herd is fattened on traditional pasture, and 20% of animals are fattened on improved pasture) and twice that of a semi confinement system [58]. However, as shown in countries where confinement is the basis of beef production systems (e.g., the United States and several European countries), the supply of feed for cattle requires intensive labor use, machinery, equipment, and energy supply, which increase the costs of producing animal protein and require a focus on management, location, and animal welfare, and their high environmental cost [61].

Although a feedlot is considered a path to production intensification and is expanding rapidly in Brazil, this system still plays a small role in beef cattle [60]. According to Meyer and Rodrigues [27], only 2.85% of the Brazilian cattle herd is kept in confined systems, indicating that livestock activity predominantly occurs on pastures. In Brazil, grazing animal management systems vary widely, from extensive systems with a low use of inputs and technology to more intensive systems, which, according to Latawiec et al. [23], are characterized by using forage cultivars with high production and quality levels, in addition to management that promotes more efficient grazing by the animals. However, the sustainable intensification of pasture-based animal production systems in typical biomes where livestock is most relevant (e.g., Amazon, Cerrado, Pampa, and Pantanal) may offer new perspectives to minimize the impact of Brazilian livestock on the planet [4].

4.3. Pasture Conditions

According to the information gathered in this study, in 2017, only 10.6% of the planted pastures were considered by AC respondents to be in poor condition and/or degraded, representing a total area of 11.9 Mha (Table 5). However, other studies show that degraded pastures in Brazil account for more than half of the total pasture area [62,63]. This scenario led to the hypothesis that the information provided by respondents as part of the AC surveys did not represent the actual condition of the planted pastures, and the degree of degradation was apparently underestimated. The definition of "degradation" is challenging because it is a subjective term, leading to variations in estimates or classifications arising from consultations with different respondents [7,64,65]. Therefore, other evaluation methodologies, such as image analysis or field studies, are recommended to classify the condition of pastures [66]. In addition to the census data, the present study used MapBiomas data derived from the analysis of satellite-generated images, which were more consistent with the actual pasture conditions reported by other studies, allowing a spatial analysis by biome.

According to Feltran-Barbieri and Féres [67], besides the different perceptions of which pastures are considered to be in good condition (nondegraded) or in poor condition (degraded) by producer respondents, another reason for the discrepancy is that when responding to the AC survey, the farmers may have felt encouraged to underreport areas of degraded land for fear that under such conditions, they may be subject to regulatory sanctions, despite the confidentiality practiced by IBGE. Therefore, this discrepancy between the data implies the necessity of integrating both methods into policymaking and agricultural management decisions.

In the 2014/15 crop year, the North and Northeast regions of the country had the lowest stocking rates, calculated in animal units per ha (AU ha^{-1}), while the South region had the highest rate [68]. These data are consistent with the results of our study. According to MapBiomas data, 63.4% and 59.6% of the pasture areas in the country were in poor condition in 2006 and 2017, respectively. Within the major Brazilian regions, the degradation

of pasture areas is greater in regions where livestock is advancing along the agricultural frontier (North, Northeast, and Central–West), a phenomenon that is likely to be associated with a premature reduction in pasture productivity, resulting in decreased productive longevity and encouraging deforestation to form new pasture areas. In turn, the degree of pasture degradation is intermediate in the Southeast region and comparatively low in the South region. These results partially agree with the analysis in this study based on MapBiomas data; i.e., the regions that had the lowest percentages of degraded pastures were the North region, in 2006, and the South region, in 2017, and the Central–West and Northeast regions had high percentages of pastures in poor condition, with these values being similar to those determined for the Southeast region, despite the latter region having technologically, economically, and structurally well-developed agriculture [27]. Therefore, the estimates based on the information provided by the producer respondents to the AC surveys were probably underestimated regarding pasture degradation.

Among the major regions of the country, the South region had the highest stocking rate (1.63 head of cattle ha^{-1} in 2017), possibly due to its use of technologies and its good soil and climate conditions, infrastructure [69], organizational factors, and soil–plant–animal management practices. On the other hand, overgrazing is a reality in most of the natural pasture of the Pampa biome in southern Brazil, historically driven by production-oriented policies that inaccurately established minimum stocking rates as a measure of land productivity but disregarded the non-linear relationship between these variables and the conservation of this biome [70]. Consequently, livestock productivity has been historically low, because overgrazed pastures have short swards and low forage mass, resulting in low forage dry matter intake by animals [71].

In the South region, cattle farming—mainly dairy farming—still predominates on small farms with intensive production systems [27]. Fasiaben et al. [72] highlighted that compared to the other two states in the South, Paraná has a greater number of beef cattle farms with low technological levels, considering the stocking rate indicator, the use of supplementary feeding, the use of pasture fertilization, the use of crops for pasture recovery, confinement, and the use of technical assistance. Volsi et al. [73] explain that such regions with low and medium modernization of pastures are related to lower-quality lands and predominantly have sandy soils. In turn, most of the microregions of the states of Santa Catarina and Rio Grande do Sul have intermediate and high technological levels related to beef cattle production.

The South region also stands out in terms of dairy production, with Paraná accounting for 14.1% of national dairy production, making it the second-largest producing state in Brazil [74]. Telles et al. [75] and Bacchi et al. [76] analyzed the milk production systems in Brazil by microregion and found, as observed for beef cattle by Fasiaben et al. [72], high levels of technological heterogeneity, which are due to complex biophysical, technical, and social interactions. Other agricultural activities, such as soybean, corn, rice, and forestry, have gained importance in the region in recent decades [46], displacing traditional pasture areas.

In the North region, there is a strong predominance of beef cattle, with dairy production being a smaller-scale activity (only 3.9% of all cattle) and dominated by family businesses, with production carried out for subsistence or to serve the local market [77]. However, in this region, there is a predominance of low-technology beef cattle raising [72]. The main causes of pasture degradation in the North region are similar to those reported for other tropical and subtropical zones, including the absence or poor use of inputs and inadequate pasture management.

The Central–West region had the largest pasture area in Brazil in all the years of the AC series and in both years of the MapBiomas series (Tables 4 and 5), and this region has traditionally produced beef cattle and grains [27]. Degraded pastures, or those in the process of degradation, in the Central–West region are unproductive pastures or areas of very low productivity with, consequently, low zootechnical indices. The adoption of forage species adapted to low-fertility soils, especially those of the genus *Urochloa*, particularly *U.*

decumbens, which was gradually replaced by *U. brizantha*, led to the formation of extensive pasture areas in the Central–West region. Although well adapted, these pastures are commonly established with a minimal addition of inputs, resulting in net exports of soil nutrients, leading to the loss of their productive capacity over time. This type of pasture management, which is close to an extractive livestock production system and is still practiced in several locations in the Central–West region, is likely to be the main factor responsible for much of the existing degraded pastures. On the other hand, the increase in the cattle herd and planted pasture, at the expense of natural pasture (Table 4), has pushed up the stocking rate [27].

Since much of the pasture areas in Brazil show some degree of degradation, an important opportunity for the mitigation of GHG, mainly by carbon sequestration in the soil, could be achieved by restoring these areas. Carbon sequestration by pastures has been shown to play a relevant role in mitigating GHG worldwide [19]. Pasture-fed cattle systems occupy 150,1 million hectares in Brazil (Figure 2). Therefore, carbon sequestration by pastures has impacts beyond the country level. The adoption of improved management strategies in cultivated pasture areas may provide opportunities for the intensification of cattle production, in addition to the preservation of native vegetation areas, contributing to a sustainable model of animal production.

4.4. Toward Sustainable Intensification

Some of the public policies that have been implemented by the Brazilian government, such as the ABC Plan, have promoted sustainable intensification through training, technical assistance, and credit for farmers who decide to adopt good agricultural practices. In addition to direct actions by the state, Gibbs et al. [56] note that there is a need to strengthen public–private partnerships, including the participation of nongovernmental organizations, to ensure the sustainability of cattle farming. Examples of this type of partnership are the *Rede ILPF* (Integrated Crop–Livestock–Forestry network) and the *Boi na Linha* program from Imaflora (Institute of Forestry and Agricultural Management and Certification). The *Rede ILPF* was established in 2012 with the objective of accelerating the adoption of technologies of crop–livestock–forestry integration by rural producers, formed and cofinanced by companies such as banks, cooperatives, manufacturers of agricultural equipment and agricultural inputs, and public research institutions. In fact, the adoption of ICLS has increased from 1.9 to >17 million ha in 16 years [26]. The states with the largest areas are Mato Grosso do Sul (3.2 million ha), Mato Grosso (2.3 million ha), and Rio Grande do Sul (2.2 million ha) [73]. The *Rede ILPF* network operates through projects to support technology transfer, and technical assistance training on integration systems. It also engages in institutional and governmental relations and communication, including conducting statewide surveys of the area occupied by ICLS in Brazil [78]. In turn, the *Boi na Linha* program was created in 2019, through the initiative of the certifier Imaflora and the *Ministério Público Federal* (MPF), which is the Brazilian Public Prosecutor's Office, having as its purposes the acceleration of the implementation of the commitments made by the beef supply chain in the Amazon and the encouragement of a supply chain free of socio-environmental irregularities. Besides voluntary efforts like these two examples, from the point of view of law enforcement, since 2009, in the North region of Brazil, some representative companies in the sector (slaughterhouses, meatpacking plants, and exporters of live animals) have signed conduct adjustment agreements (known by their acronym, as TACs), under which they adopt a commitment not to purchase animals raised on properties that do not comply with environmental and social laws. The signing of an individual TAC by the four larger Brazilian beef processors in 2009 (Bertin, JBS, Marfrig, and Minerva) is referred to as the G4 Cattle Agreement (G4), which was implemented in 2010 and excludes suppliers with post-2010 deforestation from selling to these four signatory slaughterhouses [79].

Livestock production intensification, with an increase in the stocking rate, may reduce or eliminate the need to expand into new pasture areas. Strassburg et al. [80] highlight that since the current productivity of cultivated pastures in Brazil is 32–34% of their potential,

increasing this productivity to 49–52% would be enough to meet the country's demand for meat, grains, wood products, and biofuels to at least 2040, without having to convert more areas of natural ecosystems. There is evidence that the integration of market-led (such as G4) and public-led anti-deforestation policies exert an impact by increasing cattle ranching productivity and decreasing deforestation [79]. Bajželj et al. [81] argue that even if it were possible to eliminate the gap between the current yields of agricultural systems and their potential yields, the projected demand for production would still result in the expansion of the total area occupied by agriculture, causing the advancement of crops and pastures into native vegetation areas. Thus, the expansion of agricultural lands and reduction of GHG emissions would need to be limited, as would the excessive food consumption and waste by humans. According to Putman et al. [5], food waste reduction is one of the most important strategies for improving the environmental sustainability of the beef supply chain in the United States.

The generation of scientific and technological information, the dissemination and adoption of improved pasture and animal management practices, and the strengthening of public policies appropriate to each region or set of local conditions are necessary for the sustainable intensification of Brazilian cattle breeding so that new deforestation can be reduced or prevented and GHG emissions can be reduced [82]. The promotion of sustainable agricultural production systems is urgently required so that the growing global demand for animal foods and proteins can be met [83], and the interests of society in more efficient natural resource use, biodiversity preservation, and the prevention of the adverse effects of pollution and climate change on human welfare, animal welfare, and the environment are addressed.

5. Conclusions

The increase in Brazilian cattle herds from 1970 to 2017 (+120%) occurred in parallel with a reduction in cattle pasture areas (−2.6%) and the migration of these herds from the South and Southeast regions to the North (+1948%) and Central–West (+1947.1%) regions of Brazil. Notably, only in the North was there an increase in cattle pasture areas (+611.4%), highlighting the displacement of cattle production to the North region, specifically the Amazon biome.

Brazilian livestock is showing signs of intensification, particularly in southern Brazil, where the stocking rate has reached 1.63 head per hectare, accompanied by the highest increase in pasture quality. However, in agricultural frontier regions, traditional extensive cattle farming is still on the rise. This study highlights several actions to enhance sustainability, such as implementing government programs like the ABC and ABC+ plans, to help reduce deforestation and improve both environmental and productive outcomes.

Since 1985, natural pastures have been largely replaced by planted pastures across most of the regions of Brazil. The South region remains an exception, where natural pastures still predominate, despite a decrease. Strategies to add value to products from these high-biodiversity natural pastures could further enhance their preservation.

In Brazil, there is a significant discrepancy between farmers' perceptions and data from instrumental methodologies (i.e., data from MapBiomos) regarding the condition of planted pastures (10.6% vs. 59.6% of pasture areas in poor condition in 2017, respectively). This suggests that farmers tend to overestimate the quality of their pastures, which may contribute to the low stocking rates in cattle production. To better understand the impacts of livestock production on pasture conditions and obtain more accurate data, technical–scientific field studies are necessary.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14102429/s1. Figure S1: Dynamics of pasture areas, based on the relative participation of pasture areas in the total area of farms, using data from Brazilian microregions published in the agricultural censuses of 1995, 2006, and 2017 of the Brazilian Institute of Geography and Statistics.

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