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Land-use transformation and carbon balance in Brazil's biomes

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Abstract. The study reviews the types of land cover and analyzes the transformation of land use in Brazilian biomes over the past 30 years. Carbon balance data in connection with changes in land cover are analyzed. The total area of Brazil's transformed lands has been counted more than 100 million hectares over the past 30 years. The biomes of Amazonia, Cerrado, Mata Atlantica and Caatinga have undergone the greatest changes. One of the main reasons for the transformation is the expansion of agricultural land through deforestation. Thus, the total proportion of the country's lands subjected to deforestation is 72%. Anthropogenic land cover transformation affects the carbon content in the biomass. Carbon stocks in case of some biomes of Brazil are negative. The lowest rate in Caating is – 43.8 CO_2 E/year. The analysis was based on open spatial, statistical data and international scientific publications. The aim of the research is to study land use transformation in some Brazilian biomes and carbon balance in their ecosystems.

Keywords: agriculture, carbon fluxes, geoecology, forest landscapes, land cover

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Трансформация землепользования и баланс углерода в биомах Бразилии

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Аннотация. Проведен обзор типов наземного покрова и анализ трансформации землепользования в биомах Бразилии за последние 30 лет. Проанализированы данные по углеродному балансу в связи с изменениями наземного покрова. Общая площадь трансформированных земель Бразилии составила более 100 млн га за последние 30 лет. Наибольшие изменения претерпели биомы Амазония, Серрадо, Мата Атлантика и Каатинга. Одна из основных причин трансформации – это расширение сельскохозяйственных земель за счет сокращения лесов. Так, общая доля земель страны, подвергшихся обезлесению, составляет 72 %. Трансформация наземного покрова, имеющая антропогенные причины, влияет на содержание углерода в биомассе. Запасы углерода на примере некоторых биомов Бразилии отрицательные. Наиболее низкий показатель в Каатинге – 43,8 CO_2 Е/год. Основу анализа составили открытые пространственные, статистические данные и международные научные публикации. Цель исследования – изучение трансформации землепользования в некоторых биомах Бразилии и баланса углерода в их экосистемах.

Ключевые слова: геоэкология, лесные ландшафты, сельское хозяйство, наземный покров, потоки углерода

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Вклад авторов. *Попова Ю.С.* – концептуализация, формулирование идеи, формулирование исследовательских целей и задач, разработка методологии исследования, визуализация данных, написание – подготовка черновика рукописи; *Комарова Т.В.* – деятельность по аккумулированию исследовательских данных как для первоначального использования, так и для последующего повторного использования, редактирование рукописи. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Introduction

Brazil is the largest country in Latin America in terms of population (216,422,400 people) and land area (8510.3 thousand km^2).[1] It has the leading economy in the region and is a member of many international organisations. Over the past two decades, Brazil has made significant progress in its development. Priority and long-term scenarios for the country's sustainable development are being developed with a primary focus on improving human capacity, governance, trade and investment [1]. Environmental protection and land degradation control are still secondary issues. Brazil has 5.3 million km^2 of humid equatorial and subequatorial forests (Amazonian and Mata Atlantica biomes) and 3.2 million km^2 of dry tropical forests, savannas, grasslands and wetlands (Caatinga, Cerrado, Pantanal and Pampa biomes), representing a significant proportion of the area of these biomes. Cerrado savannas and Caatinga dry forests cover an area of more than 2.7 million km^2 [2].

Over the last three centuries, human-induced changes in the natural environment due to land use and land cover changes have intensified especially in the second half of the 20th century. Land use transformation due to deforestation and agricultural development is a key driver of climate change and contributes significantly to greenhouse gas (GHG) emissions. Food production and associated land-use change are also responsible for a significant share of anthropogenic GHG emissions. Direct carbon emissions directly caused by land use change over the period 1992-2015 counted 26.5 Pg (1.15 Pg/year) with a decreasing trend to 0.15 Pg/year [3].

In Brazil, which has a large agricultural sector, direct sources of GHG emissions and indirect sources (carbon emissions from deforestation and other forms of land-use change) account for most of all emissions. To ensure the country's food security while reducing the environmental impact of agriculture, it is necessary to implement new policies and technologies that will increase

[1] *Great Russian Encyclopedia*. (In Russ.). Available from: https://bigenc.ru/c/braziliia-e3108d (accessed: 09.03.2024).

agricultural yields on the one hand and reduce GHG emissions on the other hand [4; 5].

Brazil is the world's largest source of net-zero carbon emissions – 17-29% of the global total [6]. Emissions in 2019 are 2.18 Pg, 9.5% higher than in 2018, mainly due to deforestation and land use change. High demands are placed on achieving a 43% reduction in emissions by 2030 (compared to 2005 emissions). To achieve these targets, 12 million hectares of forest are planned to be reforested by 2030. At the 26th UN Climate Change Conference, Brazil signed an agreement to halt deforestation and land degradation by 2030 [2].

Land-use changes in Brazil are characterised by the rapid expansion of agricultural areas and urban areas at the expense of forests and natural pastures. These changes may contribute to increased carbon dioxide emissions, reduced carbon sequestration capacity and exacerbate the effects of climate change. Brazil is estimated to account for 35% of total tropical forest carbon emissions, of which 52% is attributed to the decline of forests and natural pastures [7].

In Brazil, the greatest land-use transformation occurred in Amazonia and Cerrado. At the same time, significant land cover changes have been observed in Mata Atlantica, Caatinga and Pampa biomes. Transformations in Brazil, mainly related to agricultural and forestry development, require the development of actions for agroecological sustainability. The focus on improving the resilience of rural landscapes, preserving ecosystems and, at the same time, meeting the demand for food, energy, water, raw materials and other goods and services, creates a need for research on the dynamics and functions of ecosystems and landscapes [8].

Materials and methods

Analysis of land cover, land use transformation is based on the use of spatial databases of products The MODIS Terra+Aqua Combined Land Cover product (MODIS),[2] Global Forest Monitoring Database Global Forest Watch (GFW),[3] cartographic data on Brazil – MapBiomas,[4] Sentinel satellite data for vegetation mapping worldwide ESA Worldcover,[5]statistical information from the Food and

[2] *MODIS Land Cover Type/Dynamics*. Available from: https://modis.gsfc.nasa.gov/data/dataprod/mod12.php (accessed: 13.03.2024).

[3] *Global Forest Watch (GFW)*. Available from: https://data.globalforestwatch.org/ (accessed: 13.03.2024).

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[5] Worldwide land cover mapping. *WorldCover*. Available from: https://esa-worldcover.org/en; Climate Change Initiative Land Cover, CCI-LC. *ESA*. Available from: https://esa-landcover-cci.org/ (accessed: 13.03.2024).

Agriculture Organisation of the United Nations FAO (Faostat),[6] Economic Commission for Latin America and the Caribbean (ECLAC) – CEPALSTAT,[7] as well as scientific publications (especially with regard to carbon balance studies in Brazilian biomes).

Results and discussion

Land use transformation

Land use and land cover change in Brazil is mosaic. Historically, land development has been oriented towards different needs of the time: mining, deforestation for valuable tree species and fuel, and agricultural development to solve the food problem. Currently, land use in the country is focused mainly on agriculture (Table 1).

Table 1. **Characteristics of land cover and land use of Brazilian biomes**

Biome	Area, million hectares (share of country area %)	Land cover	Predominant land use type
Amazonia	419 (49.29%)	Evergreen forest with savanna in the south, natural grasslands and extensive wetlands (20% of the biome has been deforested)	Livestock (cattle), farming, mining, logging and non-timber forestry
Mata Atlantica	111 (13.04%)	Fragmentation of forest covering 7-10% of the biome (mainly secondary thickets surrounded by arable land, pastures, forest plantations, urban and transport infrastructure)	Farming, livestock (cattle), urban development, forest plantations
Caatinga	84 (9.92%)	Dry forests (50% of the original area transformed)	Farming, livestock (cattle and sheep breeding), non-timber forestry and urbanisation
Cerrado	203 (23.92%)	Mosaic of savannas, grasslands and forests (50% of indigenous vegetation converted)	Farming, livestock (cattle), and logging for coal mining
Pampa	17 (2.07%)	Natural pastures with scattered shrubs and trees, rocky ledges	Farming, livestock (cattle) (on natural pastures), plantation and urbanisation
Pantanal	17 (1.76%)	Wetlands	Farming and livestock (cattle)

Source: compiled by Yu.S. Popova, T.V. Komarova according to the data of Mapbiomas. Available from: https://brasil.mapbiomas.org/en/ (accessed: 11.10.2024).

The transition from forest to grassland is the dominant process in the Amazonian biome frontier, while in central Brazil it is mainly characterised by the expansion of soybean crops in place of pasture. The dynamics of wetland and

[6] *FAOSTAT. The Food and Agriculture Organization of the United Nations*. Available from: https://www.fao.org/faostat/ (accessed: 12.03.2024).

[7] *CEPALSTAT. Statistical Databases and Publications*. Available from: https://statistics.cepal.org/ (accessed: 11.03.2024).

grassland areas in Pantanal are determined by interannual variability in precipitation. In Mata Atlantica and Amazonian biomes, reforestation processes in place of croplands are outlined [5; 9]. However, there are no reliable quantitative values on Brazilian land cover type transitions and insufficient data on land use dynamics. Its analysis in case of pasture areas by spatial data demonstrates marked differences in the values of areas (Table 2).

Table 2. **Area of pastures in Brazil by spatial data for 2020**

Data type	Area of pastures, million hectares
Moderate Resolution Imaging Spectroradiometer, MODIS	186.8
WorldCover	183.8
Faostat	173.4

Source: compiled by Yu.S. Popova, T.V. Komarova using spatial data of MODIS, Worldcover: Faostat. Available from: https://modis.gsfc.nasa.gov/data/, https://esa-worldcover.org/en, https://www.fao.org/faostat/en/#home (accessed: 11.10.2024).

The area of pastures in Brazil increased rapidly by 2005, and in the following years gradually began to be replaced by arable land, mainly with soybean crops and, in the place of humid equatorial forests, by oil palm plantations. Net pasture area increased only in Amazonia and Pantanal, decreasing in other biomes due to the conversion of rangelands to intensive agriculture. In 2020 48% of land in Brazil was under pasture and 25% under cropland (9% under soya and 16% under other crops). The deforestation process caused by the spread of pastures persists in most biomes. Primary and secondary deforestation of vegetation accounts for a significant proportion of the total forest loss, 72 and 17%, respectively. Lower rates of deforestation are recorded in the Mata Atlantica biome, which has been significantly affected by anthropogenic activities since 1986. While only 8% of the forest ecosystems in this biome have been preserved [5; 9].

It is evident that the reduction of forested areas is due to the expansion of agricultural land: pastures and croplands (Figure 1). Amazonia and Cerrado, together lost approximately 15,690 km^2 of forest between 2010 and 2020 [6]. The Cerrado biome, represented by savannas, is located in eastern Brazil. It covers an area of 204 million hectares. It is estimated that about 46% of the natural vegetation is in an intact state. Pastures occupy 25.13% of the Cerrado area, while annual and perennial crops (mainly soybean, maize, cotton) occupy 12.85% [10]. This biome is currently the main agricultural area in Brazil.

Anthropogenic transformation in Brazilian biomes increased between 2000 and 2018, ranging from 82.2% (in Mata Atlantica) to 11.6% (in Pantanal) of the area of biomes (Figure 2).

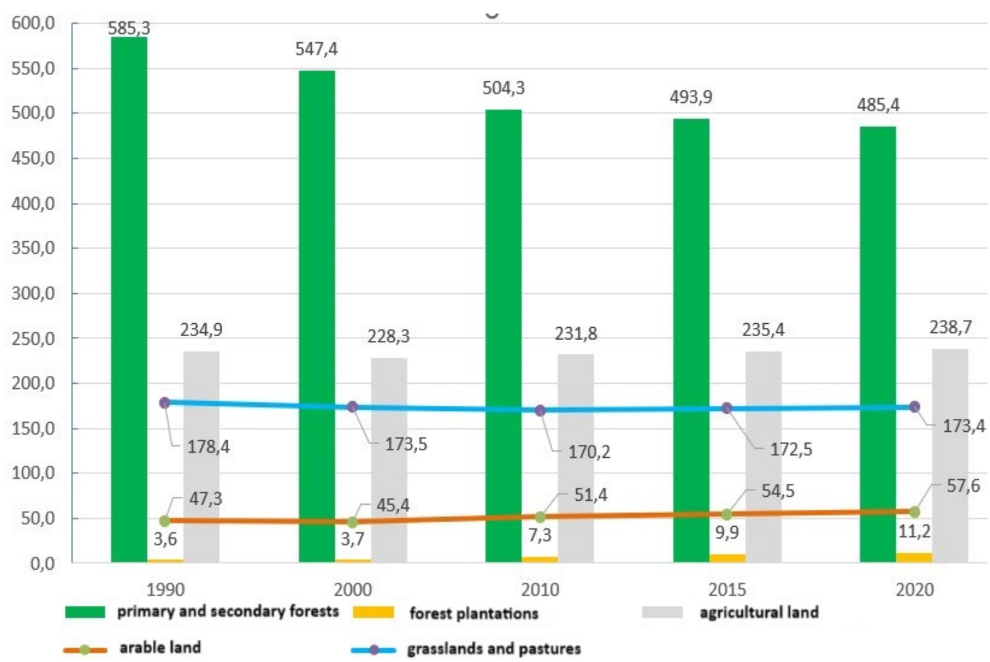

Figure 1. Ratio of forested and agricultural areas, million hectares
Source: compiled by Yu.S. Popova, T.V. Komarova according to the data of CEPAL. Available from: https://www.cepal.org/en (accessed: 11.10.2024).

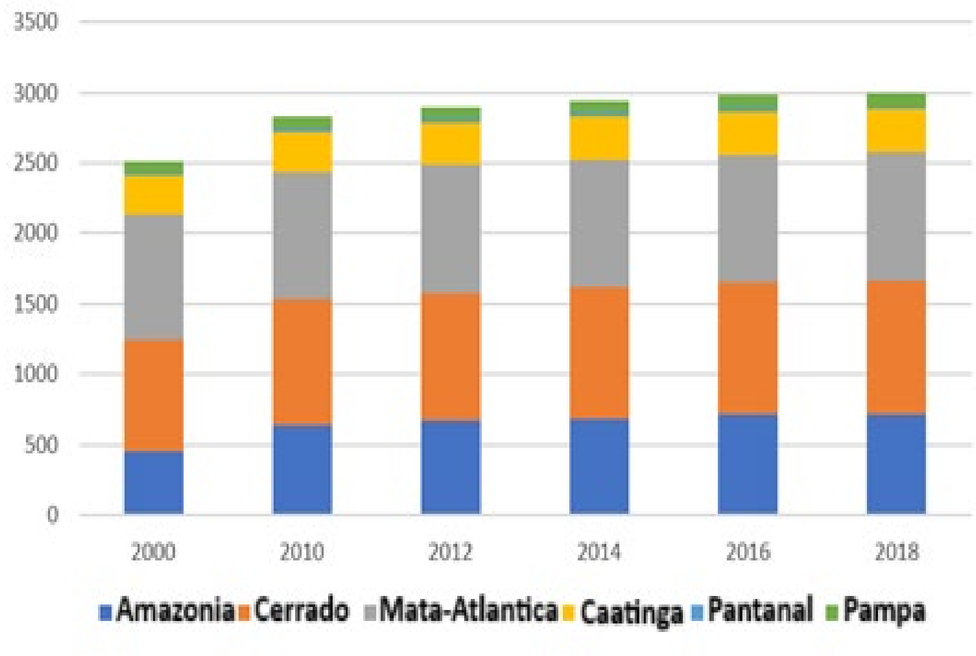

Figure 2. **Anthropogenic transformation in Brazilian biomes between 2000 and 2018, million hectares**
Source: compiled by Yu.S. Popova, T.V. Komarova according to the data of MapBiomas. Available from: https://brasil.mapbiomas.org/en/ (accessed: 11.10.2024).

Carbon balance

Brazil is the fifth largest GHG emitter in the world, it also has one of the largest potentials for ecosystem restoration and conservation. Carbon stocks in living biomass are estimated at 51894.2 million tonnes (Figure 3). In the short term, emission reductions through ecosystem conservation will be necessary for Brazil to meet its 2030 climate goal, as it can reduce emissions from 1.5 to 4.3 Pg, compared to 0.127 Pg from ecosystem restoration. However, in the long term, restoration in all of Brazil's biomes could reduce emissions by 3.9 to 9.8 Pg by 2050 and 2080 [2].

It is estimated that Amazonian forests contain about 229-280 Pg of carbon in living biomass and soils, which is about 10% of the world's soil carbon stock. However, for the Amazon biome, a projected result was obtained that shows that total carbon sequestration will reach 736,904 tonnes by 2050 [7].

Carbon stocks in Brazilian biomes have been negatively affected by significant land use and land cover change associated with demographic and agricultural expansion. Despite a significant slowdown in deforestation in Brazil, it still accounts for between 17 and 29 % of global emissions. However, discrepancies in the global carbon cycle budget calculations for Brazil have contributed to a significant share of the corresponding overall global uncertainty [8].

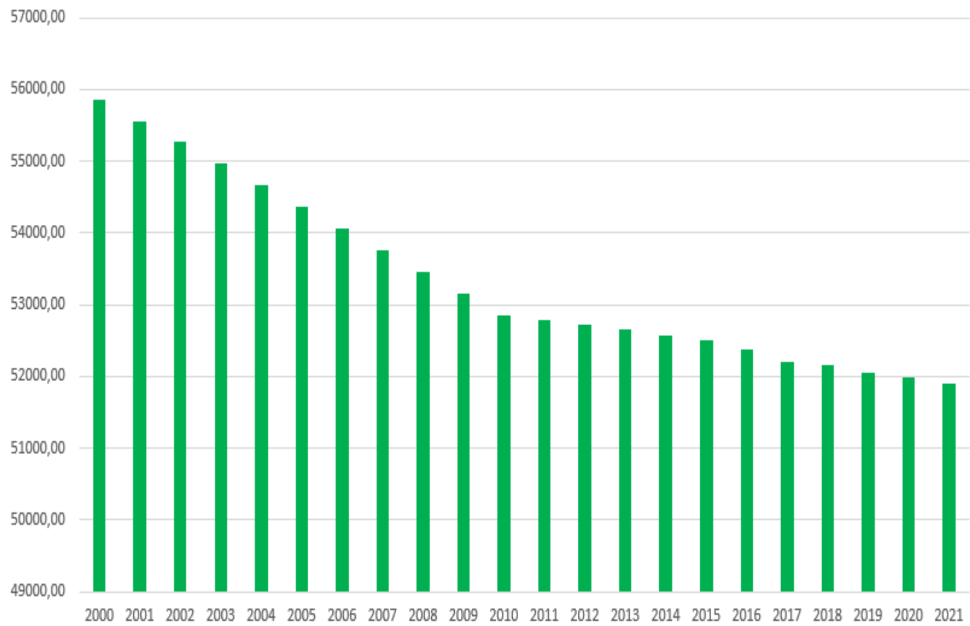

Figure 3. Brazil's carbon stock in living biomass, million tonnes
Source: compiled by Yu.S. Popova, T.V. Komarova according to the data Faostat. Available from: https://www.fao.org/faostat/en/#home (accessed: 11.10.2024).

According to Global Forest Watch, some biomes in Brazil show that forest area is significantly smaller than other land cover types, ranging from 18 to 45% of the land cover (Table 3).

Table 3. **Relationship of land cover areas and carbon fluxes in Cerrado, Caatinga, Pantanal biomes**

Biome	Area, million hectares	Forest area, million hectares	Area of other land cover types	Carbon fluxes, million tonnes CO_2E/ year		
				emissions	sequestration	stocks
Cerrado	29.58	11	18.6	48.4	–66.9	–18.5
Caatinga	71.37	13	58.4	23.3	–67.2	–43.8
Pantanal	15.45	6.99	8.46	16.3	–35.2	–18.8

Source: compiled by Yu.S. Popova, T.V. Komarova according to the data GFW.

For instance, the Cerrado biome is considered one of the world's biodiversity hotspots and this region currently has the largest agricultural area in the country, which has resulted in the loss of 55% of indigenous and secondary vegetation types. On the other hand, this region accounts for 26% of the country's carbon emissions from land use change [11]. The given data on carbon fluxes for some biomes in Brazil show negative stocks.

Conclusion

In Brazil, various programmes are being developed to minimise the effects of land-use transformation and, in particular, the impact of agriculture on ecosystems. The current trend is to develop and implement alternative approaches, commonly known as low-carbon agricultural practices, which aim to reduce agricultural emissions without compromising productivity. Several low-carbon agricultural practices include integrated crop, livestock and forestry systems, improved animal waste management, restoration of degraded pastures, no-tillage, biological nitrogen fixation and afforestation. However, in the current realities in Brazil, there is a lack of institutional framework, and the implementation of strategies is not proceeding according to plan.

As emissions from deforestation and land-use change have continued to increase over the past decades, ecosystem conservation and restoration are increasingly seen as necessary to achieve climate change mitigation goals. Global agreements are most often associated with climate change mitigation, perhaps because of the existence of an established global carbon market. The prevalence of carbon sequestration potential as the primary criterion for determining where to implement these actions has led to a global focus on restoring forest ecosystems, especially tropical rainforests (e.g., Amazonian biome) known for their high carbon storage potential. However, other biomes, such as grassy and woody savannas, which cover 50% of the world's tropical areas, are experiencing similar degradation (in Brazil, Cerrado and Caatinga biomes). Moreover, there is strong evidence that these seasonally dry biomes have a high value in terms of their contribution to carbon storage, plant species diversity, national water security and local resources for indigenous peoples. In this aspect, it may be important for Brazil to reorient strategies towards ecosystem restoration of the most degraded ecosystems.

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