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CHANGES IN LAND USE AND ENVIRONMENTAL CONDITIONS IN MUNICIPALITIES OF MARANHÃO ALONG A LOGISTIC CORRIDOR IN THE EASTERN AMAZONIA

Mudanças no uso do solo e nas condições ambientais em municípios do Maranhão ao longo de um corredor logístico na Amazônia oriental

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Abstract: Understanding the temporal dynamics of land use and the economy of territories is relevant for guiding more effective actions to improve sustainability and resilience. The study's objective was to investigate the recent dynamics of land use and economic conditions of 12 municipalities in Maranhão state along the Carajás Railroad logistic corridor. The methodology involved examining seven socio-environmental variables and qualitative analysis of MapBiomas (2022) mappings between 2010 and 2020. Results show that there have been relevant changes in land use. Our empirical model confirmed the concentration of agricultural activities using the Ellison-Glaeser index, which was correlated positively with sectoral inequality (measured by the Gini index). The result indicates that, in the municipalities studied, a higher concentration of agricultural activities and greater sectoral inequality are correlated positively. Therefore, policymakers, public and private executive agents, and other interested parties must prioritize interventions in municipalities with a higher agricultural concentration.

Keywords: Maranhão, logistic corridor, soil use, sustainable agriculture.

Resumo: Entender a dinâmica temporal do uso do solo e da economia dos territórios é relevante para orientar ações mais efetivas para melhorar a sustentabilidade e a resiliência. O objetivo do estudo foi investigar a dinâmica recente do uso do solo e as condições econômicas de 12 municípios do estado do Maranhão ao longo do corredor logístico da Estrada de Ferro Carajás. A metodologia envolveu o exame de sete variáveis socioambientais e a análise qualitativa dos mapeamentos do MapBiomas (2022) entre 2010 e 2020. Os resultados mostram que houve mudanças importantes no uso do solo. Nosso modelo empírico confirmou a concentração de atividades agrícolas usando o índice de Ellison-Glaeser, que foi positivamente correlacionado com a desigualdade setorial (medida pelo índice de Gini). O resultado indica que maior concentração de atividades agrícolas está positivamente correlacionada com maior desigualdade setorial nos municípios estudados. Portanto, formuladores de políticas, agentes executivos públicos e privados e partes interessadas devem priorizar intervenções em municípios com maior concentração de atividades agrícolas.

Palavras-chave: Maranhão, corredor logístico, uso do solo, agricultura sustentável.

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1 INTRODUCTION

Santos (1998) highlights the importance of technology and information in transforming geographic space. In the Eastern Amazon region, this transformation is particularly strong because of the influence of mining (Cristo *et al.*, 2022). In demographic terms, the activity attracts migrants seeking employment, which can lead to a rapid increase in the population in certain areas. This, in turn, can pressure public services and local infrastructure. Economically, mining can generate jobs and income for local communities and the entire country. However, it can also lead to uncontrolled exploitation of natural resources and excessive dependence on a single economic activity, making the region vulnerable to fluctuations in commodity prices. In terms of environmental impacts, they can result in deforestation, water and air pollution, loss of biodiversity, and destruction of natural *habitats* and ecosystem services (Santos *et al.*, 2021). This has long-term consequences for the local ecosystem, affecting not only fauna and flora but also local communities, especially indigenous communities that depend on these resources for subsistence and cultural identity.

Mineral exploration in the Brazilian Eastern Amazon is a massive and complex operation. The latter is crucial for transporting iron ore from the Serra de Carajás mines to the Port of Ponta da Madeira, as Cristo *et al.* (2022) mentioned. This infrastructure supports mining activities and plays a significant role in the regional economy by providing jobs and facilitating trade. However, it raises environmental and social concerns, particularly regarding deforestation and its impact on local communities.

New studies focusing on municipalities located along large logistic structures (as is the case of EFC) are necessary to evaluate socio-environmental dynamics, especially because they are located in regions of great socioeconomic and environmental importance, such as the Eastern Amazon. Despite the growing body of literature, few studies involving this type of methodology in a logistic corridor have focused on municipal or smaller scales. Given this motivation, the objective of this study is to analyze the dynamics of land use and socio-environmental conditions in 12 municipalities from the Carajás railroad corridor in Maranhão, during the recent period.

Land use and changes in scenarios in 10 dimensions in the 12 municipalities of Maranhão for the 2010-2020 period were analyzed using environmental and economic indicators, as well as geographic information from various sources. Based on official data sources or those of recognized scientific merit, we sought to construct an original analysis of the land-use in the municipalities. The observed variables were area, primary forest, natural pasture, primary crops, deforestation, urban area, and body of water from 2010 to 2020. Different landscapes provide different opportunities for wealth generation, employment, and occupation, and the analysis of regional landscape patterns becomes important for understanding the resulting production structures and the associated population socioeconomic conditions.

As mentioned, the territory researched covers 12 municipalities in Maranhão, which are locations with hundreds of rural and urban communities located along this corridor, with a total population of around 450,000 inhabitants in 2022, representing 6.6% of the state of Maranhão, according to the Demographic census (IBGE, 2024).

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Some previous studies have analyzed this territory focusing mainly on biological, physical, and environmental analyses (Araújo *et al.*, 2018). Focusing on the territory, we can mention works by Becker (2010, and 2013) and by Jacobs (1969). Becker (2013) explored territoriality as a product of political relations that manifested at different scales, from state actions and large corporations to social movements of organization and resistance. Her reflections on social dynamics in the Amazon were fundamental for innovative program development and projects, highlighting the need for an ethical commitment that is often absent in the academic field. Becker argued that the scientists' contribution is vital for implementing a new development pattern that reconciles the exploitation of natural resources with social justice.

This study brings innovation to the literature, since we can analyze recent socioeconomic transformations in Maranhão state by considering the robust variables used in published works in the area (Santos *et al.* 2021). In addition to characterizing the land use of the 12 municipalities in Maranhão, the dynamics of the concentration of agricultural production on this soil in recent times was observed.

Therefore, this study seeks to answer the following questions:

1. How is land use dynamics in municipalities crossed by the EFC?
2. What concentration levels are observed in regional agricultural activities and services?
3. Is there a relationship between land use and agricultural sector concentration?

The article is organized into four sections in addition to the introduction and conclusion. The second section details the methodology constructed with the purpose of better understanding the reality of the municipalities crossed by the Carajás Railway (EFC) in the state of Maranhão, both quantitatively and qualitatively. In the third section, the main results obtained are presented and analyzed.

The main steps are summarized as follows. First, land use mapping is used to obtain information about land use classes and their areas during the study period. Second, the concentration analysis of the two main productive activities. Furthermore, correlation between variables was used to select the most significant parameters for each agricultural sector (described by various economic statistical indices). Then, we run regression analysis to model the Ellison-Glaeser, Herfindahl, and Gini concentration indicators to evaluate their influences and correlations when explaining productive concentration.

2 MATERIALS AND METHODS

Studies must consider this history in socioeconomic indicators by analyzing demographic and environmental data to reduce risks and build resilience in such locations. Important aspects of these processes include promoting social justice and maintaining ecological integrity, which are concepts directly related to sustainability (Vogt *et al.* 2015), including the Sustainable Development Goals (SDGs) established by the UN to be achieved by 2030 (2023).

Based on these references, we sought to conduct our own innovative analysis of the investigation, characterization, and use of land in the 12 municipalities in Maranhão.

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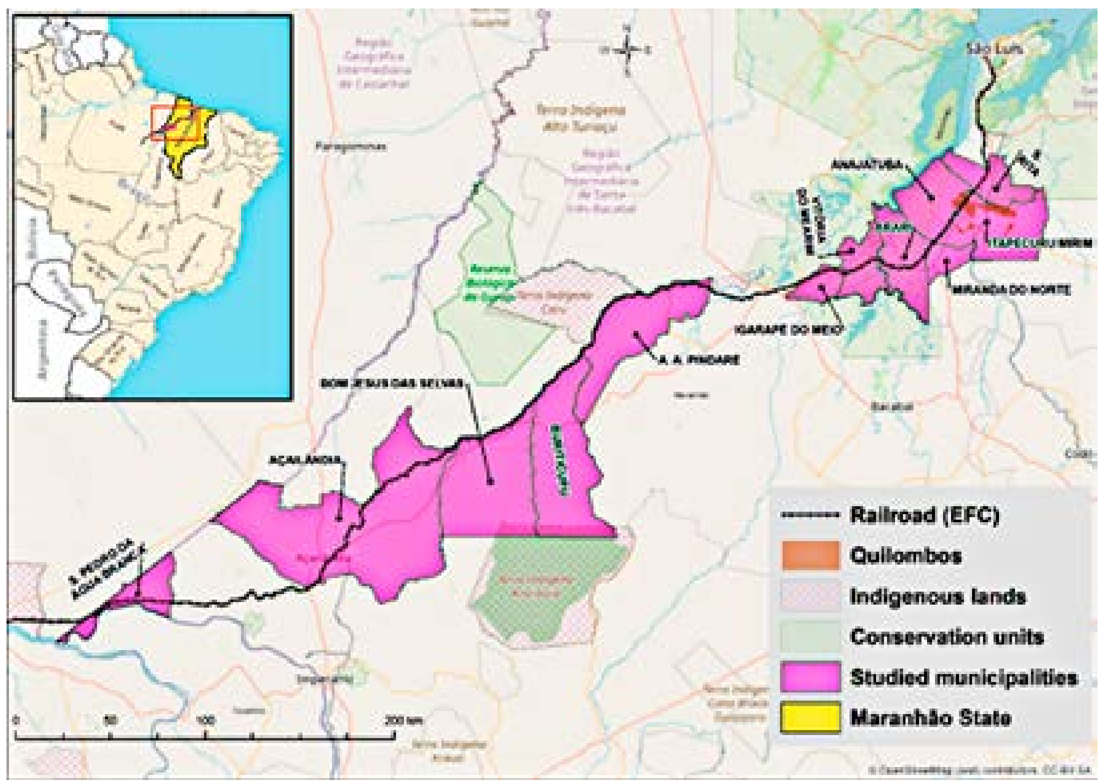
For this purpose, we selected seven variables: i) Area; ii) Primary forest; iii) Natural pasture; iv) Primary farming; v) Deforestation; vi) Urban area; and vii) Water bodies for the period 2010-2020. We selected these variables because they help us understand and adequately prove the variability in land cover dynamics. An important source of this data was MapBiomas, which generates land use and occupation classifications for the Brazilian territory, according to Fortunato *et al.* (2019). These data allow the creation of matrices and mosaics of land use and land cover, enabling temporal analysis by municipality.

As mentioned, the area covered by the research includes 12 municipalities in Maranhão, namely: São Pedro da Água Branca, Açailândia, Bom Jesus das Selvas, Buriticupu, Alto Alegre do Pindaré, Igarapé do Meio, Vitória do Mearim, Arari, Miranda do Norte, Itapecuru Mirim, Anajatuba, and Santa Rita, which are locations with hundreds of rural and urban communities located along this route (Figure 1), representing a population of around 6.6% of the state of Maranhão, as mentioned. The Carajás Railway, opened in 1985, including its branch completed in 2016, constitutes a long logistics corridor that passes through Pará and Maranhão states (Cristo *et al.*, 2022).

Figure 1 – Location of the research territories crossed by the EFC



Source: Prepared by the author based on IBGE data (2022).

To analyze local concentration and inequality, we calculated the Ellison-Glaeser indicator, which concentrates in its formula the Herfindahl index and the Locational Gini index, measuring how unequally distributed a given segment is in relation to the general distribution of employment or products, taking as reference a set of localities (Herfindahl, 1950).

Such an index is defined as follows:

$$H = \sum_{i=1}^{n} s_i^2 \qquad \text{(Equation 1)}$$

Writing this formula alternatively gives:

$$H = \sum_{i=1}^{n} s_i^2 \qquad \text{(Equation 1.1)}$$

Thus, the market shares of each firm are transformed into weight w_i, i.e., $w_i = s_i$. Note that squaring each parcel s_i increases the relative weight of the larger parcel.

The upper limit of this index is equal to one, which occurs in a monopoly situation because in this case $s_i = i$ for some i and $s_j = 0$ for all $j \neq i$.

The concentration measures proposed by Ellison and Glaeser (1997) and Maurel and Sedillot (1999) can be considered more general indicators in which they seek to control divergences in size between sectors relating to activity (Resende; Wyllie, 2005).

This metric can also be used to calculate the activity concentration. In these cases, the index is known as the Locational Gini Index or Hoover Location Index (Hoover, 1936). In adapting the index to the Hoover Location index proposed here, we have information regarding the amount of employment (or product) in a segment that the regions retain depending on the volume held by the regions in terms of total employment in this segment.

The study developed by Ellison and Glaeser (1997, p.895) considered a group indexed by $j = 1, 2, \ldots N$. We assume that a geographic area is divided into subareas and that $s_{1j}, s_{2j}, \ldots, s_{ij}$ employment actions or sector *j are* included in each of these areas. Since $x_1, x_2, \ldots, x_i$ it is another measure of the size of these areas, such as the population share of each area or aggregate employment, we obtain a simple measure of the raw geographic concentration of industry *j as follows:*

$$G = \sum_{i=1}^{I} \left(s_{ij} - x_i\right)^2 \qquad \text{(Equation 2)}$$

where s_i is the share of the i th locality in total sectoral employment (in relation to the sector) and x_i indicates the share of the *i* th locality in total employment.

The application of this indicator has some advantages, such as being easy to read, an index for immediate comparison between activity sectors immediately, and ability to be measured relative to the local economic scale, as opposed to the simple participation of the location in employment or sectoral production. However, it suffers from some weaknesses because it is a measure that depends on the geographic units selected as reference (spatial division) and is sensitive to the level of sectoral aggregation adopted.

Ellison and Glaeser (1997) noted that it is problematic to perform a cross-sectoral analysis or make comparisons between countries or regions using this measure because it is affected by the distribution of industrial plant size and the limited geographic data available. Therefore, they propose an alternative measure of agglomeration that we refer to as the index $\grave{E}G$:

$$EG = \frac{\hat{G} - \left(1 - \sum_i x_i^2\right)H}{\left(1 - \sum_i x_i^2\right)(1 - H)} \qquad \text{(Equation 2)}$$

where $\hat{G} \equiv G = \sum_i (s_{ij} - x_i)^2$ represents a "natural" (absolute) concentration estimator;

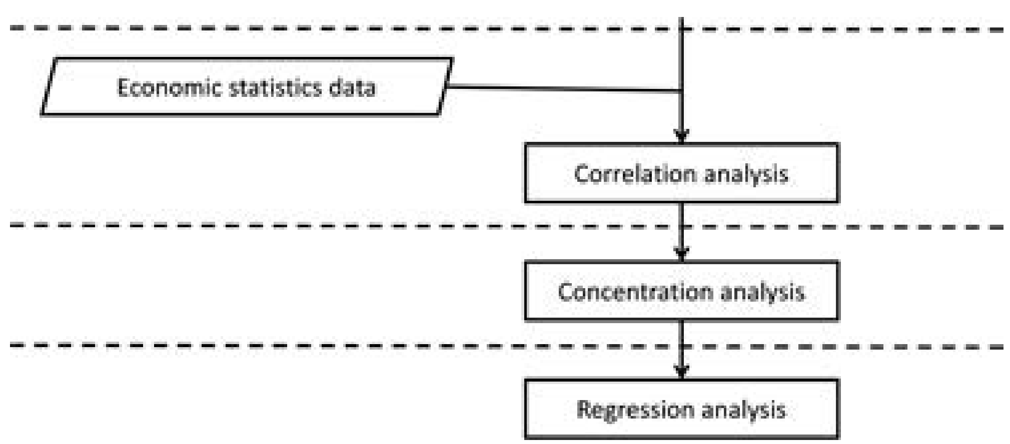
$\left(1 - \sum_i x_i^2\right)$, indicates the regional distribution of total employment (if = 1, there is an equal distribution);

$H = \sum_j s_{ij}^2$, which characterizes the Herfindahl concentration index (the closer *H is to 1*, the higher the concentration).

The authors adopt what they call the geographic concentration index — comprising the combination of *G* and the Herfindahl index —which expresses the influence of locational factors on the degree of geographic concentration of the industry. The higher the index, the greater the influence of locational factors in determining the geographic concentration of the manufacturing industry, and the opposite is also true, that is, the lower the index, the smaller the interference of these factors in determining the geographic industrial concentration.

The interrelationship between information, socioeconomic development, and the concentration of productive activities is the basis of the proposed method, which attempts to reflect economic development through remote sensing images. The general workflow (Figure 2) was divided into four steps: (1) information extraction, (2) selection of concentration factors (Ellison-Glaeser, Herfindahl, and Gini), (3) model construction, and (4) analysis of the results.

Figure 2 – Flowchart of the proposed Method



Source: Elaboration based on Chen *et al.* (2020).

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The variables selected to analyze land use (in hectares) in the 12 municipalities crossed by the Carajás Railway (EFC) in Maranhão in 2020, extracted by Mapbiomas (2022), are as follows:

1. Natural pasture;
2. Primary forest;
3. Temporary farming;
4. Vegetable deforestation and;
5. Urbanized area.

The indicators Ellison-Glaeser (EG), Herfindahl (H), and Gini (G) were calculated based on the variable 'formal employment' for the following agricultural divisions, directly or indirectly related to agricultural production and services, from the Relationship Annual Social Information of the Ministry of Labor and Employment (RAIS/MTE, 2023):

Division 1: Agriculture, Livestock and Related Services;

Division 2: Forestry Production;

Division 3: Fisheries and Aquaculture;

Division 13: Manufacturing of Textile Products;

Division 25: Manufacture of Metal Products, except Machinery and Equipment;

Division 28: Machinery and Equipment Manufacturing;

Division 33: Maintenance, Repair, and Installation of Machinery and Equipment;

Division 46: Wholesale Trade (except for Motor Vehicles and Motorcycles.

Division 74: Other Professional, Scientific and Technical Activities;

Division 82: Office services, administrative support, and other services mainly provided to companies.

We obtained geographic data from the Mapbiomas (2024) and OpenStreetMap (2024) projects. The *software* packages used in this study were QGis for geoprocessing and STATA for statistical analyses.

We present below an approximation of the log-linear model (Gujarati; Porter, 2009) to be estimated and analyzed based on the exposed theory:

$$\log(EG) = \beta_0 + \beta_1 \log(H) + \beta_2 G + \epsilon_i \qquad \text{(Equation 4)}$$

where $\log(EG)$, our dependent variable and is the logarithmic of the Ellison-Glaser (EG) concentration indicator.

$\log(H)$ is the log of the Herfindahl concentration indicator (H);

G is the Gini inequality indicator (G); and

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$\beta_0, \beta_1, \text{and } \beta_2$ are the parameters or coefficients, with the first being the vertical intercept of the model and the remaining two being slopes of the model of the respective explanatory variables;

ϵ_i is the error term of the model on which randomness, normal distribution with homoscedasticity and independence, and no correlation with independent variables are assumed.

The specification in Equation 4 is adequate to explain our variable of interest; that is, the theoretical framework of this study indicates that it is plausible to explain EG by H and G (Ellison; Glaeser, 1997). Regarding taking the logarithm of the dependent variable and one explanatory variable, according to the literature, this measure is justified by the following advantages in the model estimation process (Gujarati; Porter, 2009):

1. Variance Stabilization: in some cases, the data may have variance that increases with the mean (heteroscedasticity). Transforming the data into a logarithmic scale can help stabilize the variance, making the residuals more homoscedastic and therefore more appropriate for regression analysis.
2. Linearization of Nonlinear Relationships: sometimes, relationships between variables can be nonlinear. Transforming variables to a logarithmic scale can help linearize these relationships, making them more suitable for linear modeling, such as multiple linear regression.
3. Bias Reduction and Distribution Improvement: in some situations, transforming variables can help reduce bias and improve data distribution, making data closer to a normal distribution, which is useful for many statistical techniques.

5 RESULTS AND DISCUSSION

5.1 Characterization of land use and occupation

When analyzing the data in an aggregated manner, considering the 12 municipalities crossed by the Estrada de Ferro de Carajás (EFC) in Maranhão, we found that the predominance of land use and occupation for 2019-2020 is in Pasture areas, except indigenous lands, protected areas, and some fragmented forest remnants. In general, the maps clarify vegetation dominance in the territory, followed by Forest areas, to the detriment of the other land cover classes presented (Table 1) (Mapbiomas, 2022).

Table 1 – Land use (in hectares) in 2020 for 12 municipalities in the state of Maranhão crossed by the Carajás railroad (EFC)

Municipalities of Maranhão	Natural Pasture	Primary Forest	Temporary farming	Vegetable deforestation	Urbanized Area
São Pedro da Água Branca	40,127	23,243	169	447	271
Açailândia	338,141	168,644	53,912	3,809	2,204
Bom Jesus das Selvas	165,222	96,903	3,655	2,144	424
Buriticupu	123,517	100,915	28,579	3,209	973
Alto Alegre do Pindaré	119,419	63,288	1,327	1,897	366
Igarapé do Meio	18,175	11,901	8	349	165
Vitória do Mearim	24,385	29,918	541	239	479
Arari	25,597	32,017	1,538	638	269
Miranda do Norte	15,960	15,302	9	1,068	451
Itapecuru Mirim	29,698	94,963	25	1,366	1,459
Anajatuba	14,802	19,186	1,218	1,676	145
Santa Rita	30,525	24,600	594	1,880	533

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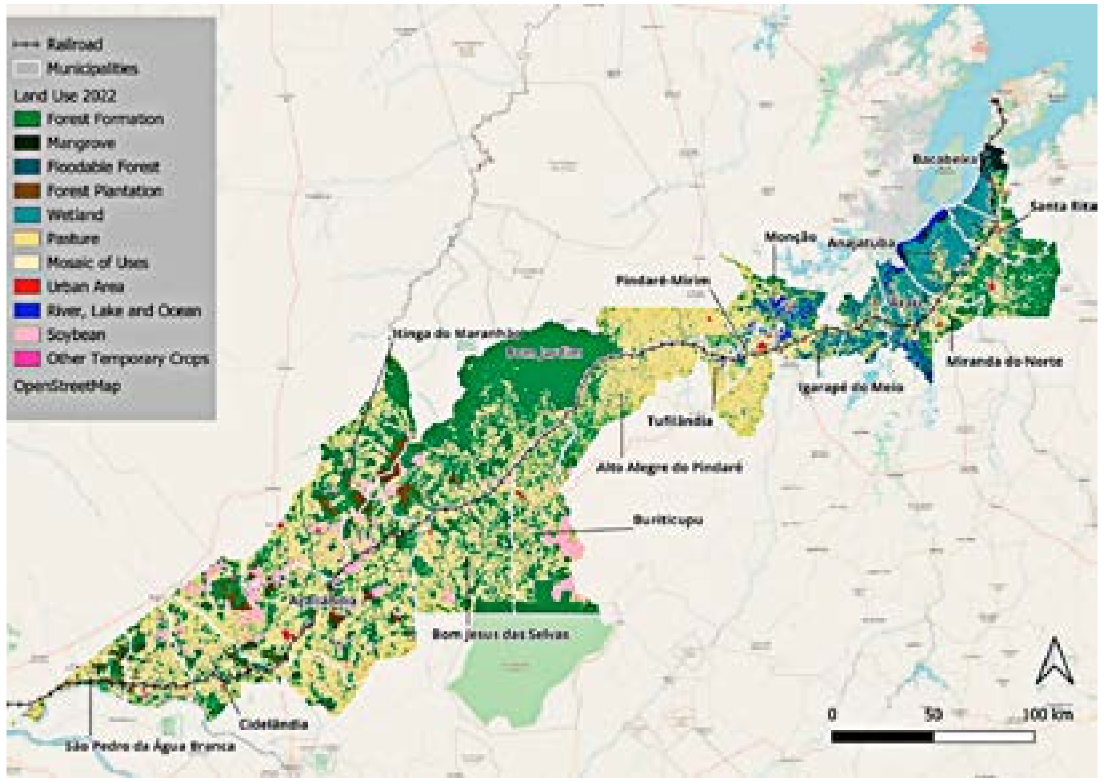
Source: Mapbiomas (2022).

Besides pasture areas in all municipalities, there are other significant classes of land use, as we mentioned. Some remaining forest areas are in Alto Alegre do Pindaré, Bom Jesus das Selvas, Vitória do Mearim, Miranda do Norte, Itapecuru Mirim, and Santa Rita. We can see bodies of water, floodable forests, and wetlands in São Pedro da Água Branca, Igarapé do Meio Vitória do Mearim, Arari, Anajatuba, and Santa Rita due to Tocantins and Mearim rivers. Concerning temporary crop areas, we can emphasize soybean production in Açailândia, Buriticupu, and Bom Jesus das Selvas. Finally, São Pedro da Água Branca and Açailândia have relevant areas of forest plantations (Figure 3).

Figure 3 – Characterization of Land Use and Occupation



Source: Elaboration based on Mapbiomas data (2022).

Note: The territory has 22 municipalities. However, this article focused on 12 municipalities that were investigated in the first phase of the project.

The environmental conditions of communities are directly related to their location to the Railway, regardless of whether they are urban or rural (Cristo *et al.*, 2022). Figure 3 shows a certain degree of land use primacy concerning pasture, forestry, and temporary crop use. Except for Protected Areas, indigenous lands, and some fragmented Forest remnants, the EFC municipalities also presented significant numbers of deforested areas, with approximately 16% in relation to the state of Maranhão; that is, it is the variable with the greatest representation followed by crop temporary, with around 9%, among those analyzed when compared with the state as a whole and not the municipalities separately (Table 1).

5.2 Effects of agricultural sectoral concentration

The selected divisions are those related to the agricultural services sectors and were more significant for these municipalities in Maranhão in the agricultural services and services sector, as they are part of the analysis of the use of cultivable land and relate to agricultural services in general.

The Ellison-Glaeser indicator is sub-related to the two other sub-indicators of Herfindahl and Gini. Its measurement varies between 0 and 1, with the closer to 1, the more concentrated the sector is the opposite occurs if the indicator is closer to zero.

We named the divisions according to the National Classification of Economic Activities of the Brazilian Institute of Geography and Statistics (CNAE/IBGE, 2023), which is traditionally used and accepted in studies focused on economic activities in Brazil. Divisions 1, 2, and 3 comprise the large segment of agriculture, livestock, forestry production, fishing, and aquaculture. Division 13 corresponds to the Manufacturing of Textile Products; division 25 refers to the Manufacture of Metal Products, Except Machinery and Equipment; 28th Machinery and Equipment Manufacturing; 33 is Maintenance, Repair and Installation of Machinery and Equipment; 46 is Wholesale Trade, except Motor Vehicles and Motorcycles; division 74 comprises Other Professional, Scientific and Technical Activities and division 82 comprises Office Services, Administration Support and Other Services.

When analyzing the sub-indicators separately, Gini contributed most to a high concentration of the Ellison-Glaeser in divisions 1, 2, and 3, which are genuinely agricultural, including division 28, which is the manufacturing industry. These divisions have the highest EG, indicating a high degree of concentration in these sectors in 2021 (Table 2), the last year with employment data available from RAIS/MTE. These results are consistent with those obtained in the first part of the land use analysis, as well as concentration studies in Resende and Boff (2002), and Schettini *et al.* (2016).

The service division (82) was not very significant for concentration in Maranhão's municipalities. The divisions with the lowest degree of concentration were 33, 46, and 74, and the sub-indicator with the greatest contribution to the lowest degree of EG concentration was Herfindahl for 2021 (Table 2).

Table 2 – Most relevant divisions selected for analysis for 2021

Division	E.G.	H	G
1	0,5006	0,04807	0,33702
2	0,7648	0,22491	0,5150
3	0,48270	0,05753	0,3267
13	0,05094	0,26687	0,03678
25	0,03374	0,49669	0,02305
28	0,97051	0,49768	0,65354
33	0,02266	0,43271	0,01565
46	0,03033	0,22543	0,02044
74	0,02520	0,43409	0,01793
82	0,07907	0,62237	0,05327

Source: Prepared by the authors using STATA software.

Resende and Boff (2002) stated that market power can be demonstrated by the participation of a certain region in the production or sales of a certain industrial sector. To analyze the structure of charcoal production, we used concentration indices to provide the necessary empirical data. To measure competition between charcoal-producing regions, it must be understood that when the degree of concentration between companies increases, competition between them decreases. The increase in control exercised by the activity is an essential element for escalating competition.

As can be seen, the division that first appeared as the most concentrated was 28, followed by 2, 1, and 3. Division 28 is atypical in the analysis because it generally concerns Machinery and Equipment; in this case, we can include Agricultural Implements and Machinery intended for Agriculture. The other prominent divisions - 2, 1, and 3 - are directly agricultural, and we can be observe through a more refined analysis that the subclasses with the highest contribution in this concentration were the cultivation of soybeans, the raising of beef cattle, support activities for forestry production, and charcoal production, planted in forests (Table 3).

Table 3 – Ranking of the Ellison-Glaeser indicator in descending order between divisions analyzed for 2021

Ranking	Division	E.G.
1	28	0,97051
2	2	0,7648
3	1	0,5006
4	3	0,48270
5	82	0,07907
6	13	0,05094
7	25	0,03374
8	46	0,03033
9	74	0,02520
10	33	0,02266

Source: Prepared by the authors using STATA *software*.

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The divisions with the lowest contribution to the ranking were 33, 74, and 46, occupying the last positions of the divisions selected for the study (Table 3).

For the Brazilian forestry sector, several studies on concentration were conducted. Schettini *et al.* (2016) studied the global wood pellet market, and Coelho Junior *et al.* (2018) studied cellulose exports. These studies are important and support the understanding of land use and its distribution of agricultural activities and services, which have a significant impact on the state and regional economy of Maranhão.

Agricultural services still need to achieve greater representation because the high concentration comes from agricultural activities and not services related to agricultural activities. Agriculture has been growing and gaining more space and should continue to do so, unless an unusual situation occurs. The 4.7% growth in the state's grain harvest contributed greatly to maintaining positive expectations for the year; The good performance of agriculture points to another record harvest, reaching approximately 6 million tons in 2022, with emphasis on soybean production, which reaches 3.5 million tons (IMESC, 2022).

Table 4 – Ellison-Glaser (EG) concentration indicator results estimated by the ordinary least squares method

Variables	Coefficient
Constant	-3.8200*** (0.31)
log(H)	-0.3827*** (0.12)
G	5.6781*** (0.38)
Number of observations	10
Adjusted R-Squared	0.95

Source: Elaboration based on secondary data from RAIS/MTE (2023).

Note: the coefficient estimations are with robust standard errors, which are in parenthesis; *** = the coefficients are statistically significant at the 1% level.

We can express our model originally through the following regression (application of Equation 4):

$$\log(EG) = -3.81 - 0.382\log(H) + 5.67G + \epsilon_i \qquad \text{(Equation 5)}$$

A model with a coefficient of determination and adequacy (Adjusted R-Squared) of 0.95 indicates an excellent fit of the variables for explaining our dependent variable. The dependent variable , which is transformed into logarithmic form, represents the growth in the concentration of agricultural activities (EG) in the municipalities crossed by the EFC.

The value of β_0, our coefficient that indicates the origin from which the simple linear regression graph will start, in this case is -3.81 and is the expected value when $\log(EG)$ the independent variables are equal to zero, which does not happen in our example.

The coefficient associated with β_1 is -0.382. This reveals how the Hirschman log index $(\log(H))$ varies in response to a change in the level of the Ellison-Glaeser ($\log(EG)$) concentration. More specifically, a percentage unit change in the Ellison-Glaeser concentration index (EG) leads to a negative change of -0.382 percentage units in the Herfindahl concentration (H).

The Gini indicator, which portrays economic inequality, proved to be very positively explanatory, that is, there is a direct and positive relationship between concentration and sectoral inequality. As one increases, the other increases by unit at a value of 5.67 (Table 4).

We performed consistency and robustness tests of the model. The VIF (Variance Inflation Factor) is a measure used to evaluate multicollinearity between independent variables in regression models. The VIF result associated with both independent variables was 1.10 and is considered low (VIF<10), suggesting that the existing multicollinearity is very low and negligible between the independent variables (Montgomery *et al.*, 2006; Mostafá, 2017). The correlation between these variables is weak, which helps interpret the model coefficients and estimate stability.

For heteroscedasticity, we used the Breusch-Pagan test. The null hypothesis that there is constant variance was tested against the alternative hypothesis that heteroscedasticity (variable variance) exists in the errors. The results show that:

1. *Ho* (null hypothesis): Here, assumes that there is constant variance.
2. *"lag"* values are being tested for heteroscedasticity.
3. The chi-square statistic is 2.39.
4. The probability (*p* value) associated with the chi-square statistic (Prob>chi2) is 0.1225.

Therefore, because the *p* value (0.1225) was greater than the typical significance level of 0.05, we did not reject the null hypothesis. This indicates that there is no significant evidence of heteroscedasticity in the errors and that the assumption of constant variance holds for our data. Regarding autocorrelation, as it is a *cross-sectional analysis*, in this case we did not observe relevant changes, which are not important or have a significant impact on our model (Greene, 2003).

Elisson-Glaeser concentration concept refers to the unequal distribution of economic activities in each region. The concentration can be measured using indices such as the Herfindahl index and the Gini index. The Herfindahl index is used to measure market concentration in specific sectors. In the regional context, we can use the index to measure the concentration of economic activities in different sectors within the region, which we have done in this article with the agricultural divisions in the locations crossed by the EFC, and the index was not concentrated within our region sample, being a section with little expressiveness of large companies in the agricultural sector, since the region's strong point is family and subsistence farming.

The Gini index is an indicator of inequality that was developed to measure income distribution in a population. In a regional context, the Gini index can be applied to measure inequality in the distribution of economic activities in a region. For example, a

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region with a high Gini index for the distribution of companies across sectors suggests an uneven concentration of economic activities. This indicator is highly explanatory for the sample of municipalities we studied in Maranhão. There is a latent inequality in the agricultural context investigated.

The relationship between the Elisson-Glaeser concentration index and the Herfindahl and Gini indices in a regional context can be understood as follows: the Herfindahl index measures concentration in specific sectors, whereas the Gini index measures inequality in the distribution of these sectors. Together, these indices can offer valuable *insights* into the economic structure of a region and its level of concentration and inequality. This is the innovation and originality of the article in empirical terms. Ellison and Glaeser (1997) presented the construction of the indicator and its application to the North American industrial manufacturing sector but did not present the regression after analyzing the indicators. Figueroa *et al.* (2018) also studied the analysis of the indicator of a North American survey with the introduction of new firms. Reinforcement that research like this for the Brazilian reality is new and brings a rich regional aggregation, adding to the context of land use through images and with the analysis of the agricultural concentration of the 12 municipalities crossed by the Carajás Railroad (EFC).

6 CONCLUSION

The article investigated 12 municipalities in Maranhão belonging to a logistic corridor of the Carajás Railway in the recent period, emphasizing the environmental and economic conditions of these locations. This study answered the three research questions asked in the introduction section. To achieve this, the analysis involved an examination of seven socio-environmental variables and a qualitative analysis of images from MapBiomas (2022), INIMET (2019).

The results revealed environmental transformations in some municipalities and, to a certain extent, changes in land use. A less sustainable situation was detected in Igarapé do Meio, Vitória do Mearim and São Pedro da Água Branca, which had greater changes in some of the indicators analyzed, such as Urbanized area and Temporary farming. The municipalities of Açailândia, Buriticupu, and Bom Jesus das Selvas are in a stronger situation in terms of primary crops and forests. The strongest conditions for urbanized areas were found in Açailândia, Itapecuru Mirim, and Buriticupu.

Given their intermediate position in the ranking of concentration in the agricultural sector (both production and services), municipalities with dynamics of agglomerative increase were Bom Jesus das Selvas, Alto Alegre do Pindaré, Santa Rita, and Arari. The municipalities with a tendency toward less agglomeration were Miranda do Norte and Anajatuba.

The main four characteristics of these municipalities related to land use and occupation are Natural pasture; Primary Forest; Primary farming; Vegetable deforestation; Urbanized area and water, which are associated with their location in the territory, influencing environmental conditions and the quality of life of the local population.

The innovation of the research consists of bringing to debate, with empirical evidence, the socioeconomic transformations that have occurred in recent years in the state of Maranhão and how they have affected land use among the agricultural economic sectors of the studied municipalities. The development of maps, figures, and indicators is important in studies covering this Brazilian region and has been little explored by academic research with a more local focus. Our results are partially in line with those in Schettini *et al.* (2016), Coelho Junior *et al.* (2018), and Santos *et al.* (2021) concerning the relationships between land use and economic activities. We confirmed the concentration of agricultural activities using the Ellison-Glaeser index. This index showed a negative correlation with the traditional Herfindahl index and a positive correlation with sectoral inequality (measured by the Gini index). The result indicates that, in these municipalities, the greater concentration of agricultural activities and greater sectoral inequality are positively correlated..

The results can help design actions to reduce vulnerability and improve sustainability and resilience in the EFC territory, if recognized by policymakers and other local stakeholders. Identifying existing primary environmental barriers can help identify potential solutions.

The answers to the initial questions obtained through the analyses also look for new investigations of the possible impacts of this agricultural concentration and the need for greater diversification of sectors to expand local and regional development policies.

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