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Dynamics of land use and land cover in Jari (RS) and soybean expansion scenarios between 2025-2030

Dinâmica do uso e cobertura da terra em Jari (RS) e cenários de expansão da soja entre 2025-2030

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Abstract

In recent decades, the Pampa Biome has rapidly transitioned from grasslands to soybean crops. This article aims to simulate soybean expansion in Jari (RS), Brazil, between 2025 and 2030. Methodologically, the software Dinamica EGO was used. The dynamic data entered refers to the land use and land cover from the MapBiomas 8.1 project for the years 2000 and 2022. The static data refers to altitude, slope, landforms and soils. The results showed 33% increase in the area under soybean cultivation between 2000 and 2022, with a significant reduction in the significant reduction in grassland areas. The probability of transition from grassland to soybean crops is higher close to areas with a mosaic of uses, and smaller near forested areas. The Dinamica EGO showed an overall accuracy of 65.6%, comparing the real map with the simulated map for the year 2022. It should be noted that the software had greater difficulty in estimating small soybean crops, which were planted on land less suitable for cultivation, such as steeper slopes. In this way, the projections indicate a continued increase in the area of soybean cultivation by 2030, covering 51% of the municipality's area, mainly due to the replacement of natural grassland areas. Therefore, it is crucial to continue monitoring the expansion of soybean in the Pampa Biome.

Keywords: Pampa Biome, Soybean expansion, Spatial simulation, Dinamica EGO, MapBiomas.

Resumo

Nas últimas décadas, no Bioma Pampa, observou-se uma rápida transição das áreas de formação campestre para lavouras de soja. Este artigo tem como objetivo simular a expansão da soja em Jari (RS), Brasil, para o período entre 2025 a 2030. Metodologicamente, utilizou-se o software Dinamica EGO. Os dados dinâmicos inseridos se referem ao uso e cobertura da terra do projeto MapBiomas 8.1, dos anos de 2000 e 2022. Os dados estáticos se referem a altitude, declividade, formas de relevo e solos. Quanto aos resultados, identificou-se um aumento de 33% na área de cultivo de soja entre 2000 e 2022, com redução significativa nas áreas de campo. A probabilidade de transição de campo para lavouras de soja é maior em proximidades de áreas com mosaico de usos, e menor nas imediações de porções com floresta. O Dinamica EGO apresentou uma exatidão global de 65,6%, comparando o mapa real com o simulado do ano de 2022. Salienta-se que o software teve maior dificuldade na estimativa de pequenas lavouras de soja, que foram implantadas em terrenos menos indicados para o cultivo, como de maior declividade. Dessa forma, as projeções indicam a continuidade no aumento na área de cultivo de soja até 2030, abrangendo 51% da área do município, a partir principalmente da substituição de áreas de campo natural. Desta forma, destaca-se a importância da continuidade no monitoramento da expansão da soja no Bioma Pampa.

Palavras-chave: Bioma Pampa, Expansão da soja, Simulação especial, Dinamica EGO, MapBiomas.

I. INTRODUCTION

Agriculture is one of the world's most long-standing human interactions with the environment (MAZOYER, 2010; HARARI, 2018; SKENDŽIĆ et al., 2021). Over the centuries, there has been an evolution in this sector, especially in the second half of the 20th century, when an intense process of modernization of agriculture took place at a global level (DE OLIVEIRA GERARDI, 1980; GRAESSER et al., 2015; GRAESSER; RAMANKUTTY; COOMES, 2018; LOBÃO; STADUTO, 2020). Soybean is currently the world's largest source of protein for animal feed and the second-largest source of vegetable oil (SONG et al., 2021).

In the context of agricultural expansion, soybean has emerged as a prominent crop, representing a vector for transforming the rural landscape (ANHOLETO; MASSUQUETTI, 2015; CHIARAVALLOTI et al., 2022; GASS; DA SILVA; DE ARRUDA, 2024; KEYS; McCONNELL, 2024). As such, it has caused profound changes in land use and land cover in South America (GRAESSER et al., 2015; GRAESSER; RAMANKUTTY; COOMES, 2018).

In the case of Brazil, the modernization and expansion of agriculture have stimulated import substitution and the development of soil management technologies, allowing, for example, cultivation in the Cerrado (SILVA and ARIMA, 2023). While this modernization has brought significant advances in terms of productivity and efficiency, it has also brought environmental and social challenges (FOLEY et al., 2005; LAMBIN; MEYFROIDT, 2011; MAEDA et al., 2011; ANDRADE; COLLICCHIO, 2022).

Despite conservation efforts, the loss of native vegetation, especially in the Amazon, Cerrado and Pampa biomes, is still significant (HASENACK et al., 2007; FERREIRA et al., 2013; DA COSTA SILVA, 2016; MAIA et al., 2019; SONG et al., 2021; ALENCAR et al., 2022; MARCOVITCH, 2022; CERQUEIRA; GOMES, 2023; HINATA; BASSO; REKOWSKY, 2023). As a result, the dilemma between economic development and environmental conservation is causing tensions (DOS SANTOS; FÁVARO; DA ROCHA FILHO, 2022), as the country has become one of the largest soybean producers in the world (ANDRADE; COLLICCHIO, 2022).

Modeling plays a crucial role in understanding the factors that influence the past and future dynamics of land use and land cover (RODRIGUES; SOARES-FILHO; COSTA, 2007; OSIS; LAURENT; POCCARD-CHAPUIS, 2019; HINATA; BASSO; REKOWSKY, 2023). Among the many software programs available for this purpose, Dinamica

EGO was chosen for this research, developed by the Remote Sensing Center of the Federal University of Minas Gerais, Brazil (CSR-UFMG). Dinamica EGO is free software designed specifically to model environmental changes (SOARES-FILHO et al., 2002; RODRIGUES; SOARES-FILHO; COSTA, 2007). As a result, the software has been used to simulate changes in land use and land cover in the Amazon (OSIS; LAURENT; POCCARD-CHAPUIS, 2019; MAEDA et al, 2011; SILVA; BLANCO; OLIVEIRA JUNIOR, 2022; ANDRADE; COLLICCHIO, 2022), in the Cerrado (FERREIRA et al., 2013; CHIARAVALLOTI et al., 2022; SILVA; ARIMA, 2023), and in the Pampa biome (BASSO; SANTOS, 2021; HINATA; BASSO; REKOWSKY, 2023).

In South America, the grasslands extend over an area of approximately 750,000 km², shared by Brazil, Uruguay, and Argentina. In Brazil, the Pampa biome is restricted to Rio Grande do Sul, where it occupies 178,243 km². Data from the MapBiomas Pampa platform (https://pampa.mapbiomas.org/) indicates a significant change in the Rio Grande do Sul Pampa biome between 1985 and 2022. In 1985, native grassland encompassed approximately 89,000 km² (46.6%), while soybean production covered 8,280 km² (4.3%), which were concentrated in the north of the biome. By 2022, the soybean area had expanded to 39,000 km² (20.4%), moving into the central portions of Rio Grande do Sul and areas close to Lagoa dos Patos. This expansion resulted in the loss of 29,000 km² of native grassland.

With these premises in mind, this article aims to simulate the expansion of soybean in Jari (RS) between 2025 and 2030. The municipality was chosen due to the expansion of soybean in the last two decades and the economic dependence on this monoculture, so it is important to understand in which portions of Jari (RS) the advance of plantations is possible. Jari (RS) is located in the Pampa biome.

Study area

The municipality of Jari (RS) is located in the southern region of Brazil, in the state of Rio Grande do Sul (Figure 1 B and C), between the geographic coordinates 29°08'92'' to 29°46'07" south latitude and 54°07'59" to 54°50'75" west longitude (Figure 1 A), with an area of 853,080 km².

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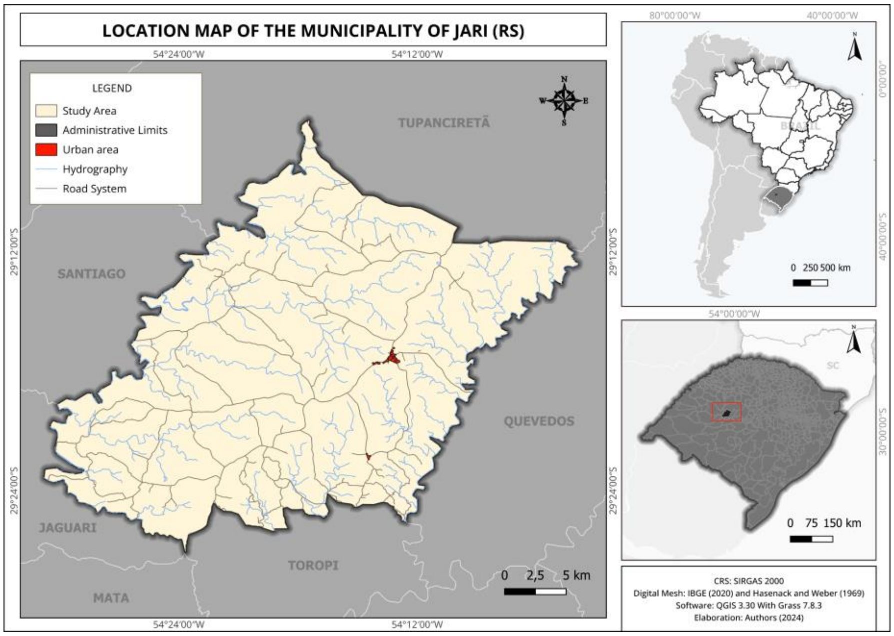

Figure 1 - Location of the study area (Source: Authors, 2024).

It should be noted that in terms of the distribution of GDP (Gross Domestic Product) in the municipality, the Gross Value Added (GVA) was approximately R$ 462,301.70 in 2021. According to the IBGE, the largest contribution comes from the agricultural sector, totaling R$ 377,841.11 (80.6%). Services then contribute R$46,620.51 (9.9%), while another R$26,344.44 (5.6%) comes from administration, defense, education, public health and social security. Industries have a relatively low share, accounting for just R$11,495.65 (2.5%), followed by taxes on products net of subsidies, which total R$6,703.65 (1.4%).

The municipality of Jari (RS) is located in a Subtropical II climate zone, with an annual precipitation of between 1500 and 1700 mm, distributed over 90 to 110 days, according to Rossato (2011). The northwestern part of the municipality is in a transition zone between Subtropical Climates II and III. Subtropical climate III has annual average temperatures of 17°C to 20°C, reaching 20°C to 23°C in the western part, with rainfall between 1700 and 1800 mm (ROSSATO, 2011). Beilfuss et al. (2022) indicate that Jari (RS) has an annual average of 1922 mm, ranging from 1000 mm to 2800 mm, between 1990 and 2020, which is higher than the values provided by Rossato (2011). Such information is crucial to understanding the occurrence of precipitation in Jari (RS), which has a significant impact on agriculture.

II. MATERIALS E METHODS

This is a qualitative-quantitative study, which used the software Dinamica EGO, version 3.0.17 (SOARES-FILHO; RODRIGUES; COSTA, 2009) to model expansion scenarios for soybean cultivation in the municipality of

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Jari (RS). The model used a Cellular Automata (CA) approach, in which the likelihood of a change in the state of a cell is defined by its previous state and the arrangement of neighboring cells, according to a set of transition rules (ROCHA, 2012; WOLDEYOHANNES et al., 2020; VIEIRA et al., 2021).

Five steps were required to develop the land use and land cover scenarios (Figure 2):

(1) Calculation of transition rates and transition probabilities per pixel;

(2) Analysis of correlation between variables;

(3) Allocation of simulated land use and land cover changes;

(4) Evaluation of the model's performance;

(5) Simulating future scenarios.

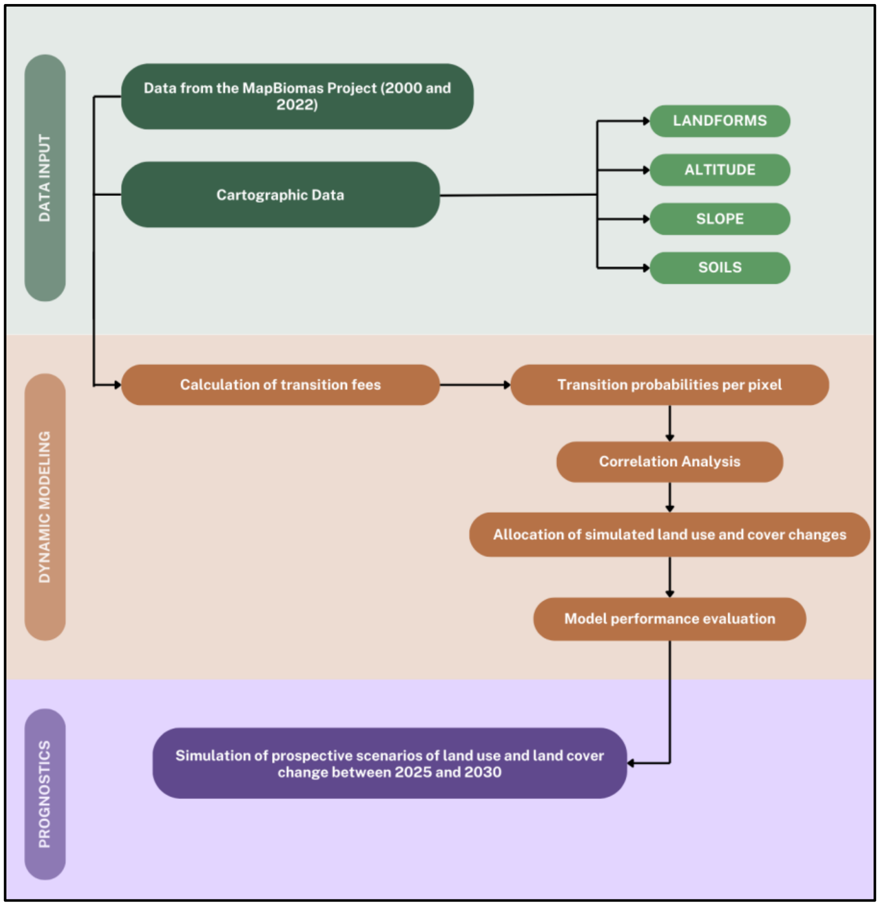

Figure 2 - Flowchart used in the work to develop the scenarios (Source: Adapted from Pisani, 2014).

Database and pre-processing

Data on land use and cover was obtained from the MapBiomas 8 project (SOUZA et al., 2020), which was accessed via the Google Earth Engine (GEE) cloud computing platform, for the years 2000 and 2022. This

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MapBiomas data has an accuracy of 90%, according to the Algorithm Theoretical Basis Document (ATBD) of the collection.

Several land use and land cover classes were combined to increase the size of each class in order to allow for better performance in the cell analysis carried out by Dinamica EGO (Table 1). It should be noted that the urban area is only 38 km², so it was not considered a significant class for the model and was included in the "mosaic of uses". The Wetlands were included in the Grassland class, as farmers commonly use these spaces to raise cattle.

The forest and river classes were merged, considering that rivers are linear features with a very small area and are predominantly associated with forest areas. In addition, forest areas have a low probability of transition into crops, so, as the focus of the research is on areas of soybean expansion, combining the forest and river classes did not imply any changes in the results sought by the study.

Table 1 - Land use and land cover classes used to develop the scenarios.

Subclasses of land use and cover	Land use and land cover reclassified	Code (ID) reclassified
Forest Formation	Forest	1
Grassland Formation	Grassland	2
Wetlands	Grassland	2
Soybean	Soybean	3
Mosaic of Uses	Mosaic of Uses	4
Other Temporary Crops	Mosaic of Uses	4
River	Forests	1
Urban Area	Mosaic of Uses	4
Other non-vegetated areas	Mosaic of Uses	4

Organized by the authors (2024).

In addition to the dynamic data referring to the initial landscape (land use and land cover 2000) and the final landscape (land use and land cover 2022), the static variables were merged into a raster cube, which included: altitude, slope, soils, and landforms. It is important to stress that the static variables selected for analysis were chosen based on previous studies (BEILFUSS, 2022; BEILFUSS et al., 2022; BEILFUSS; PETSCH; TRENTIN, 2023), considering both the quality and availability of the data.

The digital elevation model (DEM), which was derived from the Shuttle Radar Topography Mission (SRTM), was used to create the altitude and slope maps and downloaded from the United States Geological Survey website (https://earthexplorer.usgs.gov). The landform data file was obtained by cross-referencing the slope and altitude data generated from the TOPODATA DEM, resulting in three classes: hills and hillslopes, undulating hills, and buttes. The soil map was extracted from the classification available on the IBGE platform (2006) at a scale of 1:250,000, with subsequent validation in the field, based on profiles exposed in cuts in the main roads.

Overall transition rates and transition probabilities per pixel

The overall transition rates refer to the total amount of change that occurred for each class of land use and land cover during the observed period, in this study's case 22 years. Thus, three specific transitions were considered: (A) from forest to soybean; (B) from grassland to soybean; (C) from mosaic of uses to soybean.

Next, the transition probability of each pixel was defined using the weights of evidence approach (*WoE*), a Bayesian method used to identify the most favorable areas for changes in land use and cover (SOARES-FILHO et al., 2002; SOARES-FILHO; RODRIGUES; COSTA, 2009). Therefore, the weights of evidence approach are used to select the most important independent variables that control changes in land use and land cover and to quantify their influence on each type of transition. The higher the value of W+, the greater the likelihood of a particular land use and land cover transition occurring; on the other hand, negative values of W- indicate a lower likelihood of a specific transition (MAEDA et al., 2010).

Correlation analysis

This step was necessary to eliminate spatially correlated redundant independent variables to explain land use and land cover transitions. In this study, the Joint Uncertainty Information (U) and Cramer's (V) tests were applied to analyze the degree of spatial dependence between the independent variables.

Allocation of simulated land use and land cover changes

The functions for defining transitions between cells in Dinamica EGO are patcher and expander (SOARES-FILHO, 2002). The expander considers the expansion of existing spots of a given land use and land cover class, while the patcher is responsible for generating new independent spots, which are physically unconnected to previous patches of the same land use and land cover class. To determine the model's calibration parameters, several simulations were carried out with different expander and patcher values, 1% and 99% respectively. The values of the landscape metrics were calculated in the Fragstats software to help with this simulation stage.

Evaluation of the model's performance

Two starting dates were inserted for the model's analysis: land use and land cover for the years 2000 and 2022. In this way, the land use and land cover simulated by Dinamica EGO for 2022 were compared to the reference map for the same year, using a visual analysis. The parameters were adjusted several times, the model was re-executed and re-evaluated, starting with the generation of a map comparing the simulated scenario with the real one. This process was repeated until maximum similarity was achieved between the simulated map and the reference map.

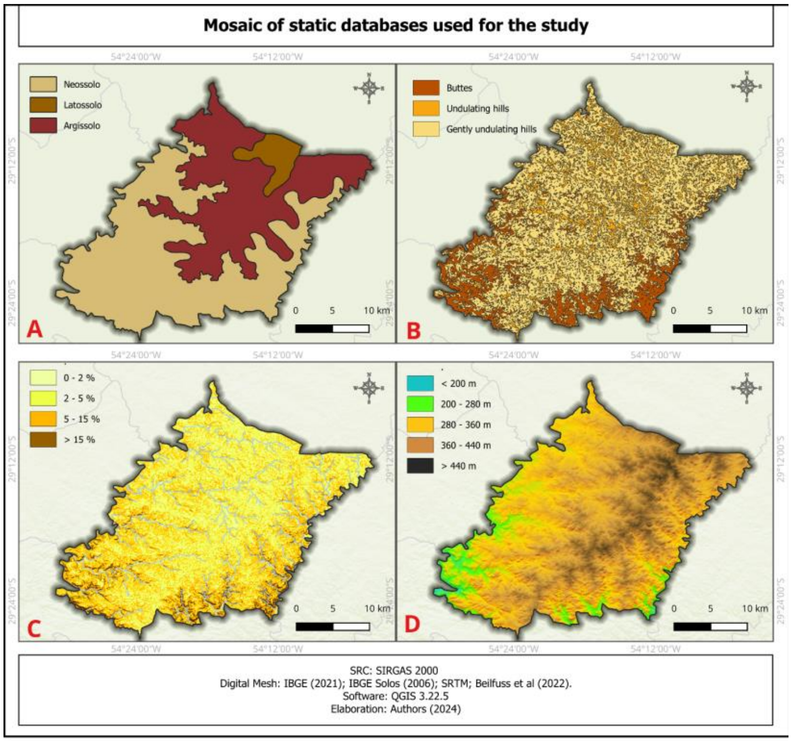
For validation, the Confusion Matrix was used and the overall classification accuracy was calculated by comparing the files pixel by pixel. The processing was carried out using the SCP (Semi-Automatic Classification Plugin) add-on, available in the QGIS software. It should be noted that the validation method was chosen as it is considered to be simple but also effective in representing the accuracy of the simulations generated.

Simulation of future scenarios

In order to observe changes in land use and land cover in Jari (RS), and especially the expansion of soybeans, scenarios were developed between 2025 and 2030. The year 2030 was selected to be the limit of the model's application, given that extrapolating too many years might increase the chances of error in the modeling.

III. RESULTS

The static variables used in the study are described below. The municipality of Jari (RS) has a topography with altitudes varying between 127 and 465 meters (Figure 3 D). The slope of the terrain (Figure 3 C) is predominantly in the 2 to 5% class (43%). The study area has three types of soil (Figure 3 A), with Neossolo predominating (56.7%). Argissolo occupies 38.7% of the municipality and Latossolo 4.6%. In terms of topography (Figure 3 B), gently undulating hills account for 64.9% of the territory (556 km²). Undulating hills account for 17.7% of the territory (152 km²). Representing 17.4% of the total study area are of buttes (149 km²), on the edge of the plateau.



SRC: SIRGAS 2000
Digital Mesh: IBGE (2021); IBGE Solos (2006); SRTM; Beilfuss et al (2022).
Software: QGIS 3.22.5
Elaboration: Authors (2024)

Figure 3 - Static databases used for the study: soils (A), landforms (B), slope (C), and altitude (D). (Source: Authors, 2024).

Transition rates in land use and cover in the municipality of Jari (RS)

In 2000 (Figure 4 A), the municipality of Jari (RS) had 10.8% of its area devoted to soybean cultivation, which corresponded to 62.11 km², with the greatest concentration in the northern regions of the municipality. In 2022 (Figure 4 B), a significant increase was observed in the areas dedicated to soybean production, which expanded from north to south, concentrating mainly in the central portions. In that year, soybean covered approximately 370 km², representing 43.3% of the municipality's total area.

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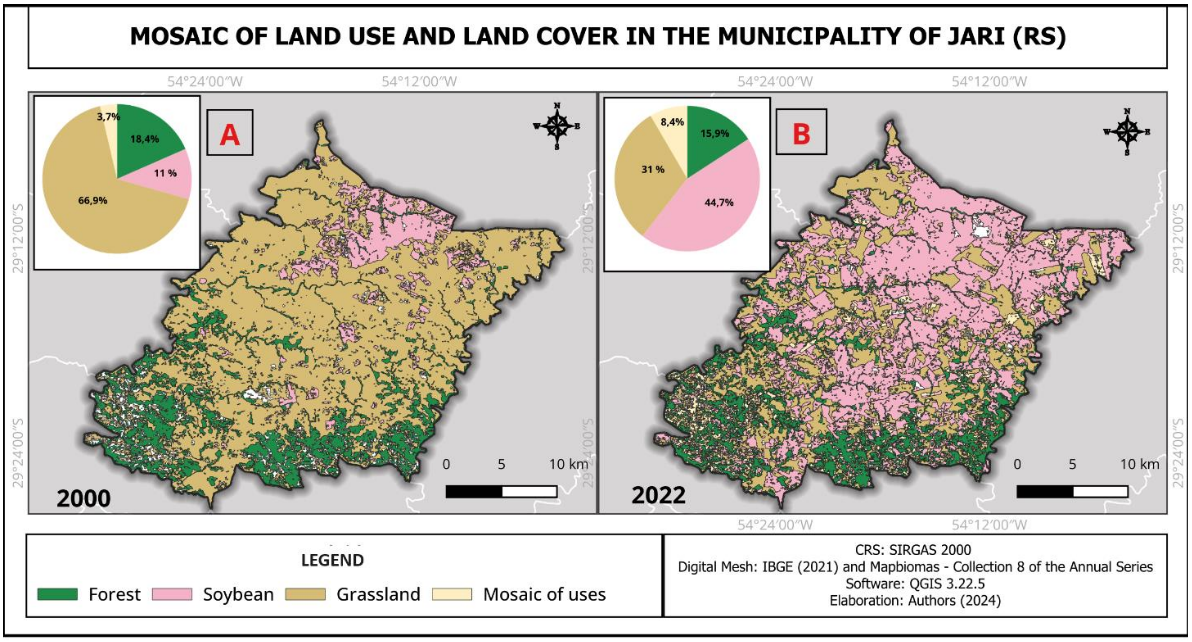

Figure 4 - Land use and land cover in the municipality of Jari (RS) in 2000 (A) and 2022 (B). (Source: Authors, 2024).

The changes in land use and land cover show a 34% reduction in the grassland class, and a 2% reduction in the forest class when comparing 2000 with 2022. As for the mosaic of uses, there was an increase of 5%. Soybean cultivation increased by 33% between 2000 and 2022 (Table 2).

Table 2 – Increase and decrease in the area of land use and land cover classes in Jari (RS), in reference to the year 2000. Negative values represent losses and positive values represent gains.

Land use and land cover	2000		2022		2000 – 2022	
	Km²	%	Km²	%	Km²	%
Forest	149	17	131	15	-18	-2
Soybean	89	10	370	43	281	33
Grassland	544	68	257	30	-287	-34
Mosaic of uses	30	3	70	8	40	5

Organized by the Authors (2024).

The gross transition rate for the period between 2000 and 2022 demonstrates the greater possibility of transformation from grassland and mosaic use to soybean, at 48.2% and 31.7% respectively (Table 2).

Table 2 – Transition rates of land use and land cover for soybean cultivation.

Base line 2000 – 2022

Transition	Annual rate (%)
Forest to soybean	3,7
Grassland to soybean	48,2
Mosaic of use to soybean	31,7

Source: the authors (2024).

Correlation of variables and calculation of evidence weights

Regarding the correlation of the variables, no spatial dependence has been observed in the variables used in this study. The highest U value was 0.195 between the distance from grassland to mosaics of uses. The highest V value was found between the variables distance to grassland and distance to the mosaic of uses (0.081). Bonham-Carter (1994) indicated that values under 0.5 for these indices suggest low spatial dependence and that these can be maintained in the model.

The transition probabilities in the cells were calculated based on the weights of evidence values assigned to each range of variables. The transition from grassland to soybean is the most common in the study area. As for distance from the forest (Figure 5 A), it can be seen that from 225m there is a greater probability of pixels undergoing the transition from grassland to soybean, that is, corresponding to portions of high slope. As for the distance from the mosaic of uses areas (Figure 5 B), up to 940 m, there is a greater probability of these pixels transitioning from grassland to soybean.

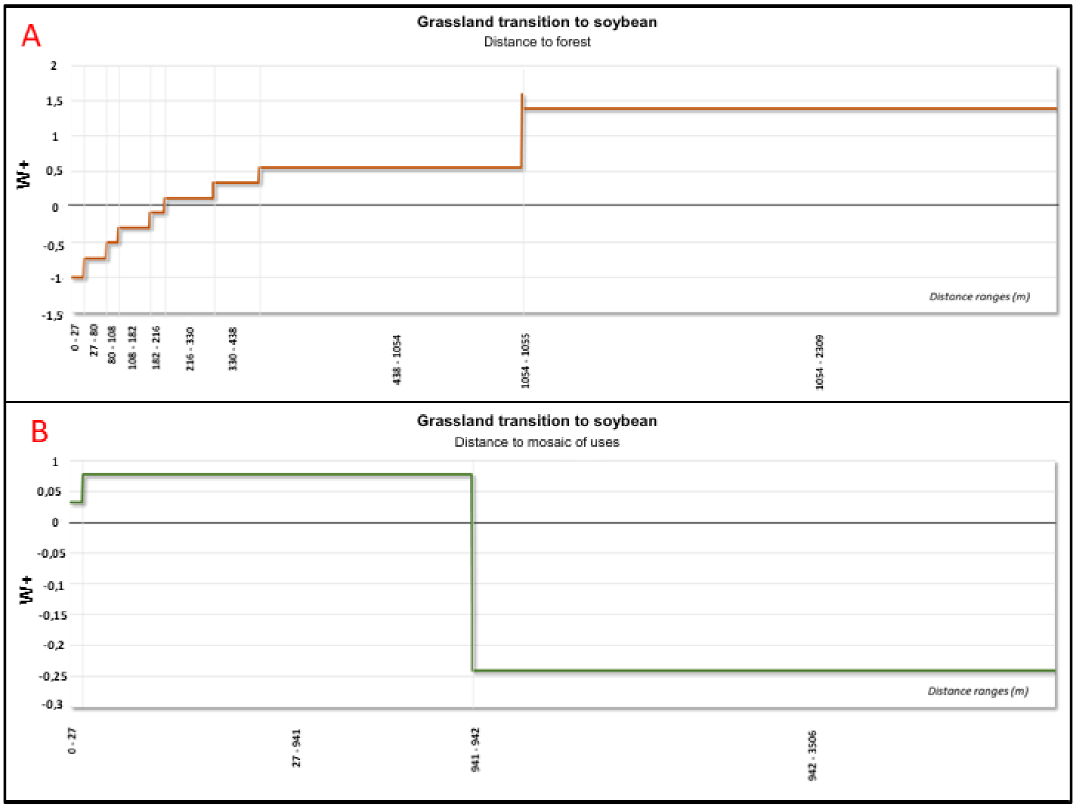

Figure 5 - Evidence weight values (W+) obtained in the simulations considering: (A) the variable 'distance to the forest' in relation to the 'grassland to soybean' transition; (B) the variable 'distance to mosaic of uses' in relation to the grassland to soybean' transition. (Source: Authors, 2024).

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The analysis of the probability of transition from grassland to soybean, for each pixel, was simulated (Figure 6 A) and compared with the real transition (Figure 6 B), obtaining similar results. Evaluating the simulation, the central regions and some areas to the west are more likely to develop soybean production. On the other hand, the areas with the lowest probability are located near the Permanent Preservation Areas (APP, in portuguese), where the terrain is rougher, characterized by the presence of buttes. Analysis of the transition in land use and land cover between the years 2000 and 2022 (Figure 6 B) shows that soybean is expanding in the central portion, limited only by hilly terrain near the drainage channels and the Rebordo do Planalto landform in the south.

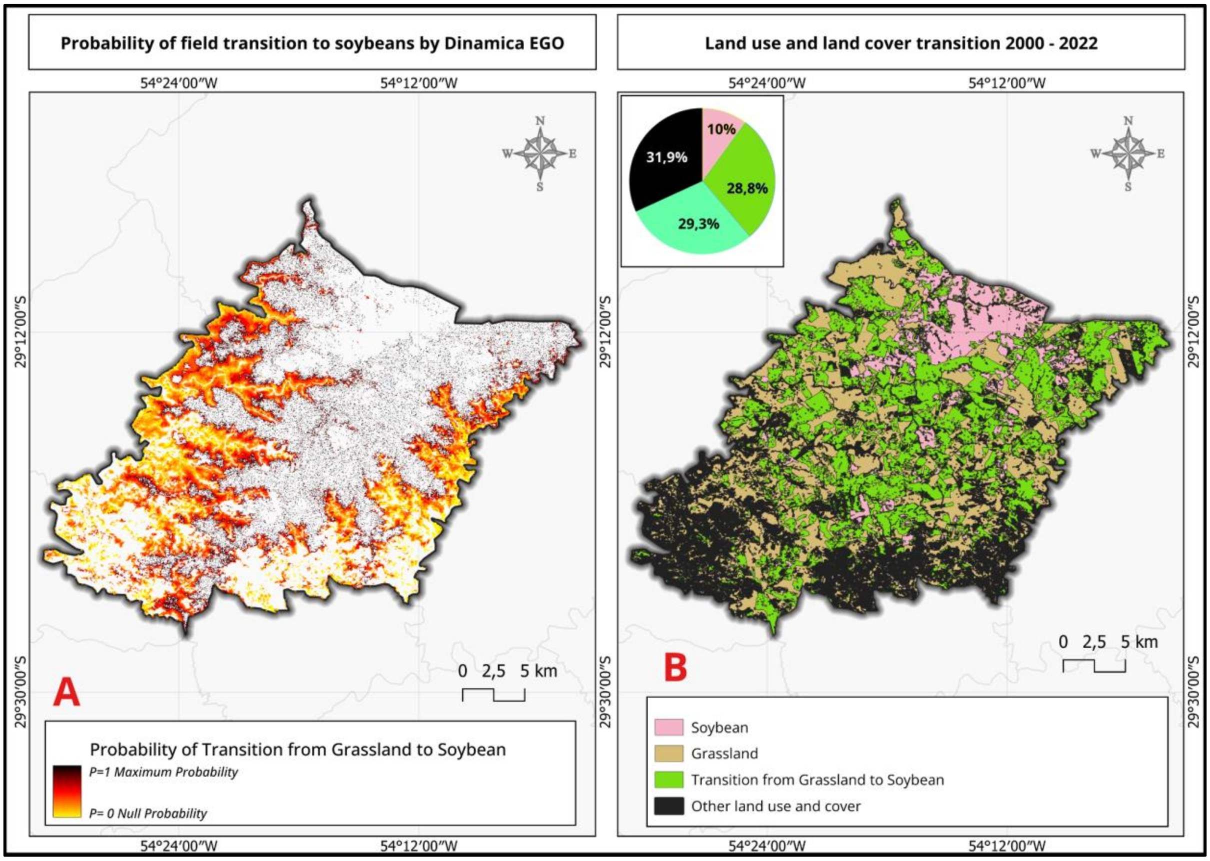

Figure 6 - A: Probability of grassland transition to soybean by Dinamica EGO; B: Land use and land cover transition 2000 - 2022. (Source: Authors, 2024).

Model calibration and performance assessment

Comparing the simulated model (Figure 7 B) with the real land use and land cover map for 2022 (Figure 7 A), quantitatively, there are smaller absolute percentage errors for the forest, grassland and soybean classes, with 11%, 11%, and 6% respectively. The class of mosaics of uses showed an absolute error of 70%, due to the diversity of uses and land covers clustered in this class. Figure 7 C shows the soybean areas correctly estimated by the model.

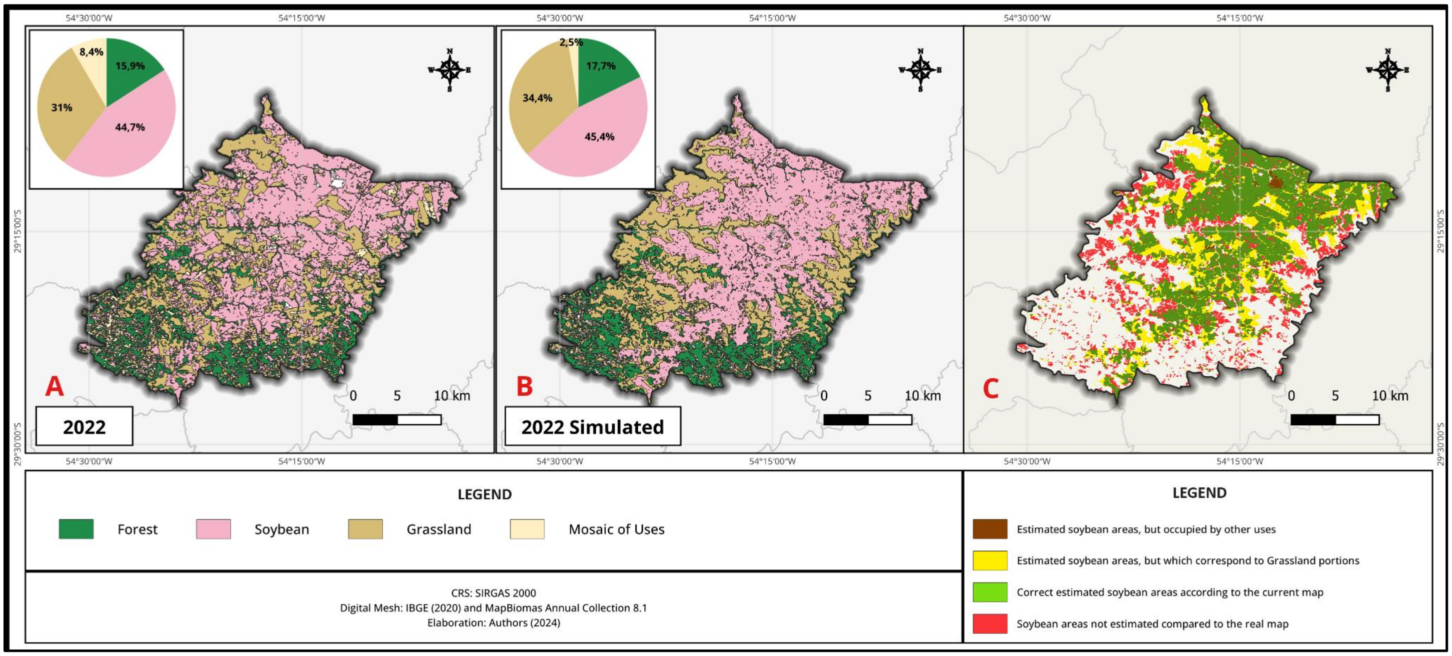

Figure 7 - A: Real land use and land cover map for 2022; B: Simulated land use and cover map for 2022; C: Difference between the real map and the simulated map for 2022. (Source: Authors, 2024).

Comparing the data from the simulated map with the actual 2022 land use and land cover map showed an overall accuracy of approximately 65.6%. Based on the analysis of the confusion matrix, which accounted for the pixels in each class compared to the real map (Table 3), it was found that the forest class showed the best accuracy in classifying the pixels. Of the 170,704 pixels in the forest class on the real 2022 map, 88.4% were correctly classified.

Table 3 - Confusion matrix based on the pixel count of the simulated map compared to the real 2022 land use and cover map.

Confusion Matrix (by pixel count)								
Class	Forest	%	Soybean	%	Grassland	%	Mosaic of uses	%
Forest	150.937	88,4	7.161	1,5	8.074	2,4	22.985	26,6
Soybean	3.187	1,9	333.347	71,2	120.695	36,6	20.535	23,8
Grassland	12.445	7,3	124.317	26,5	195.553	59,6	30.544	35,4
Mosaic of uses	4.135	2,4	3.432	0,7	5.360	1,6	12.297	14,2

Total Pixels	170.704	100	468.257	100	329.682	100	86.361	100

Organized by the authors (2024).

As far as the soybean class is concerned, 71.2% of the pixels were correctly classified when compared to the real map, as can be seen in Table 3. The grassland class had a correct classification rate of 59.6%. On the other hand, the mosaic of uses class performed poorly, with only 14.2% of pixels correctly classified (Table 3). Most of the pixels in this class were wrongly assigned to other classes, especially the grassland class, which absorbed 30,544 pixels (35.4%) originally belonging to the mosaic of uses.

Scenario search up to 2030

The simulation of the scenarios for the municipality of Jari (RS) shows a considerable increase in the soybean area. In the last year, according to data available on MapBiomas (2022), the soybean crop occupied an area of 370 km²; in 2030, 437 km² is projected, which represents 52.6% of the municipality's total area. As a result, the countryside will be significantly impacted, losing 34.4 km² of area between 2025 and 2030 (Figure 8).

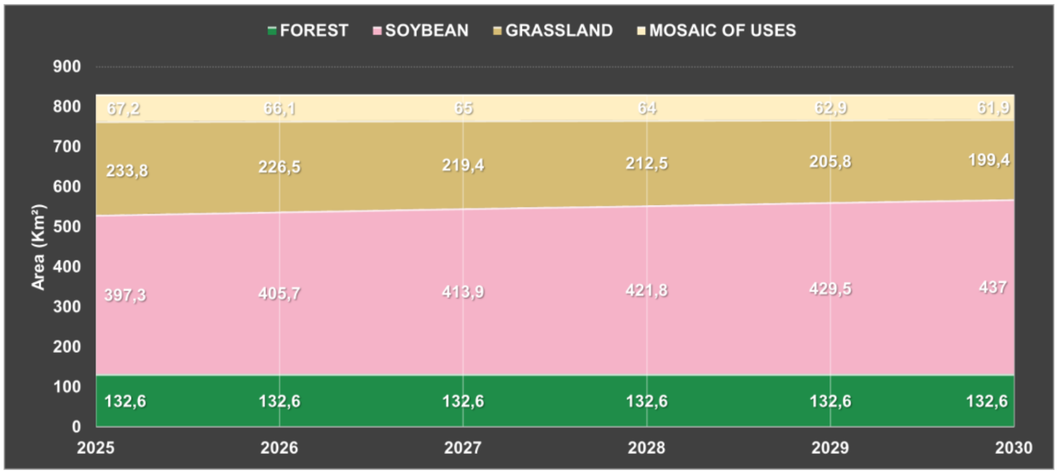

Figure 8 - Land use and land cover in the municipality of Jari (RS) from 2025 to 2030 (Source: Authors, 2024).

Spatially, in the years 2025 to 2030 (Figure 9 A and B), soybean expansion is concentrated in the central regions, mainly related to the replacement of grassland areas. Subsequently, it is noticeable that soybean cultivation will advance towards the few southern portions of the municipality where there are still areas of grassland, especially in the southwestern region, close to forest areas and the steepest slopes of the Rebordo do Planalto landform.

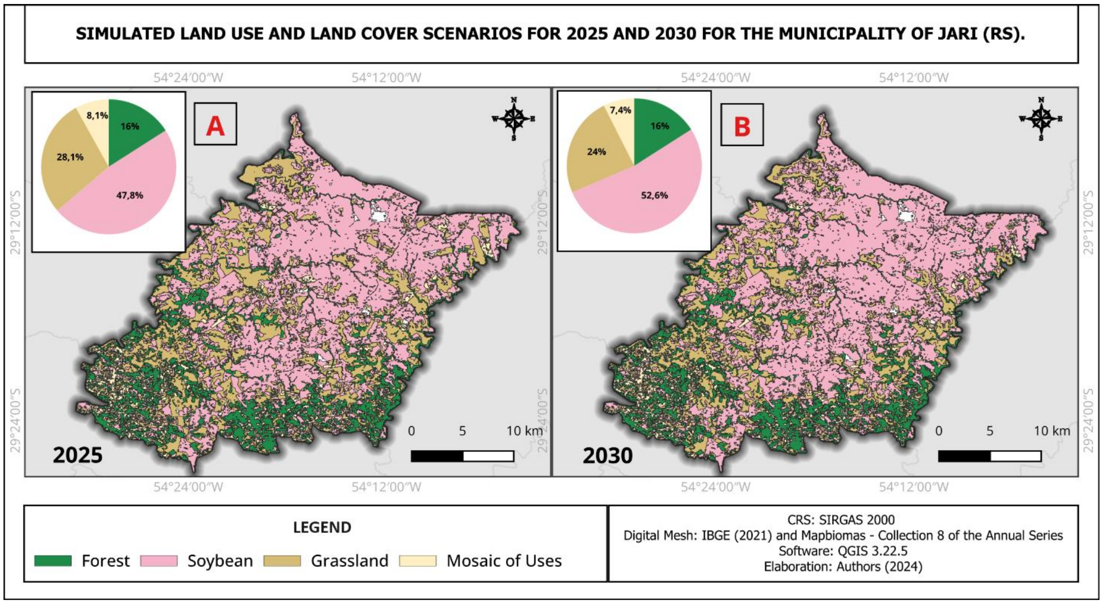

Figure 9 - Simulated land use and land cover scenarios for 2025 and 2030 for the municipality of Jari (RS). (Source: Authors, 2024).

IV. DISCUSSIONS

The study showed a 33% increase in soybean cultivation in the municipality of Jari (RS) between 2000 and 2022. These data are in line with other studies that point to the replacement of grassland areas by soybean throughout the Pampa biome in recent decades (OLIVEIRA et al., 2017; KUPLICH; CAPOANE; COSTA, 2018; MENGUE et al., 2020; PETSCH et al., 2022). In addition, the model has also indicated the continued expansion of soybean in Jari (RS), with more than half of the municipality's area likely to be occupied by this crop, linked to the continued replacement of grassland areas, and in the background, the replacement of other temporary crops.

The replacement of natural grasslands with crops is linked to several factors, such as the rising price of soybean, the loss of areas destined for livestock, and the strong impetus of the international agricultural commodities market, which has motivated producers to seek new areas for conversion to soybean cultivation (ROCHA et al., 2018; BEILFUSS, 2022; CHIACCHIO; LÍRIO DE SOUSA, 2024). Many of these natural areas of the Pampa Biome are in a situation of overgrazing, characterized by the large number of animals per hectare in areas of grassland formation, which causes soil degradation (KUPLICH; CAPOANE; COSTA, 2018). In turn, the introduction of agriculture is likely to result in a significant loss of biodiversity, especially due to the intensive use of pesticides on crops (BOLDRINI, 2009; HASENACK et al., 2019). In this way, both activities have an impact on the natural vegetation of the Pampa biome.

In addition, there was an expansion of soybean cultivation on shallow and steeper soils between 2000 and 2022. Such a phenomenon is attributable to the pressure to increase cultivated areas and the exhaustion of more favorable soils, driven by investments in efficient technologies and machinery in the agricultural sector and the high profitability of soybean production (OVERBECK et al., 2009; PETSCH et al., 2022; TRENTIN; LAURENT; ROBAINA, 2023). In the municipality of Jari (RS), even though the slope hinders the expansion of soybean, it does not prevent it completely, as the model results indicate.

The portions where the Dinamica EGO software had the greatest difficulty in estimating the presence of soybean refer to small patches further south in the municipality. These areas represent recently established crops and exhibit distinct characteristics compared to those to the north, where the model was trained, after the transition to soybean crops, with environmental characteristics more favorable to cultivation. It should be noted that the models learn the relationship between historical land use and land cover patterns and the explanatory variables (ARSANJANI et al., 2013). To increase the accuracy of the model, Jining et al (2019) pointed out that other years can be included to teach the software about land use and land cover.

In the case of the municipality of Jari (RS), the forests are confined to permanent preservation areas on the banks of rivers and high slopes, so there is little transition to soybean cultivation areas. As a result, it was observed that the forest area remained practically untouched by the advance of soybean simulated until 2030, since there was the greatest change in the grasses, the region's natural vegetation. This contrasts with deforestation patterns observed in other biomes, such as the Amazon, where agricultural expansion has caused a significant reduction in forest areas (MAEDA et al., 2011; OLIVEIRA; DOS SANTOS; FERREIRA, 2019). While in the south of the country natural grassland areas have been replaced by the introduction of grain crops, in the north, paradoxically, the native forest has been cleared to be occupied by livestock, what is common in both situations is the devastation of natural resources (MATTE; WAQUIL, 2020).

As for the static data used in Dinamica EGO, it should be noted that there may be limitations, such as the availability, appropriate scale, or reliability of the data. Particularly given that different spatial determinants, such as soil quality, rainfall, or socioeconomic characteristics, influence agricultural expansion and intensification (MEYFROIDT, 2016). In this study, for example, it became necessary to carry out soil validation in the field to increase the accuracy of the mapping, while rainfall data was not used due to the absence of weather stations with more than 30 years of recorded data.

As for dynamic data, it should be noted that the use of the MapBiomas project combined with Dinamica EGO can provide a relatively quick and cost-free method, since the software and data are available free of charge, to project soybean expansion over the next few decades. However, it has been necessary to reclassify the land use and land cover of Map Biomas to allow processing on less robust computers. As observed by Batty et al. (1999), the higher the number of classes, the greater the complexity of the model. As a negative factor, the spatial resolution of MapBiomas does not provide enough detail, for example, to study sub-watersheds (HINATA; BASSO; REKOWSKY, 2023), but for larger municipalities or watersheds, the data is adequate, allowing advances to be made in these areas.

V. CONCLUSIONS

According to the modeling data, the advance of soybean in Jari (RS) will continue in the coming years, occupying more than half of the municipality by the year 2030. The simulated scenarios in the Dinamica EGO have shown that mainly the portions occupied by grasslands could be converted to soybean. In this context, it is imperative to consider the preservation of the Pampa biome and the implementation of public policies aimed at protecting its biodiversity. The Pampa biome, in particular, is increasingly vulnerable to conversion to soybean cultivation, and therefore lacks specific legislation for its preservation, highlighting the urgency of appropriate conservation measures.

Essentially, between 2000 and 2030, soybean consolidation was observed in scenarios that were more favorable to grain production, followed by expansion into less favorable scenarios, such as shallow soils with steeper slopes in the south of the municipality. The simulated scenarios show two conversion processes for soybean crops, with the second occurring more frequently. The first relates to the conversion of areas near large soybean plantations, linked to the expander function of Dinamica EGO, especially in the north and central part of the municipality. The second relates to small patches appearing on less favorable terrain, linked to the model's patcher function, located further south in the municipality.

In conclusion, it is essential to include other data in the modeling in future studies, mainly related to climate dynamics, which have a direct impact on grain production. Given that in municipalities like Jari (RS), which are linked to monoculture, a period of drought during planting and plant development can lead to an economic downturn in the municipality. To this end, it is recommended to use data from climate models if there are no weather stations available.

VI. REFERENCES

ALENCAR, A.; SILVESTRINI, R.; GOMES, J.; SAVIAN, G. Amazônia em chamas: o novo e alarmante patamar do desmatamento na Amazônia. Instituto de Pesquisa Ambiental da Amazônia-IPAM, 2022.

ANDRADE, A. D. M.; COLLICCHIO, E. Prospective analysis of soybean distribution in the Tocantins state considering climate change scenarios. Pesquisa Agropecuária Tropical, v. 52, 2022. DOI: https://doi.org/10.1590/1983-40632022v5272969.

ANHOLETO, C. D.; MASSUQUETTI, A. A soja brasileira e gaúcha no período 1994-2010: uma análise da produção, exportação, renda e emprego. Revista Economia e Desenvolvimento, v. 13(2), (2015), p. 379-404.

ARSANJANI, J.J.; HELBICH, M.; KAINZ, W.; BOLOORANI, A. D. Integration of Logistic Regression, Markov Chain and Cellular Automata Models to Simulate Urban Expansion. Int. J. Appl. Earth Obs. Geoinformações, v. 21, 2013, p. 265–275.

BATTY, M.; XIE, Y.; SUN, Z. Modeling urban dynamics through GIS-based cellular automata. Computers, environment and urban systems, v. 23, n. 3, 1999, p. 205-233. DOI: https://doi.org/10.1016/S0198-9715(99)00015-0.

BEILFUSS, E. Elaboração e Análise do Atlas Geoambiental do Município de Jari - RS. Trabalho de Conclusão de Curso (Geografia Bacharelado) - Universidade Federal de Santa Maria, 2022. Acessado em: 12 de Dezembro de 2023. Disponível em: https://repositorio.ufsm.br/handle/1/30230.

BEILFUSS, E. M.; PETSCH, C.; BEN, F. D.; ROBAINA, L. E. D. S.; TRENTIN, R.; SCCOTI, A. A. V. Atlas Geoambiental de Jari-RS, 2022. Disponível em: https://repositorio.ufsm.br/handle/1/27509. Acessado em: 12 de dezembro de 2023.

BEILFUSS, E.; PETSCH, C.; TRENTIN, R. O avanço da soja no município de Jari (rs) e sua relação com atributos do relevo e solo. Anais do 14° SINAGEO – Simpósio Nacional de Geomorfologia, Corumbá (MS), 2023.

BOLDRINI, I. L. A flora dos campos do Rio Grande do Sul. Campos Sulinos: conservação e uso sustentável da biodiversidade, 2009, p. 63-77. ISBN 978-85-7738-117-3.

BONHAM-CARTER, G. Geographic information systems for geoscientists: modelling with GIS. Elsevier, 1994.

CERQUEIRA, E. B.; GOMES, J. M. A. Expansão agropecuária e dinâmicas de uso e cobertura do solo no Piauí. Geo UERJ, v. 42, 2023. DOI: https://doi.org/10.12957/geouerj.2023.69241.

CHIACCHIO, M. A.; LÍRIO DE SOUSA, A. A expansão da soja e os efeitos no mercado de terras na Amazônia. Geografia em Questão, [S. l.], v. 17, n. 2, 2024. DOI: https://doi.org/10.48075/geoq.v17i02.29126.

CHIARAVALLOTI, R. M.; TOMAS, W. M.; UEZU, A.; SHIRAI, H. Y.; GUARALDO, E.; AOKI, C.; SALVADORI, J. F. Rapid land use conversion in the Cerrado has affected water transparency in a hotspot of ecotourism, Bonito, Brazil. Tropical Conservation Science, v. 15, 2022. DOI: https://doi.org/10.1177/19400829221127087

DA COSTA SILVA, R. G. Agentes, procesos y conflictos en la gestión territorial en el estado de Rondônia (Brasil). Polis. Revista Latinoamericana, v. 45, 2016.

DE OLIVEIRA GERARDI, L. H. Algumas reflexões sobre modernização da agricultura. Geografia, (1980), 19-34.

DOS SANTOS, F. M.; FÁVARO, C. L.; DA ROCHA FILHO, J. Sobre a morte e o comer: as implicações das tradições alimentares sobre as mudanças climáticas. Simplíssimo, 2022.

FERREIRA, M. E.; FERREIRA Jr, L. G.; MIZIARA, F.; SOARES-FILHO, B. S. Modeling landscape dynamics in the central Brazilian savanna biome: future scenarios and perspectives for conservation. Journal of Land Use Science, v. 8, n. 4, 2013, p. 403-421. DOI: https://doi.org/10.1080/1747423X.2012.675363.

FOLEY, J. A.; DEFRIES, R.; ASNER, G. P.; BARFORD, C.; BONAN, G.; CARPENTER, S. R.; SNYDER, P. K. Global consequences of land use. science, v. 309, 2005, p. 570-574. DOI: https://doi.org/10.1126/science.1111772.

GASS, S. L. B.; DA SILVA, D. M.; DE ARRUDA, S. F. A leitura e representação da paisagem rural como instrumento de gestão municipal: uma proposta para Santo Cristo, Rio Grande do Sul, Brasil. Agua y Territorio/Water and Landscape, v. 23, 2024. DOI: https://doi.org/10.17561/at.23.7266.

GRAESSER, J.; AIDE, T. M.; GRAU, H. R.; RAMANKUTTY, N. Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. Environmental Research Letters, n. 10, n. 3, 2015. DOI: https://doi.org/10.1088/1748-9326/10/3/034017.

GRAESSER, J.; RAMANKUTTY, N.; COOMES, O. T. Increasing expansion of large-scale crop production onto deforested land in sub-Andean South America. Environmental Research Letters, v. 13, n. 8, 2018. DOI: https://doi.org/10.1088/1748-9326/aad5bf.

HARARI, Y. N. Sapiens uma breve história da humanidade.32º ed. Porto Alegre: L&PM, 2018.

HASENACK, H.; CORDEIRO, J. L. P.; COSTA, B. S. C. Cobertura vegetal atual do Rio Grande do Sul. Simpósio de forrageiras e produção animal, v. 2, 2007, p. 15-21.

HASENACK, H.; WEBER, E. J.; VÉLEZ-MARTIN, E.; HOFMANN, G. S.; DEWES, H. Bioma Pampa: oportunidades e desafios de pesquisa para o desenvolvimento sustentável. Biomas e agricultura: oportunidades e desafios. Vertente edições, Rio de Janeiro, 2019, p. 123-140.

HINATA, S. S.; BASSO, L. A.; REKOWSKY, I. C. Transformações espaciais na bacia hidrográfica do Lago Guaíba (RS). Geo UERJ, n. 42, (2023). DOI: https://doi.org/10.12957/geouerj.2023.70767.

JINING, Y.; WANG, L.; SONG, W.; CHEN, Y.; CHEN, X.; DENG, Z. A time-series classification approach based on change detection for rapid land cover mapping. ISPRS J. Photogramm. Remote Sensing, v. 158, 2019, p. 249–262.

KEYS, E.; MCCONNELL, W. J. Global change and the intensification of agriculture in the tropics. Global environmental change, v. 15, n. 4, 2005, p. 320-337. DOI: https://doi.org/10.1016/j.gloenvcha.2005.04.004.

KUPLICH, T. M.; CAPOANE, V.; COSTA, L. F. F. O avanço da soja no bioma Pampa. Boletim Geográfico do Rio Grande do Sul, v. 31, 2018, p. 83-100.

LAMBIN E. F.; MEYFROIDT P. Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences, v. 108, n. 9, 2011, p. 3465–3472. DOI: https://doi.org/10.1073/pnas.1100480108.

LOBÃO, M. S. P.; STADUTO, J. A. R. Modernização agrícola na Amazônia brasileira. Revista de Economia e Sociologia Rural, v. 58, 2020. DOI: https://doi.org/10.1590/1806-9479.2020.182276.

MAEDA, E. E.; CLARK, B. J.; PELLIKKA, P.; SILJANDER, M. Modelling agricultural expansion in Kenya's eastern Arc Mountains biodiversity hotspot. Agricultural Systems, v. 103, n. 9, 2010, p. 609–620. DOI: https://doi.org/10.1016/j.agsy.2010.07.004.

MAEDA, E. E.; DE ALMEIDA, C. M.; DE CARVALHO XIMENES, A.; FORMAGGIO, A. R.; SHIMABUKURO, Y. E.;

PELLIKKA, P. Dynamic modeling of forest conversion: Simulation of past and future scenarios of rural activities expansion in the fringes of the Xingu National Park, Brazilian Amazon. International Journal of Applied Earth Observation and Geoinformation, v. 13, n. 3, 2011, p. 435-446. DOI: https://doi. org/10.1016/j.jag.2010.09.008.

MAIA, R. C.; SILVA, K. N.; BENEVIDES, J. D. A. J.; AMORIM, V. G.; DE SOUSA, R. M. Impactos ambientais em manguezais no Ceará: causas e consequências. Conexões-Ciência e Tecnologia, v. 13, n. 5, 2019, p. 69-77. DOI: https://doi.org/10.21439/conexoes.v13i5.1797.

MAPBIOMAS PROJECT. Coleções Mapbiomas. Disponível online em: https://mapbiomas.org/download. Acessado em: 23 de dezembro de 2022.

MARCOVITCH, J. A gestão da Amazônia: ações empresariais, políticas públicas, estudos e propostas. Edusp, 2022.

MATTE, A.; WAQUIL, P. Productive changes in Brazilian Pampa: impacts, vulnerabilities and coping strategies. Natural Hazards, v. 102, n. 1, 2020, p. 469-488.

MAZOYER, M.; LAURENCE, R. História das agriculturas no mundo: do neolítico à crise contemporânea. São Paulo: Editora UNESP, 2010.

MENGUE, V. P.; DE FREITAS, M. W. D.; DA SILVA, T. S.; FONTANA, D. C.; & SCOTTÁ, F. C. LAND-USE and land-cover change processes in Pampa biome and relation with environmental and socioeconomic data. Applied Geography, v. 125, 2020. DOI: https://doi.org/10.1016/j.apgeog.2020.102342.

MEYFROIDT, P. Approaches and terminology for causal analysis in land systems science. Journal of Land Use Science, v. 11, n. 5, 2016, p. 501–522. DOI: https://doi.org/10.1080/1747423X.2015.111753.

OLIVEIRA, P. C. S. D. S.; DOS SANTOS, A. M.; FERREIRA, N. C. Modelagem dinâmica do desmatamento no sul da Amazônia Ocidental. Boletim de Geografia, v. 7, n. 3, 2019, p. 189-207. DOI: https://doi.org/10.4025/bolgeogr.v37i3.42643.

OSIS, R.; LAURENT, F.; POCCARD-CHAPUIS, R. Spatial determinants and future land use scenarios of Paragominas municipality, an old agricultural frontier in Amazonia. Journal of Land Use Science, v. 14, n. 3, 2019, p. 258-279. DOI: https://doi.org/10.1080/1747423X.2019.1643422.

OVERBECK, G. E.; MÜLLER, S. C.; FIDELIS, A.; PFADENHAUER, J.; PILLAR, V. P.; BLANCO, C. C.; BOLDRINI, I. I.; BOTH, R.; FORNECK, E. D. Os Campos Sulinos: um bioma negligenciado. In:PILLAR, V.P.; MÜLLER, S. C.; CASTILHOS, Z. M. S.; JACQUES, A. V. A. Campos Sulinos, conservação e uso sustentável da biodiversidade. 2 ed. Brasilia: MMA, 2009, p. 26–41.

PETSCH, C.; SCCOTI, A. A. V.; TRENTIN, R.; DE SOUZA ROBAINA, L. E.; DA ROSA, K. K. A expansão da cultura de soja no pampa gaúcho: o caso da bacia hidrográfica do rio Santa Maria. Revista Geografar, v. 17, n. 1, 2022, p. 47-71.

PISANI, R. J.; Modelagem espacial dinâmica para o monitoramento do aporte de sedimentos na sub-bacia do Rio Capivara, município de Botucatu-SP. 2014. 162 f. Tese (Doutorado em Geociências e Meio Ambiente) – Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista, Rio Claro, 2014.

ROCHA, B. G., AMARO, H. T., PORTO, E. M., GONÇALVES, C. C., DAVID, A. M., & LOPES, E. B. Sistema de semeadura cruzada na cultura da soja: avanços e perspectivas. Revista de Ciências Agrárias, v. 41, n. 2, 2018, p. 376-384. DOI: https://doi.org/10.19084/RCA17260.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.60, n.1, p. 209–229, 8/2024
http://dx.doi.org/10.5380/raega.v60i0.96192

RODRIGUES, H. O.; SOARES-FILHO, B. S.; COSTA, W. L. S. DINAMICA-EGO: uma plataforma para modelagem de sistemas ambientais. In: Simpósio Brasileiro de Sensoriamento Remoto (SBSR), 13., 2007, Florianópolis. Anais... São José dos Campos: INPE. Artigos, CD-ROM, On-line, 2007, p. 3089-3096.

ROSSATO, M. Os climas do Rio Grande do Sul: variabilidade, tendências e tipologia. Tese de Doutorado. Tese (Doutorado em Geografia)-Universidade Federal do Rio Grande do Sul, Porto Alegre (RS), 2011.

SILVA, D. S.; ARIMA, E. Y. Sustainability Consequences of Making Land Change Decisions Based on Current Climatology in the Brazilian Cerrados. Land, v. 12, n. 4, 2023. DOI: https://doi.org/10.3390/land12040914.

SKENDŽIĆ, S.; ZOVKO, M.; ŽIVKOVIĆ, I. P.; LEŠIĆ, V.; LEMIĆ, D. The impact of climate change on agricultural insect pests. Insects, v. 12, n. 5, 2021. DOI: https://doi.org/10.3390/insects12050440.

SOARES-FILHO, B. S.; CERQUEIRA, G. C.; PENNACHIN, C. L. DINAMICA—a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. Ecological modelling, v. 154, n. 3, 2002, p. 217-235. DOI: https://doi.org/10.1016/S0304-3800(02)00059-5.

SOARES-FILHO, B. S.; RODRIGUES, H. O.; COSTA, W. L. S. Modeling environmetal dynamics with Dinamica EGO. 1ª ed. Belo Horizonte, MG, 2009.

SONG, X. P.; HANSEN, M. C.; POTAPOV, P.; ADUSEI, B.; PICKERING, J.; ADAMI, M.; TYUKAVINA, A. Massive soybean expansion in South America since 2000 and implications for conservation. Nature sustainability, v. 4, n. 9, 2021, p. 784-792. DOI: https://doi.org/10.1038/s41893-021-00729-z.

TRENTIN, R; LAURENT, F; ROBAINA, L. E. S; O impacto do uso da terra sobre o balanço hídrico na bacia hidrográfica do rio Santa Maria - oeste do Rio Grande do Sul - Brasil. Para Onde!?. Porto Alegre: UFGRS, v. 17, n. 1, ed. esp. 2023.

VIEIRA, R. M. D.; TOMASELLA, J.; BARBOSA, A. A.; MARTINS, M. A.; RODRIGUEZ, D. A.; REZENDE, F. S.; SANTANA, M. D. Desertification risk assessment in Northeast Brazil: Current trends and future scenarios. Land Degradation & Development, v. 32, n. 1, 2021, p. 224-240. DOI: https://doi.org/10.1002/ldr.3681.

WOLDEYOHANNES, A.; COTTER, M.; BIRU, W. D.; KELBORO, G. Assessing changes in ecosystem service values over 1985–2050 in response to land use and land cover dynamics in Abaya-Chamo Basin, Southern Ethiopia. Land, v. 9, n. 2, 2020. DOI: https://doi.org/10.3390/land9020037.