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Original Article

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Modeling Deforestation in the State of Rondônia

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ABSTRACT

This study applied a deforestation model for the entire State of Rondônia assuming three scenarios of deforestation: business as usual, optimistic and pessimistic. Those scenarios were constructed for the time-period of 2012-2050 using the Dinamica EGO software. Rondônia deforestation dataset was provided by the Agência Ambiental do Estado de Rondônia (Rondônia State Environmental Agency) and was used as input of the deforestation modeling. Based on this study results, we estimated that 32%, 37% and 47% of Rondônia's native forest could be fully deforested by 2050 assuming the optimistic, business as usual and pessimistic scenarios, respectively. Regardless of the chosen scenario, we expect that deforestation will be spatially concentrated in Northern Rondônia in the next decades. The greatest concern, however, could be the integrity of the protected areas assuming the business as usual and/or pessimistic scenario. In addition, we expect a substantial increase of the forest fragmentation by 2050.

Keywords: land use change, fragmentation, disorderly occupation.

1. INTRODUCTION

The Amazon rainforest is a global reference for its territory, rich flora and fauna, as well as its function on setting of noxious gases to the environment, which enhance climate change (Zarin et al., 2015; Coe et al., 2017; Azevedo-Ramos & Moutinho, 2018). In spite of its fundamental importance for the environmental balance, territorial and biodiversity aspects, a reduction of the vegetation pertinent to this forest component is constantly observed. It has been configured in increasingly alarming numbers of deforested area and its consequent fragmentation (Magnago et al., 2014; Rocha et al., 2018).

Despite the situation of the Amazon Forest scenario as a whole, the process of deforestation in Rondônia has significantly increased, especially after 1970, when the implementation of colonization projects and settlements in the State was initiated, implemented by the *Instituto Nacional de Colonização e Reforma Agrária* (INCRA) (National Institute of Colonization and Agrarian Reform). During this same period (1970), there was a great migratory flow of people to the region, which with incentive of the Federal Government expanded the agricultural frontier, replacing the forest areas with areas of agriculture and cattle raising (Le Tourneau & Bursztyn, 2010).

Nowadays, among the main States that lead the ranking of deforestation in the Legal Amazon (Amazonas, Roraima, Rondônia, Mato Grosso, Acre and Pará), Rondônia was responsible for 21% of the total deforested areas from August 2014 to January 2016, according to Fonseca et al. (2016), in report issued by Imazon.

Given these scenarios, modeling deforestation process requires high priority to subsidize measures regarding the relevance of the Amazonian forest (Fearnside et al., 2009). Thus the use of techniques aimed to simulate future scenarios and perspectives on the dynamics of deforestation in the Amazon forest, through the application of geospatial models, has assumed an extremely important role in these surveys (Barni et al., 2015; Elz et al., 2015). Also, the behavior analysis of forest fragments subsidizes the decision making regarding the forest management, having as a tool spatial analysis techniques (Foody, 2010; Gómez et al., 2011).

The present study aimed to develop deforestation forecasts to the year 2050 for the State of Rondônia, with forecasts based on three scenarios: (i) Business as usual scenario, assuming deforestation rate and average efficiency of land use proposed by the Zoneamento Socioeconômico-Ecológico (ZSEE, Socio-economic-ecological zoning), observed in the historical series between 2009 and 2011; (ii) Optimistic scenario, assuming lower deforestation rate and high effectiveness of ZSEE, also observed in the time series between 2009 and 2011; and (iii) Pessimistic scenario, assuming high rate of deforestation and low effectiveness of the Socioeconomic-Ecological Zoning observed in the historical series between 2007 and 2011. Finally, this research aims to evaluate the effects of deforestation on the natural vegetation fragmentation between the years 2012 and 2050 in the State of Rondônia in the different scenarios.

2. MATERIAL E METHODS

2.1. Study area

The study area is the State of Rondônia, located between the meridians 66°37' and 60°44' West longitude, and the parallels 7°59' and 13°42' South latitude (Figure 1). The total area of the State is 237,590 km^2, which represents 4.5% of the Legal Amazon. According to Köppen Climate classification, the State of Rondônia is predominatly classified as Aw type (the hot, humid equatorial), with rainfall between the months of September and May, total annual rainfall exceeds 2000 mm (Alvares et al., 2013).

The main types of soils are Oxisols (58%), Ultisols (11%), Entisols (11%), Inceptisols (10%) and Gleysols (9%) (Schlindwein et al., 2012). In Rondônia, the following types of forest formations are found: Semideciduous Seasonal Forest, Open Ombrophilous Forest, Dense Ombrophilous Forest, Savanna and Fluvial Influence Pioneer Formations (IBGE, 2012).

2.2. Variables and procedures

The deforestation data used in this work were made available by the State Secretariat for Environmental Development (SEDAM) of the State of Rondônia. These data were chosen based on the study of Piontekowski et al. (2014), who evaluated the accuracy of deforestation

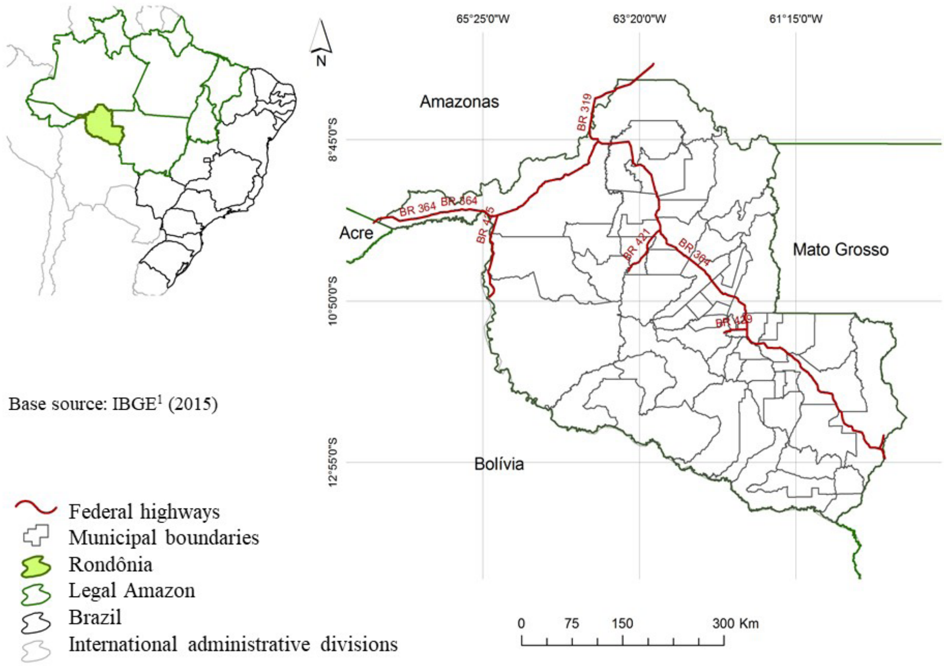

Figure 1. Location of the State of Rondônia. [1]Instituto Brasileiro de Geografia e Estatística (IBGE, 2015).

maps produced by the Instituto Nacional de Pesquisas Espaciais (INPE, National Institute for Space research) and the SEDAM. The authors concluded that SEDAM maps had greater accuracy.

Computer applications used for generation and manipulation of this study's results were the software ArcGIS® 10 and Dinamica EGO software, version 1.8.9, a public domain program with modeling platform, developed by the Center for Remote Sensing at the Federal University of Minas Gerais, Brazil.

The data, originally in vector format, was converted to matrix format with spatial resolution of 120 m, projection UTM, zone 20, Datum WGS84. In addition, were also included the data values relating to bodies of water (hydrography) and native vegetation remaining. Also, maps of the vegetation typologies, types of soils, protected areas, main and secondary roads, rivers, INCRA settlement projects, hydroelectric location, urban areas, altitude and slope were used.

For the set of static variables, categorical maps of vegetation, soil and protected areas were used. For all continuous static variables, the maps of the main distant roads were used, as well as distance of the secondary roads, the main rivers, settlements and dams, urban attraction, altitude and slope.

The procedures for developing the model using the DINAMICA EGO software presents the graphical interface outlined in Figure 2.

2.3. Scenarios for deforestation

The deforestation scenarios for the State of Rondônia were constructed based on deforestation rates observed between 2007 and 2011. During this period, there were large variations in annual deforestation rates, making possible the calibration of the deforestation model in each scenario. It was deforested 225,000 ha in 2007, 128,000 ha in 2008, 60,000 ha in 2009, 42,000 ha in 2010 and 73,000 ha in 2011.

The deforestation rates of the historical series of 2009 to 2011 were selected to model the Business as usual and optimistic scenarios, as they represent the average and low rates of deforestation in the period evaluated based on the moderate values and the low variance of the annual deforestation rates of that period. For the pessimistic scenario, the rate of deforestation observed for the historical series of 2007 to 2011 was used, with an average deforestation rate higher than that of the historical series of 2009 to 2011.

For the scenarios calibration, categorical static variables were considered: maps of vegetation, soil

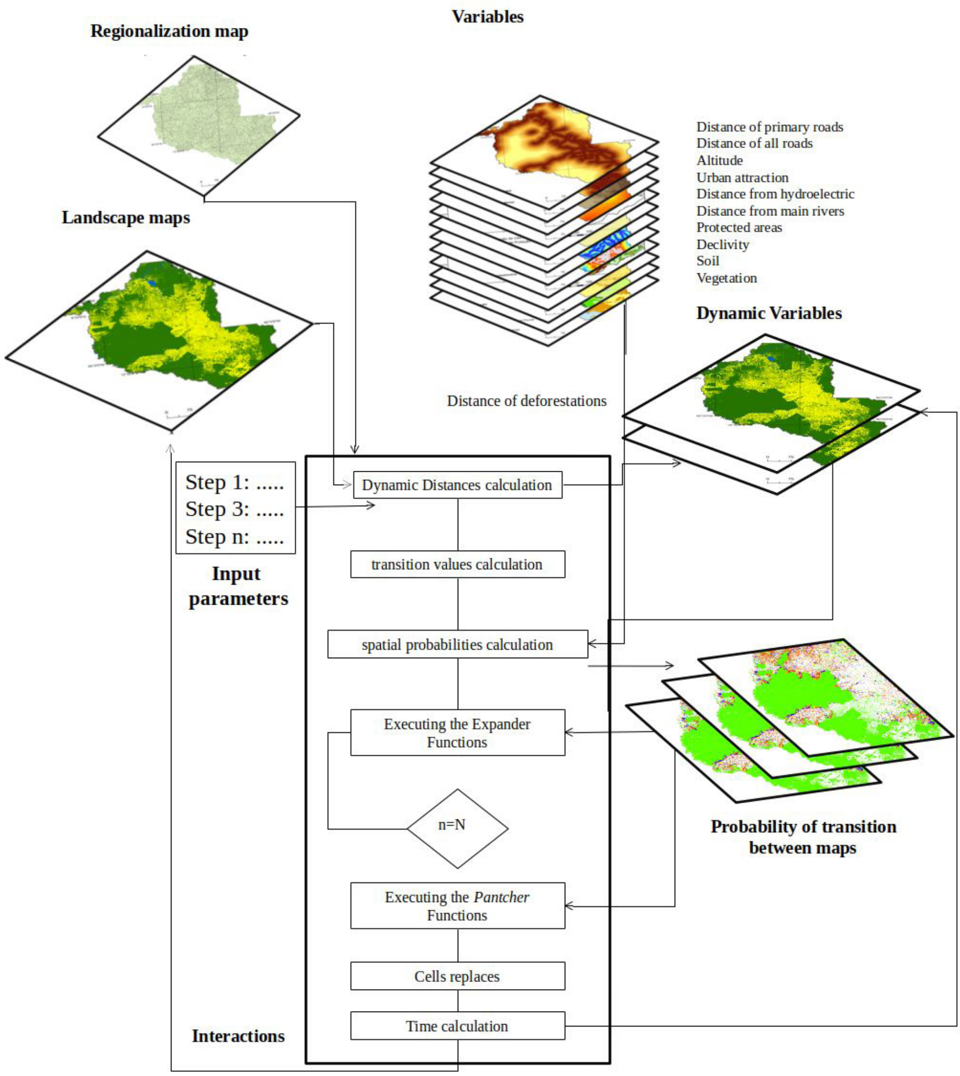

Figure 2. Flow diagram of the DINAMICA EGO program.

and protected areas. As continuous static variables, distance of main maps roads, secondary roads, main rivers and INCRA settlements projects, hydroelectric distance, urban attraction, altitude, and slope (Figure 3), and the distance from deforested areas were used as dynamic variable.

Trends of deforestation in the State of Rondônia were designed for three scenarios:

Business as usual - in this scenario were considered the prospects for keeping the current patterns of deforestation, being called "the same as ever". In this case, the historical series of deforestation that occurred in the years between 2009 and 2011 was used as annual deforestation average rate and for calibration of weights of evidence;

Optimistic - in this scenario the land use guidelines proposed by Zoneamento Socioeconômico-Ecológico do Estado de Rondônia (ZSEE-RO) were considered. Thus, in zones 2 and 3 and within a 10-km range in the vicinity of protected areas, no deforestation should occur, in addition to maintaining the limit of 80% of legal reserve on private properties located in the context of zone 1. In this scenario it was also used the historical series of deforestation observed between 2009 and 2011 to express the annual average deforestation rate and to perform calibration of weights of evidence;

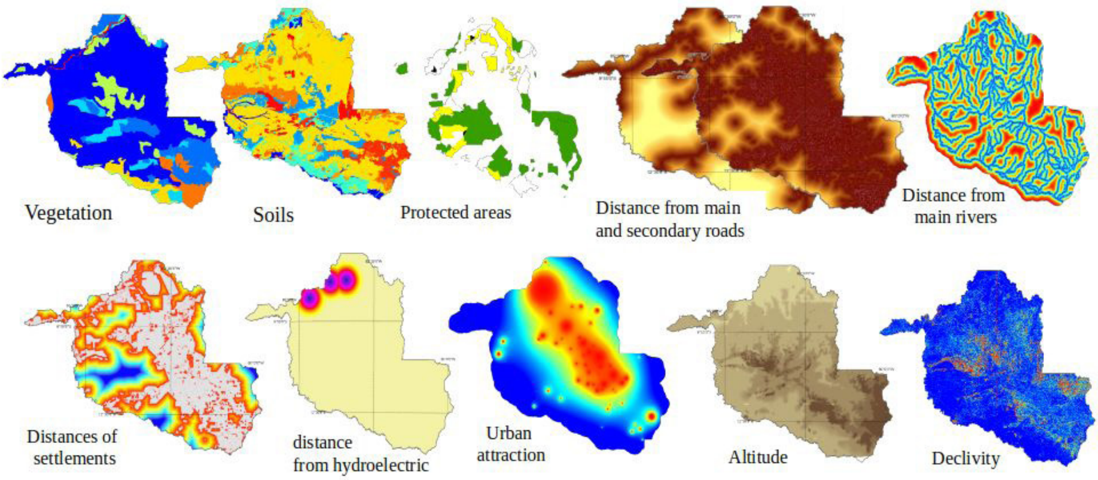

Figure 3. Maps of categorical and continuous variables in the State of Rondônia.

Pessimistic - in this scenario were retained the features of the business as usual scenario, differing only in the historical series of deforestation. In this case, the series of years between 2007 and 2011 was used, since the annual deforestation rates were well above those years. Thus, the high rates of deforestation observed and used in modeling directly influenced the amount of forest deforested in the future. For the three scenarios of this study, the deforestation in the State of Rondônia was designed by the year 2050.

2.4. Scenario modeling

The simulated and projected scenarios were derived from the procedures in five steps in Dinamica EGO software, including the generation of transition matrices, model calibration, creation and model simulation, model validation, and the generation of future scenarios. To simplify the modeling process, each scenario was developed and processed individually. In the process of modeling, transition matrices include a process of estimation of rates transition or changes in the landscape that occurred between the initial and final year of the study period (Soares-Filho et al., 2009).

Given the fact that the continuous static variables require sort parameters, the parameters set was as follows: minimum increment that, in the case of distance maps, are equivalent to the resolution of the cells (120 meters); the maximum and minimum deltas; and angles of tolerance, which measure the angle of deviation from a straight line (Soares-Filho et al. 2009).

These same parameters were applied to dynamic variable (i.e., distance of deforested areas). For the estimates of continuous static variables (slope and altitude), they were reclassified into intervals or ranges of interest. In the case of the variable slope (estimated in decimal degrees), an increase of 1 degree for each range was used. In the case of the variable altitude (estimated in meters), the increment set was 10 m.

With regard to categorical static variables, which were defined by class or category, the calculation of the weight of evidence was made for each specific category on the map. These weights of evidence influence on favorability or restricting the process of the use of new forest areas.

The modeling in Dinamica EGO software contemplates two functions responsible for the process of transition from a State to another cell. The functions are expander and patcher. Patcher defines the sizes of new spots and expander sets fringes of expansion on the basis of a lognormal probability distribution, determined by the mean and variance of each type of spot and fringe expansion (Soares-Filho et al., 2009). In this study, expander had the function to expand deforestation from areas already deforested, and patcher to create new areas of deforestation. The index of isometry was used for each transition classes, generating more fragmented patches (around 0) or more compacted spots (around 2) (Almeida et al., 2008).

Therefore, it is necessary to set the percentage of cells that are going to have changes in each time period of the scenario for the expander. And, by exclusion, the remaining percentage will be set automatically by the software by the patcher. In this work, the percentages defined for expander and patcher were 70% and 30%, respectively. These values were obtained from successive tests with the data to achieve a result that showed an apparent best space simulation deforestation result to the study area.

In this case, the average was 10 ha, while the variance was 20 ha, and the isometry was 1.5 to the expander. In the case of the patcher, the average adopted was 8 ha, while the variance and isometrics were 16 ha and 1.5 ha, respectively. These values were defined after subsequent testing and validation with the database used in the analysis.

After the definition of the parameters presented above, the model was executed to produce the simulated final deforestation map for the year 2011 (Figure 4A). Similarly, a probability map was generated, indicating the most likely areas to be deforested on basis of evidence weights of varying maps (Figure 4B).

The method of constant decay function was used for the model validation, with windows of varying sizes 1 × 1 pixels to 13 × 13 pixels. This method is called Fuzzy similarity in a context of local neighborhood established by Hagen (2003). The validation process is to verify the similarity between the simulated map and a map reference. In this study it was used land use simulated coverage maps for the year 2011 and the deforestation noted for the same year by SEDAM.

The Fuzzy similarity method in Dinamica EGO generates two maps of differences, both obtained from the maps of the initial and final landscape and the simulated map. The different window sizes span the difference maps by getting the Fuzzy value for each central cell of the window, which is always set to 1, whereas the change cells are considered regardless of their exact location in the window. In this case, Soares-Filho et al. (2009) recommends always choosing the minimum similarity to assess the similarity between the maps.

For the three scenarios of this study, deforestation in the State of Rondônia was projected until the year 2050. To evaluate the fragmentation of the forest, the following fragment sizes were analyzed: < 10, 10-20, 20-30, 30-40, 40-50, 50-100, 100-200, 200-300, 300-400, 400 -500, 500-1000 and > 1000 ha.

3. RESULTS

Initially, it is important to note that the results of the three scenarios (business as usual, optimistic and pessimistic) for deforestation until 2050 indicate critical situations in relation to the native forest remaining in Rondônia. In the business as usual scenario, the deforested percentage in Rondônia would increase from 32% (observed in 2011) to 37% (simulated to 2050).

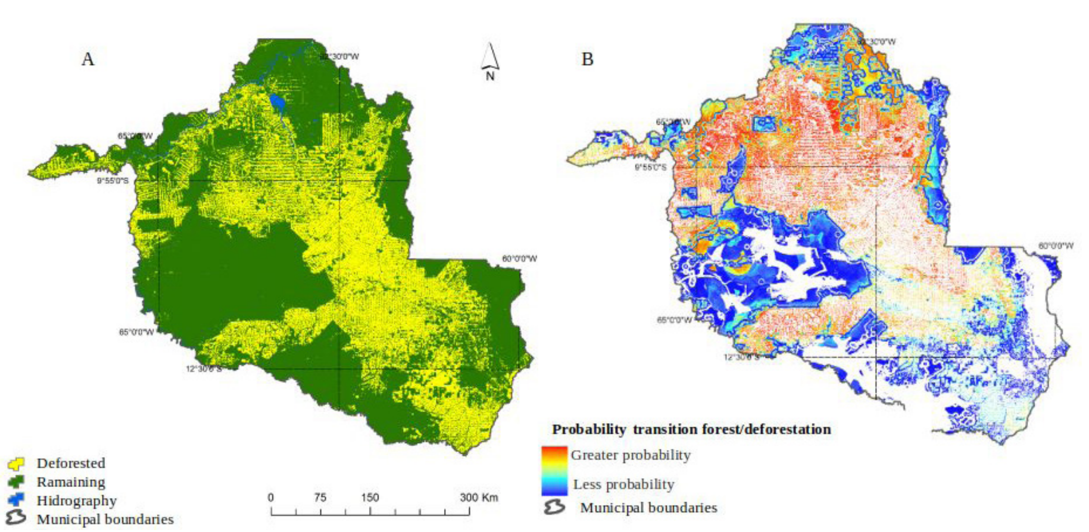

Figure 4. Maps of (A) dynamics of land use and land cover in the State of Rondônia in 2011; (B) probability of deforestation (transition from forest to deforested areas) in the State of Rondônia, estimated based on the historical deforestation series between 2009 and 2011.

When the protected areas (conservation units and indigenous lands) were excluded from the analysis, 54% and 61% of deforestation in the State territory were observed until 2011 and in 2050, respectively (Figure 5A).

On the other hand, in the optimistic scenario, the rates of deforestation in Rondônia would be virtually zero from 2012, being reduced by more than 99% in the period from 2012 to 2050 when compared with the results obtained in the business as usual scenario (Figure 5B). Based on this result, the optimistic scenario indicates that, in theory, the territorial area of Rondônia has already reached the limit of areas liable to deforestation.

Finally, for the pessimistic scenario, the amount of deforested areas is far superior to those of the business as usual scenario mainly due to differences in rates of deforestation between the historical series used for each scenario. Thus, in the pessimistic scenario it was assumed that other 3,543,600 ha of forest would be logged between 2012 and 2050 (Figure 5C). With this result, Rondônia would have 47% of its territory occupied by areas converted from forested to deforested areas, including protected ones.

In the State of Rondônia, forest fragmentation already presented critical results until the 2011 assessment. It was estimated that almost 68% of the forest polygons are areas smaller than 10 ha. About 7% are areas above 100 ha and only 0.9% have areas larger than 1000 ha (Figure 6A).

Based on the simulated result for the business as usual scenario, it was estimated an increase in the number of fragments in the order of 29%, going from 42,775 ha in 2011 to 55,341 ha in 2050. Areas with up to 10 ha would represent about 75% of the forest polygons in 2050, while for those with more than 100 ha, the

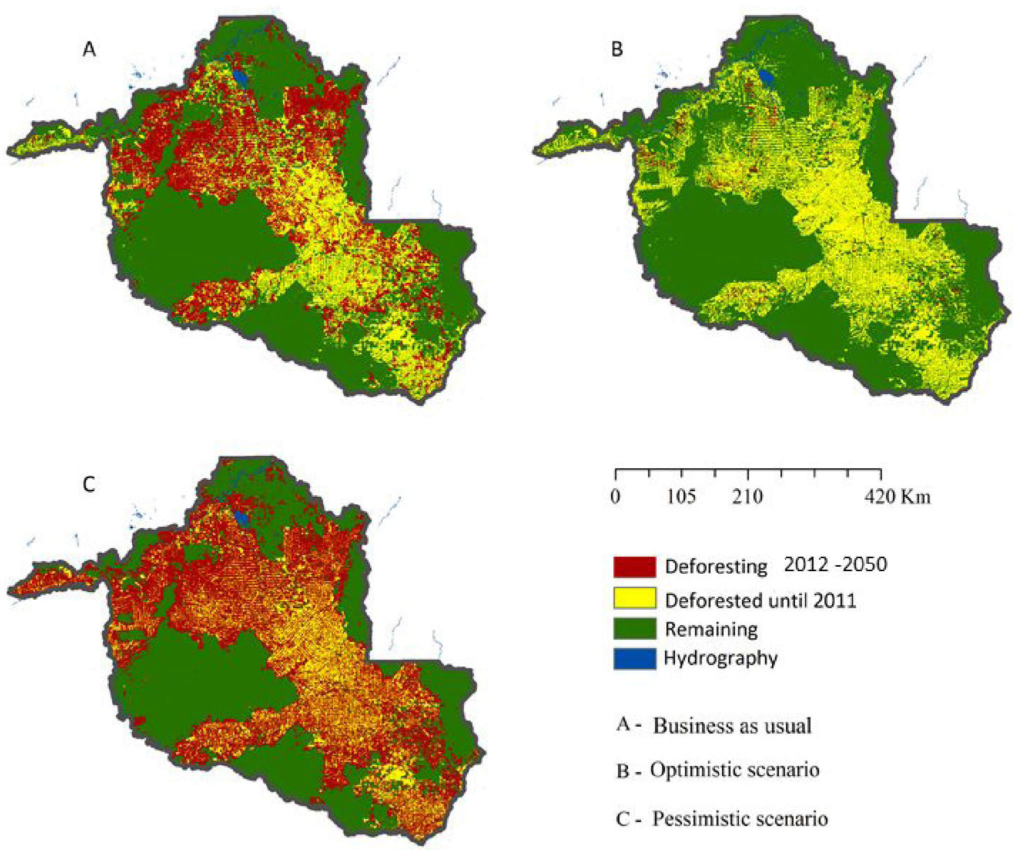

Figure 5. Spatial distribution of deforestation observed until 2011 and the areas that will be deforested in accordance to the simulation of future deforestation between 2012 and 2050, based on the conditions set out in (A) business as usual scenario; (B) optimistic scenario; (C) pessimistic scenario.

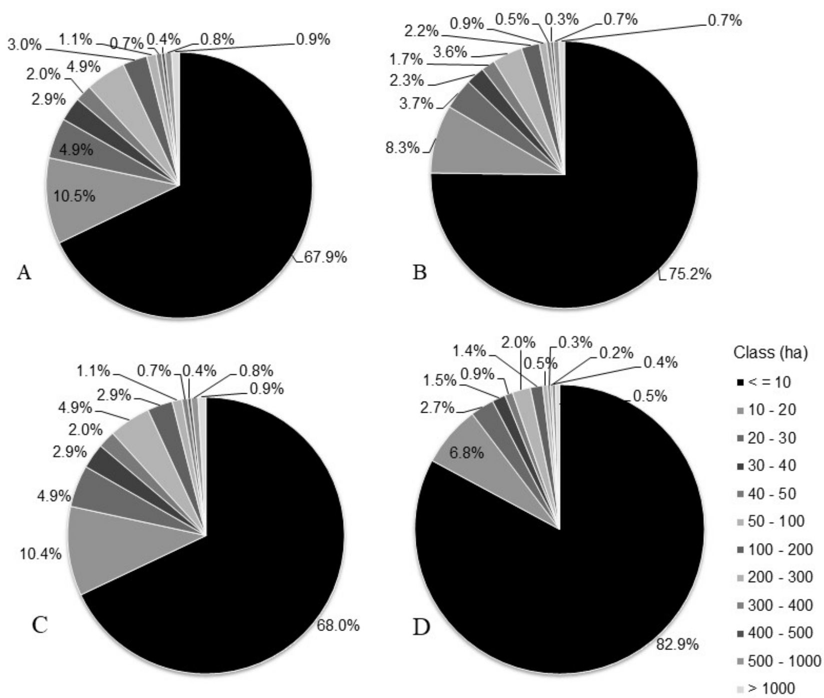

Figure 6. (A) Forest fragmentation in different sizes classes (ha) until 2011. Simulation based on the assumptions set out in the (B) business as usual scenario; (C) Optimistic scenario; (D) pessimistic scenario.

percentage would be reduced to around 5% and areas with more than 1,000 ha would represent only 0.7% of the forest polygons (Figure 6B).

In the optimistic scenario, there would be few changes in the current structure of native vegetation, with only 0.1% increase in area size class (≤ 10 ha). In other two classes (10-20 ha and 100-200 ha), there would be a reduction of 0.1% of these classes, and the other classes would remain stable (Figure 6C).

The simulation for the pessimistic scenario estimated an increase in the number of fragments in the order of 20%, going from 42,775 ha in 2011 to 51,202 ha in 2050. The prediction is that by 2050 about 83% of the forest fragments in the State would be less than 10 ha, and only 0.9% would present areas larger than 500 ha (Figure 6D).

4. DISCUSSION

The existing protected areas in the State of Rondônia could partially contribute to contain the progress of deforestation in the business as usual scenario. In this scenario, the simulation indicates that, outside of protected areas, there would be few areas of remaining natural vegetation after 2050 (Figure 7). Soares-Filho & Rajao (2014) reported that the prevalence of business as usual scenario for the Amazon region would have devastating consequences, with almost complete extermination of forests outside protected areas. In the optimistic scenario, its main characteristic is what determines the ZSEE-RO, where zones 2 and 3 and a buffer zone (10 km) of the protected areas would not suffer deforestation, and in zone 1 would be kept a legal reserve of at least 80,0% in private properties. The optimistic scenario shows that, theoretically, the State of Rondônia has already exhausted their areas for deforestation. The inclusion of protected areas effects and forms of disturbance, other than total deforestation, represented significant advantages when compared to other models that do not include such effects (Fearnside et al., 2009; Soares-Filho & Rajao, 2014; Barni et al., 2015; Elz et al., 2015).

In view of the commitment assumed by Brazil in 2015 during the 21st United Nations Conference on Climate Change (COP 21) to eliminate illegal deforestation in the Amazon until the year 2030, the

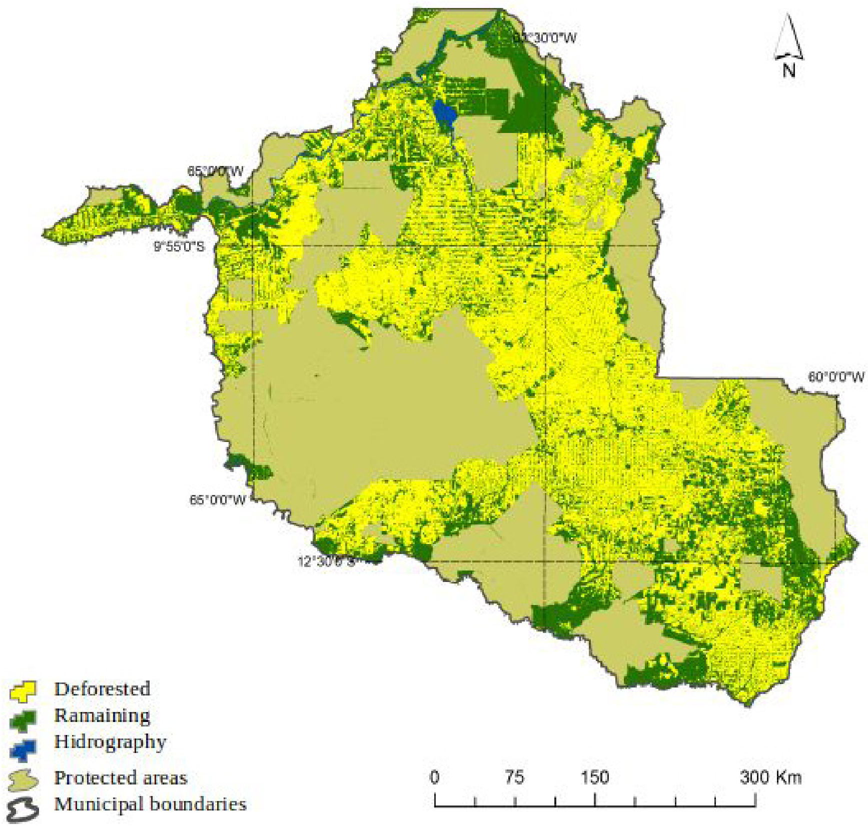

Figure 7. Simulated deforestation until 2050 in a business as usual scenario, highlighting the protected areas in the State of Rondônia.

optimistic scenario converges with the premises adopted in the campaigns to implement public policies with the aim of reducing deforestation.

Annual deforestation rates in the pessimistic scenario would be three times higher than the Business as usual until the year 2050. This simulated high rate is related to the high deforestation rates observed in 2007 and 2008, a period considered as a reference for the simulation in the pessimistic scenario. Deforestation in the Brazilian Amazon, according to Moutinho et al. (2016), did not result in better conditions and quality of life for the inhabitants of the region, which highlights the need for measures to achieve the desired zero deforestation in the coming decades.

With regard to forest fragmentation, in the pessimistic scenario only the class of up to 10 ha would add more area in 2050 than in 2011. The sum of the areas of forest fragments comprising the class of 500 to 1.000 ha would be reduced in the pessimistic scenario by more than 41.0% by 2050, compared to 2011. The effects of landscape fragmentation directly affect vegetation structure. Habitat modification in small remnants establishes a major threat to biodiversity (Haddad et al., 2015; Brawn, 2017), responsible for decreasing the effective number of trees in a population, as well as the number of pollen donors, leading to a reduction in fruiting rate (Maués & Oliveira, 2010).

The remaining minor fragments represented by ecosystems observed in Figure 6 are predominantly influenced by external factors, indicating that, according to Silva & Souza (2014), the smaller the forest area, the greater the interference on the vegetative structure. The accelerated forest fragmentation allows the formation of landscapes with little habitat diversity and isolated fragments with reduced dimensions (Calegari et al., 2010; Santos et al., 2010). In addition to this, fragmentation is one of the factors that most compromises species through the process of isolating one fragment from another, making it difficult to connect habitats (Collinge, 1996).

Other studies that simulated environmental models also found different trajectories. In general, the models provide a prediction as usual, based on the historical change of land use, with alternative environmental and forest management strategies. The viability of these processes should take into account changes in government legislation and regulation and management techniques and economic circumstances that will impact on land cover change (Fearnside et al., 2009; Soares-Filho & Rajao, 2014; Barni et al., 2015; Elz et al., 2015; Malek et al., 2015).

Such consequences of disorderly deforestation over natural resources should be appropriately considered for the future in the Western Amazon (State of Rondônia). The scenarios presented in this study should be considered in order to find alternatives to avoid or minimize the expansion of deforestation simulated here and its potential impacts.

5. CONCLUSIONS

In the business as usual, and with greater intensity in the pessimistic scenario, deforestation predicted over the years from 2012 to 2050 can lead Rondônia to reach higher levels of forest degradation. The potential changes in the original forest cover of the State could have important environmental implications.

Assuming the Business as usual scenario, the expectation of this analysis is that Rondônia deforesting reaches 1,245,100 hectares in the period between 2012 and 2050. In the optimistic scenario, only 1,700 hectares would be deforested, considering the same period. Assuming the pessimistic scenario, a total of 3,543,600 hectares would be deforested in the State.

Fragments of forest remnants would increase by more than 29.0% in the context of the business as usual and 20.0% in the pessimistic scenario. The smallest amount of fragments in the pessimistic scenario in relation to the business as usual is explained by the fragmented forest areas, which are totally extinct in the pessimistic scenario.

For the optimistic scenario, in which prevailed the reduction of opening new areas, prevented by existing public policies in the State, the results indicate that future deforestation rates should be close to zero.

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