



Environmental conservation policy can bend the trend of future forest losses in the oriental Amazon

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Abstract

Scenarios of land use and land cover (LULC) are essential to orient public policies and improve future landscape, but scenarios of LULC at high resolution aiming to guide government actions are still scarce in the frontiers of deforestation in the tropics. This study aimed to explore the historical LULC changes (1985 to 2015) and anticipate how the implementation of the Brazilian New Forest Code could affect the LULC trends for 2050 in a region between Amazon and Cerrado biomes. We classified satellite images from the years 1986, 1990, 1993, 1999, 2004, 2010, and 2015 using a machine learning algorithm and environmental covariates. We projected two scenarios for 2050: scenario 1 representing the future trend based on the past LULC changes using a predictive model, and scenario 2 representing the full implementation of the Forest Code in the region from 2015 to 2050. We found that the forest cover decreased from 29.1 to 21.7% between 1986 and 2015, being converted mainly to pasture areas. In scenario 1, there are expected intense conversions of natural vegetation areas to pastures, resulting in 80% of the basin covered by pasture, 11.3% by forest and 5.1% by cerrado up to 2050. On the other hand, the implementation of Legal Reserves according to Forest Code in scenario 2 can restore the forest cover up to 29.5% by 2050. Although forest area is expected to increase in scenario 2, about 3.7 kha of cerrado still is expected to be converted into pastures. Therefore, the compliance and full adoption of the New Forest Code can help to promote forest protection in this region.

Keywords Brazilian forest code · Future scenarios · Amazon Forest · Forest conservation policy

Introduction

The negative impacts of land use and land cover (LULC) change, especially deforestation, can significantly affect climate dynamics and the functionality of the global ecosystem (Lambin et al. 2003; Ewers and Banks-Leite 2013; Field et al. 2014; Nóbrega

2014; Silva et al. 2018; Silva and França 2018). Forest conservation policies are important strategies to decrease deforestation (Garrett et al. 2018). However, in the tropical areas that are frontiers of agriculture expansion and where occurs intense LULC changes, studies that explore plausible scenarios of LULC changes based on forest conservation policies are still scarce. In these tropical environments, LULC changes are associated with the steady increase of food production, and exploring past changes in these landscapes can help to understand local processes resulted from global markets and analyse future trends (Monteiro and Adami 2016; Lambin et al. 2003; Foley et al. 2005; Dirzo et al. 2014; Myers et al. 2000). Exploring contrasting future scenarios of LULC in these frontier regions can also guide policymakers to develop a sustainable future that combines forest protection and agriculture production.

The assessment of LULC changes is an important tool for monitoring environmental quality and can be a basis to project plausible scenarios (Mubea et al. 2010; Hadeel et al. 2011; Beevi et al. 2015; Rahman et al. 2017). The dynamics of LULC are influenced by political, social, and economic drivers (Browder 1996; Ferraz et al. 2005), but also by

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biophysical factors, such as topography, landslides, droughts, and natural fires (Geist et al. 2006; Gessesse and Bewkwat 2014). The association of remote sensing and machine learning techniques increased in the last decade and can be applied to understand and simulate LULC scenarios, helping the development of more efficient natural resource management policies (Verburg et al. 2004; Ferreira 2006; Verburg and Overmars 2009; Pisiani et al. 2016). Therefore, LULC scenarios can be modeled based on the identification of past patterns of LULC changes over a time scale, conditioned by driving factors.

In the Legal Amazon region, the expansion of agriculture is one of the main drivers of deforestation (Krusche et al. 2005; Ferraz et al. 2005; Diniz et al. 2009). In this area, the conversion of extensive areas of natural vegetation cover into agriculture has been associated with public policies of infrastructure and promotion of agricultural and livestock production (IBGE/IPEA 1994; Becker 2001). The transition areas between the Amazon Forest and the Cerrado biomes are areas of ecological tension, representing environments with a high rate of endemism and the occurrence of rare species (Haidar et al. 2013). These environments are important ecological regions because they have wide biodiversity and habitat for several species (Henry 2003) with unique and specific characteristics (Kark and Rensburg 2006), being sensitive to spatial, temporal (Milan and Moro 2016), and climatic changes (Malanson 1997). The conversion of forests to pastures that started before the 1970s impacted the LULC characteristics of this region and probably affected the functioning of the ecosystem. Therefore, there is a need to investigate the LULC changes in these transition areas to understand the main drivers and project scenarios, allowing us to anticipate the environmental consequences of anthropogenic actions and public policies, such as deforestation and environmental laws.

Environmental legislation in Brazil aims to protect the ecosystems and minimize the consequences of devastating anthropogenic actions in natural vegetation areas (Azevedo et al. 2015). According to article 225 of the Federal Constitution, “everyone has the right to an ecologically balanced environment, a common use for the people and to a healthy quality of life, imposing on the Public Power and the community the duty to defend it and preserve it for present and future generations” (Brasil 2016). The reformulation of the Forest Code instituted by Law No. 4,771, of 15th September 1965 aimed to guarantee the fundamental right to an ecologically balanced environment. The updated version of this law (no. 12.651, of 25th May 2012; http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/12651.htm) was approved by the National Congress in 2012 and establishes changes regarding general rules on the protection of natural vegetation, including permanent preservation areas (APPs, Portuguese acronym) and Legal Reserves. APPs are defined as protected areas, covered or not by natural vegetation, with the environmental function of preserving water resources, the

landscape, geological stability, biodiversity, facilitating the gene flow of fauna and flora, protecting the soil, and ensuring the well-being of human populations. Legal Reserves are areas within a property, where the natural vegetation must be preserved, which size can vary between 20 and 80% of the total area, depending on the biome where the farm is located (Alves 2013). For instance, a farm in the Atlantic forest biome must keep 20% of the area for natural vegetation, while in the Cerrado is 20–35% and in the Amazon biome is 50–80%, depending on the age of deforestation. This also means that farms with less natural vegetation than the percentage established should conduct a forest restoration. However, there are uncertainties regarding the compliance and adoption of these legal instruments without enforcement actions by the government (Brancalion et al. 2016).

This study aimed to explore the historical spatio-temporal dynamics of LULC changes in a transitional area between the Amazon and Cerrado biomes and analyze the effects of the complete adoption of the New Forest Code in the future LULC configuration. Specifically, we aimed to (i) explore the LULC changes between natural vegetation and pastures from 1985 to 2015; (ii) assess the main LULC transitions in this period; and (iii) project LULC scenarios contrasting the future trend based on the past LULC changes with a scenario where the Legal Reserves will be implemented according to the Brazilian Forest Code, delimited by the Rural Environmental Registry (CAR).

Material and methods

Study area

The study area is the river Lontra basin that covers 3870 km² in the north of Tocantins state in the Legal Amazon, Brazil (Fig. 1; Seplan 2002). The climate is tropical (Aw) with dry winter and rainy summer, mean annual precipitation of 1852 mm, and potential evapotranspiration between 1400 and 1700 mm (Alvares et al. 2013; Semades 2011). This basin constitutes an important economic center in the region, represented by the municipalities of Aragominas, Araguaína, Araguañã, Babaçulândia, Carmolândia, Piraquê, Wanderlândia, and Xambioá (Fig. 1). We selected this basin since it is an ecotone zone between the Cerrado and Amazon biomes and is located in the MAPITOBA region, the new frontier of Brazilian agriculture expansion after the 2000s (Graesser et al. 2015). Additionally, exploring the historic and future spatial LULC changes at the basin level can support future hydrological studies and local-specific public policies.

Land use and land cover classification and temporal changes

The spatio-temporal dynamics of LULC between 1986 and 2015 were assessed using Landsat images with 30 × 30 m

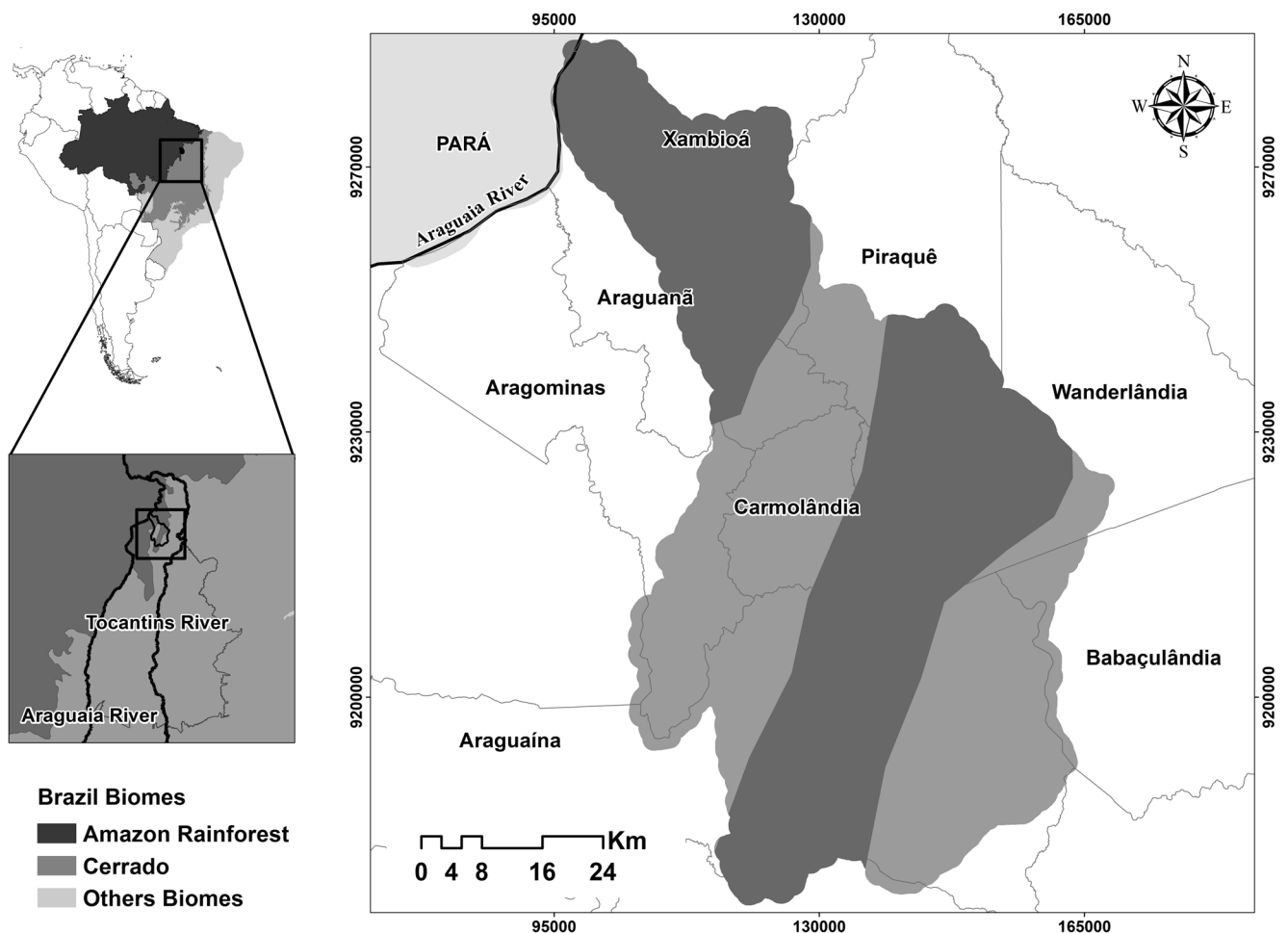


Fig. 1 River Lontra basin highlighting the biomes Amazon Rainforest (dark gray) and the Cerrado (light gray), Tocantins state, Brazil

resolution downloaded from the United States Geological Survey (USGS 2015). Specifically, we classified images from Landsat 5 and 8 resulted from the merge of two scenes (222/65 and 223/65) to cover the full study area for the years 1986, 1990, 1993, 1999, 2004, 2010, and 2015. We selected these years based on the availability of free cloud images. Moreover, aiming to improve the performance of the classification process to identify the LULC classes, we used images from two different seasons for each year analysed. For instance, for 1986, we classified images from the end of the rainy season and the start of the dry season. Detailed information about the selected Landsat images is presented in Appendix 1.

Here, we classified the satellite images into five LULC classes: forest, cerrado *strictu sensu*, pasture, urban area, and water bodies. This process comprised three main steps: (i) sampling the LULC types, (ii) selection of explanatory variables, and (iii) LULC classification using a machine learning algorithm (Appendix 2). First, we randomly selected 606 polygon samples from each LULC class using satellite images. Each polygon was composed of 12 pixels with the spectral characteristics of each LULC class. The spectral patterns

for each LULC class were identified based on known locations of references LULC types acquired during field visits. The database containing the polygons samples from all LULC types was randomly separated in the training dataset (75%) to train the predictive model and validation dataset (25%) to check the model performance.

Second, we selected 99 explanatory variables to predict the LULC classes, with 20 being spectral variables resulted from Landsat images and the others from climate, geology, soil class, climate, topography, and Euclidian distances from urban areas, paved roads and rivers (Appendix 3). In addition to spectral information, we are using environmental information (e.g., soil type) since it can improve the LULC classification performance (Zeferino et al. 2020). To improve the time processing and avoid overfitting, we eliminated correlated variables by applying the dissimilarity analysis for categorical variables (e.g., geology and soil maps) and the randomized dependence correlation (RDC) for the numerical variables (Lopez-Paz et al. 2013). Furthermore, we used the recursive feature elimination (RFE) from the caret package to select the most important variables (Kuhn et al. 2016). We used the random forest algorithm to run the RFE and create a rank of

the most important variables based on the capacity of each variable to increase the accuracy of the predictive model. This process originated a dataset with a smaller number of explanatory variables, resulting in a simpler classification model without significant loss of accuracy for each year analyzed (Appendixes 4 to 10). Finally, we classified the LULC of each year by applying random forest algorithm with the samples and covariates databases. The model accuracy was evaluated based on the Kappa index, and the full process was repeated and improved until we reach adequate values of accuracy (Landis and Koch 1977).

The change detection maps were obtained from the concordance analysis, which consists of overlapping the LULC maps between pairs of years and the assessment of pixel by pixel for each class. The result is a map with pixels representing the absence or presence of LULC changes between a specific period. When there was an agreement between the classes for the same pixel between the period, the value 1 was assigned, otherwise, the value 0 indicates the disagreement between the classifications. The agreement between the maps reveals the absence of LULC changes, while pixels with a zero value indicate the areas where occurred LULC changes between the specified period.

Modelling land use and land cover scenarios

To anticipate plausible future LULC changes in the Lontra basin, we developed two contrasting LULC scenarios for 2050 that project: (i) the future trend of LULC changes based on the LULC changes from 2004 to 2015 (scenario 1), and (ii) the implementation of the Legal Reserve areas following the Brazilian Forest Code (scenario 2).

Scenario 1 represents the future tendency of LULC in 2050 with no further assumption from 2015 and did not include the CAR data. We modeled this scenario considering the past trajectories of LULC changes from 2004 and 2015 using the LULCC package in R software (Moulds et al. 2015; R Core Team 2017). We selected this period to characterize the most recent historical trajectories. A detailed description of the steps to build this future scenario is presented in Appendix 11. We used a predictive model based on an initial condition represented by the LULC map of 2004 and a final condition by the map of 2015. Associating the spatio-temporal LULC analysis with environmental explanatory variables allows us to predict the quantity and location of the possible LULC changes that may occur in 2050. As explanatory variables, we used the spectral bands of satellites 5 and 8, the normalized difference vegetation index (NDVI), soil adjusted vegetation index (SAVI), digital elevation model, soil map, slope map, and Euclidian distances from paved roads, water bodies, and urban areas. The model performance and validation of the predictive model were assessed by simulating a map for 2015 and compared it with the classified map of 2015 using

the agreement parameters under multiple resolutions (Pontius et al. 2011).

Scenario 2 represents a future where the areas for natural vegetation in each farm (Legal Reserve) will be preserved or reforested following the Brazilian Forest Code (Law 12.651 of May 25, 2012). To build this scenario, we used the spatially explicit data from CAR that includes the areas reserved for natural vegetation in the Lontra river basin (SICAR 2017). With this scenario, we can verify the effects of the full adoption of the Brazilian Forest Code in improving and preserving the natural areas in the future.

Results

Land use and land cover changes from 1986 to 2015

The main LULC class in the Lontra basin was pasture, followed by forest and cerrado *strictu sensu* between 1986 and 2015 (Table 1; Fig. 2). Pasture areas increased from 230.6 to 257.5 kha, while the forest area decreased from 128.7 to 96.1 kha between 1986 and 2015. The expressive increase in pasture areas occurred between 2004 and 2010, reaching values up to 272 kha, with a decrease of 16.5 kha in forest areas in the same period. The cerrado had the lowest area in 2010, but in 2015 presented a similar area than in 1986 (79 kha). The urban area increased from 1.8 to 7.2 kha from 1986 to 2015.

The LULC changes between 1986 and 2015 covered 31% of the total area with a mean annual rate of 4.7 kha year⁻¹, mainly in the north of the Lontra basin in continuous and large areas (Appendix 12). A detailed description of spatially explicitly LULC changes between the analyzed years is presented in Appendix 13. The main LULC changes in the basin between 1986 and 1990 occurred in the southeast region. While the rate of LULC changes (29.5 kha year⁻¹) between 1990 and 1993 occurred mainly by discontinuous pixels in all basin, the following period from 1993 to 1999 presented a lower rate of change (16.1 kha year⁻¹) characterized by LULC changes in continuous areas. This pattern was observed also in 2004–2010 and 2010–2015 with the changes of 13.5 kha and 14.2 kha year⁻¹, respectively, mainly in the east and southeast regions, where the main soil type is Arenosols and the natural vegetation is cerrado *strictu sensu* (Appendix 13; Ker et al. 1992).

Main land use and land cover transitions

In the analysis of LULC transitions, we considered only the LULC classes forest, cerrado and pasture, since these classes combined represent 98% of the total area (Table 1). The conversion of forest to pasture was the main LULC transition between 1986 and 2015, with approximately 56 kha (12.7%) of forest being converted to pastures (Fig. 3, Appendix 14). During the period between 2004 and 2010, the conversion of

Table 1 Land use and land cover (LULC) changes from 1986 to 2015 in the Lontra basin, Tocantins, Brazil

LULC	Area (10 ³ ha)						
	1986	1990	1993	1999	2004	2010	2015
Forest	128.7	113.5	125.7	102.5	110.4	93.9	96.1
Cerrado <i>strictu sensu</i>	79.4	74.7	73.1	80.1	90.5	68.1	79.3
Pasture	230.6	248.9	239.6	252.7	235.5	272.1	257.5
Urban area	1.8	3.2	1.7	4.6	3.4	5.8	7.2
Water	1.6	1.6	1.7	1.6	1.5	1.5	1.5

natural vegetation cover to pastures reached almost 57 kha, with 23.5 kha originated from the forest and 33.5 kha from cerrado, with a rate of 9.5 kha year⁻¹. Due to this intense deforestation, 2010 was the year with the lowest forest (93.9 kha) and cerrado covers (68.1 kha). Between 2010 and 2015, pasture area decreased by 14.6 kha, representing 58.3% of the basin in 2015. On the other hand, there was an increase of 13.6 kha in the natural vegetation cover, with 5.7 kha of forests and 7.9 kha of cerrado.

Model performance and projected land use and land cover scenarios

The model applied to project scenario 1 presented an accuracy maximum of 0.25 from 0 to 1 in the figure of merit index (Appendix 15). Pontius Júnior et al. (2018) analyzed 13 LULC changes cases worldwide that used different models (e.g., CLUE, SLEUTH) and scales to predict LULC changes and found similar model performances to our study results. Therefore, considering that our study is predicting LULC changes in a high resolution, the model was satisfactory and can be used to project plausible LULC scenarios for the study area. The projected scenarios for the Lontra basin show contrasting trajectories for LULC for 2050 (Fig. 4; Appendix 16). Scenario 1, representing

the future trend of past LULC changes, shows a reduction by 103 kha of natural vegetation areas (forest and cerrado), which will cover only 16.4% of the basin area by 2050. Specifically, the areas of natural vegetation are expected to decrease by 65.1% compared with 1986 and 58.7% compared to 2015. While in 1986 and 2015, the pasture was covering 52.2% and 58.3%, respectively, the area for grazing will achieve more than 80% of the basin area under scenario 1. On the other hand, in scenario 2, which projects the complete adoption of Forest Code and implementation of Legal Reserves, the forest is expected to increase from 91.1 kha (21.8%) in 2015 to 130.3 kha (29.5%) in 2050. The urban area showed an expansion trend compared to 2015, increasing by around 3.9 kha in scenarios 1 and 4.2 kha in scenario 2 by 2050 (Appendix 16). It is important to highlight that urban growth is expected to occur around the central region of Araguaína, with no significant increase in the other municipalities in the Lontra River basin.

The analysis of transitions between pasture, forest, and cerrado classes between 1986, 2015, and scenario 1 revealed the conversion of a significant area of cerrado to pasture, overwhelming the conversion values from forests to pastures (Fig. 5a). In scenario 2, there is expected regeneration of large areas of forests over a pasture, resulting in an increase of forest cover up to 29.5% of the total area by 2050 (Fig. 5b).

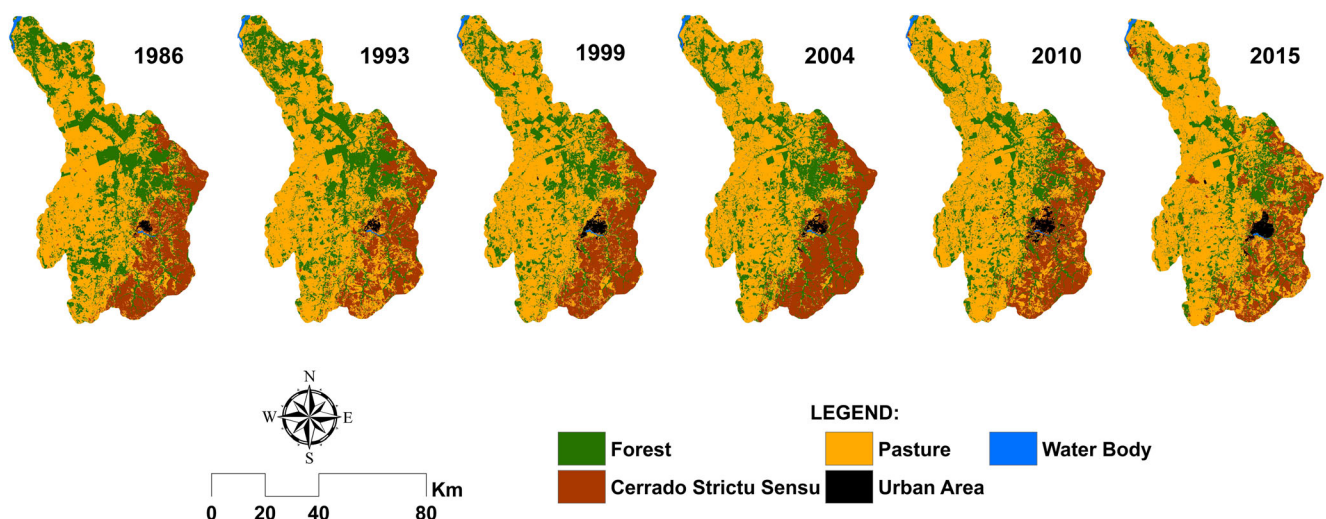


Fig. 2 Land use and land cover from 1986, 1990, 1993, 1999, 2004, 2010, and 2015 of the Lontra basin, Tocantins state, Brazil

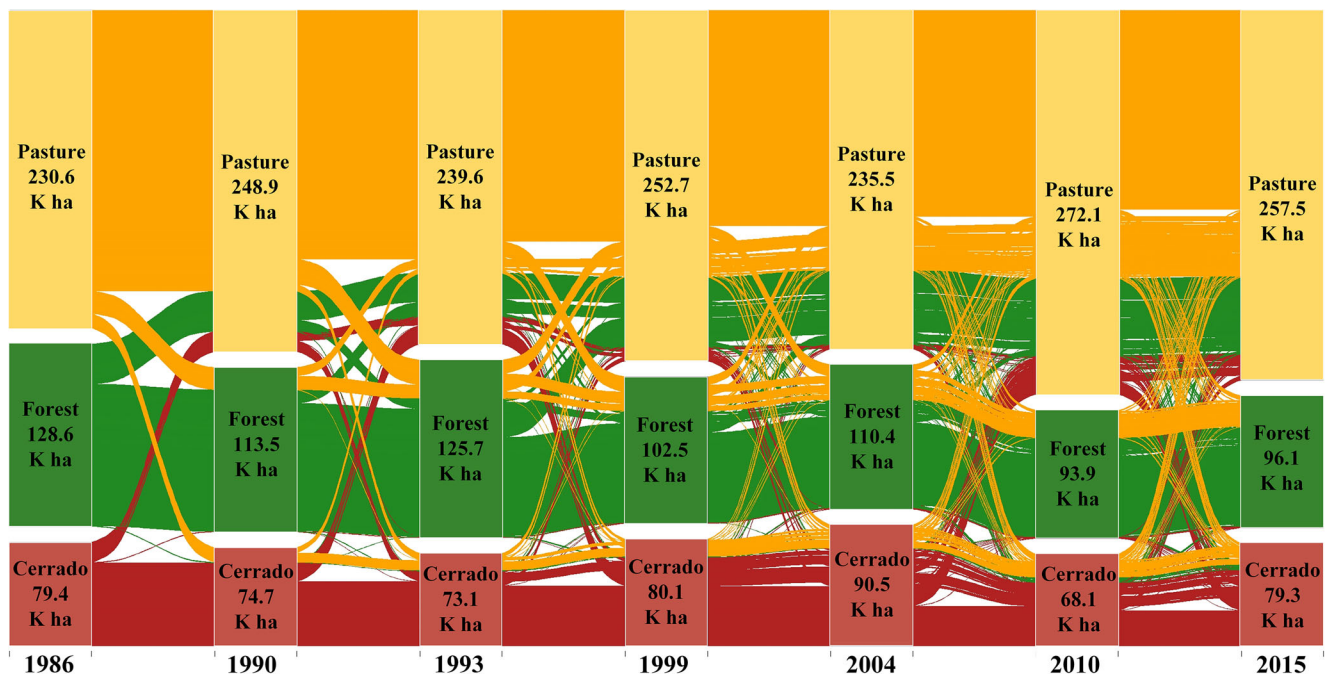


Fig. 3 Land use and land cover transitions (kha) from forest, cerrado *strictu sensu*, and pasture from 1986 to 2015 in the Lontra basin, Tocantins state, Brazil. Each line in the graphic represents the temporal trajectory of one pixel in the study area

Discussion

In this study, we explored the LULC changes from 1986 and 2015 and project future scenarios in a transition region between the Brazilian Amazon and Cerrado biomes. We also analyzed the effect of a forest conservation policy on the

future trend of LULC changes in the region. The key findings are as follows: (i) the forest area decreased from 29.1 to 21.7% of the total area during the study period, being converted mainly in pasture areas, and (ii) the scenario with the implementation of the Forest Code can change the trend of forest losses and restore the forest area to a similar path of 1986.

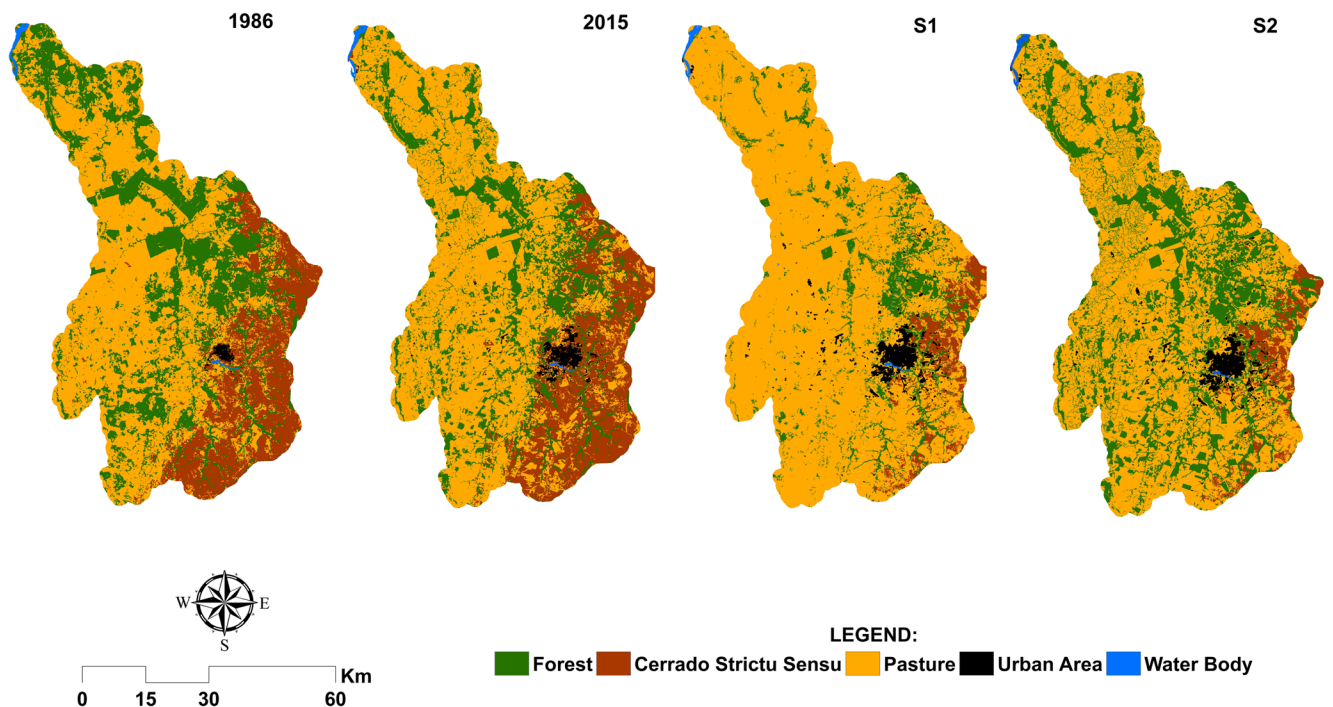


Fig. 4 Historical land use and land cover from 1986, 2015, and projected scenario 1 (S1) and scenario 2 (S2) for 2050 in the Lontra basin, Tocantins state, Brazil

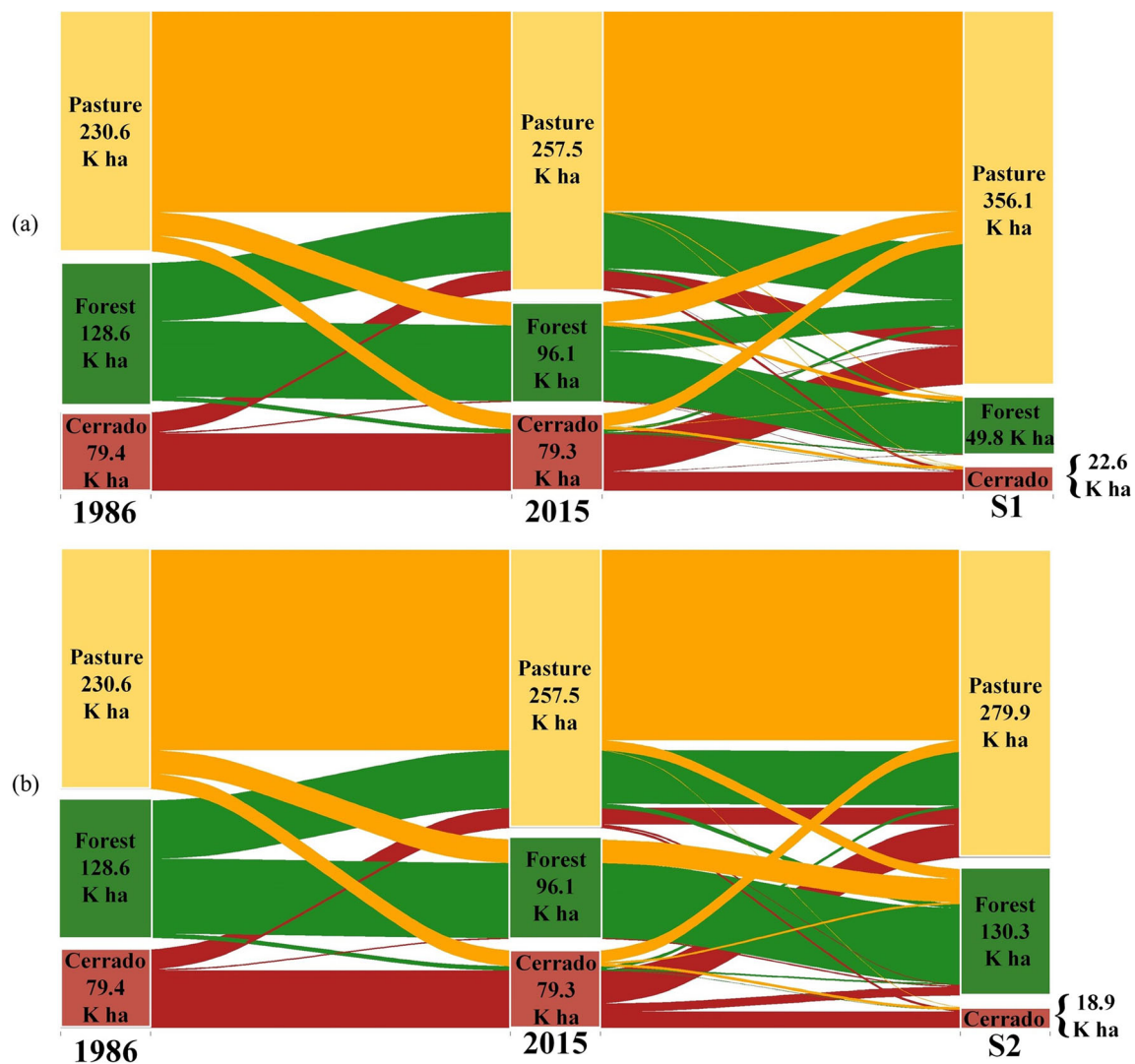


Fig. 5 Historical land use and land cover transitions between forest, cerrado, and pasture from 1986, 2015, and projected scenario S1 (a) and scenario S2 (b) for 2050 in the Lontra basin, Tocantins state, Brazil

Main drivers of past land use and land cover changes

Spatio-temporal changes in forest cover are controlled by environmental characteristics and by the flow of people, goods, and capital, which are influenced by other drivers, such as public policies, socioeconomic factors, market demands, and land reforms (Dong et al. 2011; Alcantara et al. 2013; Kozak and Szwagrzyk 2016). In our study area, different drivers influenced the LULC changes in the specific periods between 1986 and 2015. The decrease of forest and cerrado between 1986 and 1990 occurred in the southeast region and can be associated with the construction of the highway BR-153 in the 1970s, which also have been linked with the alterations of natural vegetation in the Brazilian Amazon (Machado 1998; Alves et al. 1999; Alves 2002; Alves et al. 2009; Santos et al. 2015). The shifts in currency and high inflation during the 1980s brought intense uncertainties in the Brazilian economy, and cattle ranching was considered a stable and attractive

investment until 1994 (De Zen and Barros 2005). However, Brazil had an economic recession between 1987 and 1991 (Fearnside 2006), when farmers were unable to expand deforested areas, neither governments were able to afford the construction of highways and settlement projects. This may explain the decrease in deforestation rates between 1990 and 1993, when pasture decreased despite the economic importance and growth of the livestock sector. During this period, the forest increased to 125.7 kha and almost reached the size of forest area in 1986. The timber sector was one of the most profitable economic activities in the 1990s (Homma 2011) and surpassed livestock. The peak of timber exports occurred in 1992, when more than 70% of the wood were originated in the north of the country (IBGE, 1997), linking the abandonment of pasture areas to the profitability of timber activities. These results suggest that pastures were abandoned for investment in more profitable activities between 1990 and 1993, favoring the regeneration of natural vegetation.

In the period between 1993 and 1999, the Lontra basin witnessed again an increase in pasture areas (14.6 kha), occupying more than 57% of the basin's territory in 1999. The growth of pasture areas occurred at the cost of approximately 42.6 kha of forest cover. The economic stabilization plan implemented in 1994 had a positive effect on the economy, with measures such as the increase of agricultural finance-credit for farmers. The credit for farmers was also an incentive to deforest new areas (Fearnside 2006). On the other hand, the creation of the Environmental Protection Area (APA, Portuguese acronym) of the Araguaína Springs, in 1999, contributed to the increase of 10.4 kha of cerrado *strictu sensu* between 1999 and 2004. However, the irregular urban growth in the APA (Silva 2014) and the pressure of pasture expansion led to the loss of cerrado *strictu sensu* areas in the following periods. In addition, the development of new technologies, markets and the segmentation of production and consumption, favored structuring the beef production chain for the national and international markets (Polaquini et al. 2006).

During the period between 2004 and 2010, the conversion of 57 kha of natural vegetation cover to pastures was promoted mainly by the economic benefits of the livestock market. The world scenario of beef production from 2000 favored the Brazilian market compared to other producing countries. In Europe, the "mad cow" disease brought several problems, while Argentina was facing an economic and health crisis, due to outbreaks of foot-and-mouth disease. These facts contributed to the increase of Brazilian beef exports, which was linked to the increase in the demand for pasture areas since the cattle herd in Brazil is mostly conducted under an extensive system (De Zen and Barros 2005; Polaquini et al. 2006).

Between 2010 and 2015, the decrease of pasture and increase of forest occurred mainly in the southeast of the basin, where the process of use and occupation was still reduced. In this region, the cerrado occurs predominantly over the Arenosols, where there are species resistant to water stress and with low nutrient requirements. The occupation of this region with pastures began after the areas with Ferralsols were converted to pastures, usually under the Amazon forest and some areas of Cerrado. However, the high demand for inputs to overwhelm the poor chemical quality of soil in this region of cerrado lead to pasture abandonment, resulting in the regeneration of natural vegetation in this last period.

Future land use and land cover developments and uncertainties

The analysis of future LULC scenarios is an important tool to explore the effect of public policies on the environment. In scenario 1, deforestation is expected to increase and the basin LULC will be characterized by 11.3% of forest and 80% of pasture in 2050. Scenario 1 projects an increasing trend in the conversion rates from forests to pastures, following the

demand for food and population growth estimated for 2050 (FAO 2009; Godfray et al. 2010; Tilman et al. 2001; Tilman et al. 2011) and due to the decline in soil fertility and increased degraded areas (FAO and ITPS 2015). Global estimates of LULC for 2050 reveal that agriculture and pasture will be responsible for the loss of 10^9 ha of natural ecosystems in developing countries, which corresponds to half of the areas suitable for agriculture in the world (Alexandratos 1999; Tilman et al. 2001). The expansion of agriculture and pastures will occur predominantly in the Latin America and Central sub-Saharan Africa regions, due to the availability of soils for agricultural activities (Tilman et al. 2001). Our results demonstrate that the implementation of Forest Code and the conservation areas, forest areas can increase up to 29.1% of the basin by 2050. Thus, this LULC scenario shows that the implementation of conservation policies can reduce forest losses in the future.

The impacts of LULC changes will be more prominent in scenario 1 than in scenario 2, due to the intense removal of forests. Although forest area is expected to increase in scenario 2 compared with the period between 1986 and 2015, about 3.7 kha of cerrado still will be converted into pastures. This shows that the delimitations of legal reserves for nature protection in the Brazilian law protect more the tropical forests in this transition region, and the anthropogenic pressure will be redirected to the cerrado vegetation. This projected indirect effect of LULC changes has been reported in the same region of this study, where efficient policies to contain deforestation in the Amazon may be caused by indirect LULC changes with an increase of deforestation in the Cerrado (Arvor et al. 2017). This indirect effect also has been pointed at a higher scale with the migration of Brazilian farmers to other countries in Latin America where the lands are cheaper and with restrictive forest laws (Graesser et al. 2015). Then, scenario 2 can be used to identify these vulnerable natural areas of cerrado and guide government actions aiming at the conservation of this biome (Schielein and Börner 2018).

The drastic reduction in the natural vegetation cover of the Lontra River basin projected in scenario 1 may cause damage to the ecosystem and plant communities (Laurance 2000). Indeed, this process will increase the habitat fragmentation and isolation of natural areas, reducing the gene flow in the region. Concomitantly with the impacts on vegetation, the survival of pollinators, dispersers, folivores more sensitive to fragmentation, such as specialist pollinators, rare or endemic species will be also negatively affected (Scariot et al. 2003). In tropical forests and savannas, the conversion of large areas to pastures or monocultures, promotes isolation of natural habitat fragments, leading to changes in the microclimate, structure, and dynamic vegetation processes. These factors change the environment, which becomes inappropriate for the survival and coexistence of several species (Scariot et al. 2003; Rodrigues and Nascimento 2006). The effect of climate

change associated with species invasions and habitat fragmentation can exacerbate losses of diversity, since many species may be unable to migrate between fragments to achieve better soil types and climatic conditions.

Our scenario 1 project the trends in LULC changes based on the recent historical developments and do not comprise several uncertainties about the future alterations in global trade, society awareness, advances in technological practices, and climate changes up to 2050. A large part of forest loss (62%) globally between the period 2005 and 2013 was attributed to the expansion of agriculture (e.g., cattle meat, forestry products, oil palm, cereals, and soybeans) to meet, at large and increasing share, the international demand (Pendrill et al. 2019). Then, if changes in the supply-chain occur with the consumers worldwide avoiding the use of products that originated from deforested areas, the private companies would intensify the restrictions in the acquisition of commodities from these areas, forcing the farmers to compliance with the environmental laws and adopt forest recovery and protection (Lambin et al. 2018). Using deforestation rates, land use maps CAR data, and Brazil's agricultural production and exports data, Rajão et al. (2020) linked illegal deforestation on individual rural properties to exports of soy and beef to the different EU countries. Such studies can contribute to raising awareness between private companies and consumers. Other factors that can influence the future trend in forest losses are the advances in technology practices, which can improve agriculture intensification and reduce the pressure in natural environments (Garrett et al. 2018). Future climate changes are another source of uncertainty for the future LULC in the studied region, since the increase in the frequency of longer periods of drought can be a high economic risk to the implementation of new agriculture areas. Therefore, several factors may affect the trend of forest losses in the presented scenario 1 and to decrease deforestation in the future is necessary cooperation between civil society and private companies with the government public policies.

Conclusions

In this study, we explored the past and future LULC trajectories under contrasting scenarios in a transition region between Amazon and Cerrado biomes in Brazil. In this region, deforestation decreased the forest cover from 29.1 to 21.7% between 1986 and 2015. This period was characterized by the conversion of forest to pasture, induced mainly by the success of the beef market after the 2000s.

Continuous deforestation is expected and may be intensified in the future, under the scenario that represents the trend developments between 1986 and 2015. This will result in pasture areas covering 80% and forest cover 11.3% of the basin area in 2050. Contrary, the implementation of a public

policy for forest conservation can restore the forest cover to 29.3%, the same level as in 1986. Therefore, the projected scenarios highlight the importance of environmental protection for the future environment, and can orient the development of environmental conservation measures and strategies by policymakers. Future studies should assess the effect of LULC transitions (e.g., forest to pasture) on biodiversity and ecosystem services, improving our capability to design more sustainable scenarios.

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