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The role of the rural settlements in the Brazilian savanna deforesting process

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ABSTRACT

Although the drivers of deforestation in Brazil are relatively well known, there is still limited understanding of the role of family farm-based rural settlements in land cover changes, particularly in the Brazilian savanna. This research aims to identify land use patterns within rural settlements and examine how they are influenced by regional dynamics. The study is based on GIS techniques and satellite image classification (Landsat 5-TM and RapidEye imagery), combined with geo-referenced fieldwork data in three different regions of the State of Goiás. The results reveal that the deforestation arrangement within the studied rural settlements is very similar to the deforestation found in the surrounding regions. As a positive outcome, the rural settlements have a higher share of remnant vegetation when compared to the surrounding areas, but this is still concentrated within legal reserves. We conclude that the changing patterns of rural settlement land cover are highly influenced by regional dynamics.

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Land reform; family farming; deforestation; Cerrado; GIS

1. Introduction

Although the drivers of deforestation in Brazil are relatively well known (Ferreira, Ferreira Jr., Latrubesse, & Miziara, 2013; Gibbs et al., 2015; Nepstad et al., 2014), there is still limited understanding of the role played by family farm-based rural settlements in land cover changes (Barni, Fearnside, & Graça, 2012). The rural settlements in Brazil are the outcome of the land reform process instituted in 1964 by governmental agencies to provide land to landless farmers, often organized in grassroots organizations (Bergamasco & Norder, 1996). According to the National Institute for Colonization and Agrarian Reform (INCRA), by 2015, there were 969,296 such farm families in 9,277 settlements scattered throughout Brazil, working the most diverse array of agricultural production (INCRA, 2015). Roughly one in every five farm families in Brazil is now a family 'settled' by the government (Medina, Almeida, Novaes, Godar, & Pokorny, 2015) and the environmental sustainability of the rural settlements is fundamental for the maintenance of the land reform policy.

There is still a controversy in the literature as to how settled farmers impact deforestation (Brandão & Souza, 2006; Ludewigs, D'antona, & Brondízio, 2009). A considerable number of studies have revealed high rates of deforestation in settlements that are part of the land reform policy (Batista, 2009; Brandão & Souza, 2006; Caldas et al., 2010; Homma et al., 1998). On the other hand, other studies argue that deforestation in rural settlements tends to be similar in areas in surrounding regions outside settlement borders (Alencar et al., 2016; Calandino, Wehrmann, & Koblitz, 2012; Macedo, Darnet, Thalês, & Poccard-

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Chapuis, 2013; Santos, Steagall, Veronese, & Machado, 2009; Sparovek, 2003), with good examples of the protection of natural resources within the settlements (Godar, Tizado, & Pokorny, 2012; Laris & Dembele, 2012; Maywald & Marçal Júnior, 2013; Oliveira, 2013).

Nonetheless, in the Brazilian savannas, there is still a limited understanding of the deforestation trend within the rural settlements, the role the rural settlements play in regional deforestation, and how deforestation is influenced by surrounding agricultural activities (Diniz, Oliveira Junior, Trompieri Neto, & Diniz, 2009; Maywald & Marçal Júnior, 2013; Oliveira, 2013).

The Amazon region has received the most attention in the efforts to curb deforestation (Nepstad et al., 2014) as well as the growing interest in understanding the role played by rural settlements in the deforestation process (Alencar et al., 2016). However, little is known about the Brazilian savanna region (locally known as Cerrado biome), where most land conversions are led by export-oriented cash-crop farmers and large-scale cattle farmers (Ferreira, Ferreira Jr., Latrubesse et al., 2013; Rada, 2013). In general, due to the expansion of agricultural-related land use, the Brazilian savannas are experiencing a continued net loss of remnant vegetation compared to other areas (Arraes, Mariano, & Simonassi, 2012; Beuchle et al., 2015; Grecchi, Gwyn, Bénié, Formaggio, & Fahl, 2014).

This is particularly relevant in Goiás, which is a central and most representative State in the Cerrado region, with 97% of its territory originally covered by the savanna vegetation (Redo, Aide, & Clark, 2013). Considering the amount of remnant vegetation and the occupation and land use deterministic trends, experts estimate that in Goiás alone between 58.000 and 79.600 km^2 of conversions may occur in the near future (Ferreira et al., 2013), equivalent to 17–23% of this State.

As a means to curb deforestation in Brazil, the Brazilian forest code requires landowners to conserve native vegetation in their rural properties, setting aside a legal reserve that is equal to 20% of the property area in the Cerrado and 80% in the Amazon (Soares-filho et al., 2014). There is, however, limited respect by the farmers for the legal reserves. In 2014, for example, only 9% of the properties in the State of Mato Grosso and 4% of the properties in the State of Pará had the mandated forest cover as defined in the forest code (Gibbs et al., 2015). Nearly 12.5% of recent deforestation in Mato Grosso and 16% in Pará occurred in the legal reserve areas (Gibbs et al., 2015). In the State of Goiás, preliminary information from the Rural Environmental Registry (CAR) reveals that as of May 2014 about 90% of the legal reserves were deforested or partially deforested (SICAR, 2016).

In this context, this research aims to help better understand the deforestation trend within rural settlements. It considers the following questions: (1) What role do the rural settlements play in the deforestation in the Cerrado? (2) How is this influenced by the surrounding agricultural activities? The specific goals of this study are: (a) analysis of the evolution of deforestation in rural settlement areas and their surroundings; (b) determination of the evolution of the native vegetation in the rural settlements' legal reserve areas; and (c) analysis of the evolution of agricultural activities developed in rural settlements and their surroundings.

2. Methodology

2.1. *Study area*

In 2015, there were about 1,800 rural settlements in the Cerrado. Of these settlements, 76% were acquired by expropriation of large farms considered unproductive. An unproductive farm is one that does not comply with the minimum livestock criterion or crop productivity standard in at least 80% of its farm area with potential for agricultural production, as defined by INCRA. As for the size of these settlements, 51% have up to 2,000 ha, while 35% have between 2,000 and 6,000 ha and 14% have more than 6,000 ha (INCRA, 2015). In the Cerrado settlements, 88% followed the conventional settlement project model of plot division, locally known as PA (*Projeto de Assentamento*) (INCRA, 2015). This meant that in terms of households, 47% of the settlements have the capacity to settle up to 50 families and 37% have the capacity to settle between 50 and 150 families. Specifically, in the State of Goiás in 2015, there were 421 rural settlement projects, housing 22,299 families (INCRA, 2015).

To represent the diversity of settlements, different regions in the State of Goiás were identified according to their main agricultural production: large-scale crop farming, characterized by high production of soybean and maize; large-scale livestock farming, characterized by high concentration of pastures for cattle-raising, and small-scale diversified farming, characterized by farms smaller than 100 ha. This characterization was based on official data provided by the 2006 Agricultural Census and the 2012 Municipal Agricultural Production, gathered by the Brazilian Institute of Geography and Statistics (IBGE), and made available in its aggregated database (Sistema de Recuperação Automática [SIDRA], 2013).

In each region, rural settlements were selected according to the following criteria: date of settlement creation, existence of legal reserve areas in the original settlement, and the size of the settlement, which needed to be large enough to allow assessments based on satellite images. Only settlements where families had actual access to their plots after July 2000 were considered as case studies as a means to allow an analysis of the land cover 10 years before the settlement and 10 years after the settlement.

The Umuarama settlement in the municipality of São Miguel do Araguaia was chosen to represent the far north of Goiás' large-scale livestock farming region; the Chê settlement in the municipality of Itaberaí was chosen to represent the center of the State's small-scale diversified farming region; and two rural settlements, Rio Claro and Santa Rita, considered here as one single settlement due their size and proximity, both in the city of Jataí, were chosen to represent the southwest of Goiás' large-scale crop farming region, as it was not possible to find one single settlement that was large enough for the analysis. Table 1 presents the characteristics of the selected settlements, while Figure 1 shows their locations and surrounding regions.

In 1998, (year of evaluation by INCRA for expropriation) the farm where the Umuarama settlement was created had 1.149 ha of annual crops, 1,584 ha of pasture, 2,657 ha of native vegetation, and 237 ha under permanent preservation. In 1995, (year of evaluation by INCRA for expropriation), the farm where the Che settlement was created had 662 ha of annual crops, 1,520 ha of pasture, 290 ha under permanent preservation, 818 ha of legal reserve, and 807 ha without any use. In 1997 (year of evaluation by INCRA for expropriation), the farm where the settlements Rio Claro and Santa Rita were created had 698 ha of pasture, 660 ha without any use, 77 ha under permanent preservation, and 193 ha of legal reserve (INCRA, 1998–2001).

After selecting the settlements, the size of the areas surrounding each settlement was defined by a 30 km radius from the perimeter of each settlement. An exception was made in the large-scale crop farming region settlements, in this case with a radius of 20 km, given the existence of a distance of 10 km between the Rio Claro and Santa Rita settlements. This procedure aimed to standardize the areas for all studied locations (i.e. circa of 30 km buffer). Figure 1 shows the surrounding areas of these settlements.

The selection size of this buffer was based on a sensitivity analysis in which we evaluated the deforested areas 5 km away from the settlement borders. We found that the percentage of the deforested area was not meaningfully influenced by the distance to the settlement in comparison with the percentage of deforested area within the settlement. Therefore, the buffer zone was established as 30 km, as presented in Table 2. Using the 30-km zone allowed us to avoid the influence on the settlements of overly large buffer zones of the surrounding regions, and vice versa.

2.2. *Database and analytical procedures*

In order to detect the changes in forest cover and land use in the rural settlements and their surroundings (as illustrated in Figure 1), we used a set of satellite images from Landsat 5-TM (30 m spatial resolution, paths/rows 223/69 and 222/69, 222/71, 223/72) covering the three settlements for the years 1990, 2000, and 2010. Images were always taken in July since this is the best month in Cerrado to avoid cloud cover.

As a first step of the analysis, with geo-referenced Landsat images arranged in a geographic database, we applied a supervised classification algorithm (maximum likelihood) using ENVI

Table 1. Characteristics of selected rural settlements.

Settlement project	Expropriation date	Official creation of the settlement	Beginning of subdivision of plots	Actual access by the families to the plots (estimated)	Area of the settlement (ha)	Number of families in the settlement	Average hectares /family
Large-scale livestock farming region	04 November 1998	27 October 1999	April 2000	August 2000	5.680	121	37
Small-scale diversified farming region	02 April 1998	06 August 1998	July 2000	November 2000	4.222	117	28
Large-scale crop farming region (Rio Claro)	20 October 1997	20 August 2001	October 2001	December 2001	667	17	30
Large-scale crop farming region (Santa Rita)	20 October 1997	04 May 1998	February 2000	August 2000	961	23	33

Source: INCRA/Goiás.

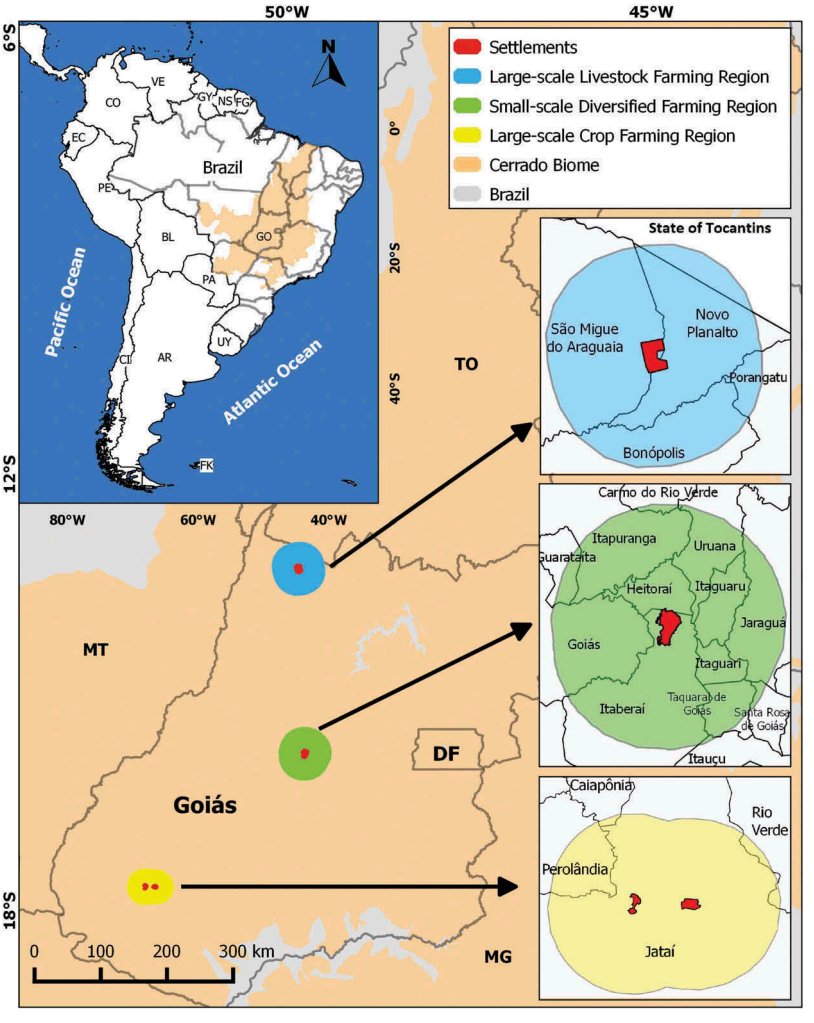


Figure 1. Location of the selected settlements and their surroundings. Cartographic projection: Plate Carree/DATUM – SIRGAS 2000. Source: INCRA and SIEG.

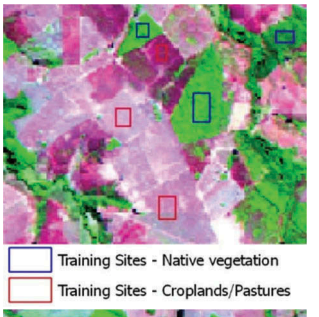
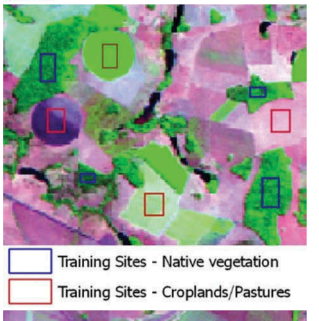
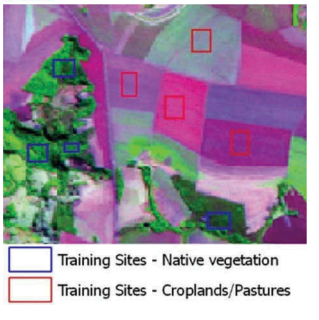
Table 2. Sensitivity analysis for the percentage of deforestation in the surroundings of settlements.

Year	Settlement project	Deforestation inside the settlement (%)	Deforestation in the surroundings of settlements (%)						
			5 km	10 km	15 km	20 km	25 km	30 km	Average
1990	Large-scale livestock farming region	45.94	58.52	51.20	49.47	47.09	47.51	48.44	50.37
	Small-scale diversified farming region	51.97	67.32	73.41	72.56	68.23	68.71	69.54	69.96
	Large-scale crop farming region	45.74	63.51	62.74	64.42	68.46	–	–	64.78
2000	Large-scale livestock farming region	56.30	71.83	67.77	66.46	63.78	63.98	65.01	66.47
	Small-scale diversified farming region	62.57	75.64	80.93	80.01	75.48	76.11	77.26	77.57
	Large-scale crop farming region	64.34	74.30	74.18	74.58	77.66	–	–	75.18
2010	Large-scale livestock farming region	65.66	79.01	74.98	73.91	71.36	71.98	72.86	74.02
	Small-scale diversified farming region	66.24	79.96	84.80	83.36	78.82	79.40	80.87	81.20
	Large-scale crop farming region	71.22	78.66	78.07	78.27	81.21	–	–	79.06

Source: estimated by the authors.

software (Environment for Visualizing Image) to produce a temporal thematic map. The following land use classes were created: water, urban area, native vegetation, cropland, and pasture. Table 3 presents the amount of training sites used for categorizing each class.

Table 3. Number of training sites for classifying the images.

Settlement project	Land use class	Training sites/year 1990	2000	2010	Example
Large-scale livestock farming region	Native vegetation	172	218	160	
	Croplands/pastures	234	191	157	
Small-scale diversified farming region	Native vegetation	278	260	270	
	Croplands/pastures	169	299	218	
Large-scale crop farming region	Native vegetation	228	309	245	
	Croplands/pastures	183	211	261	

Source: estimated by the authors. Omitted classes: water and urban area.

The derived classification was further adjusted by visually comparing the images and the derived classification using the following parameters: color, shape, texture, tone, and size of the objects in the images. This allowed correction of some mistakes generated by the semiautomated classification algorithm in the image processing stage. Table 4 follows the respective accuracy results of the classification including the Kappa coefficient according to prior sample areas in the Cerrado region (Sano, Rosa, Brito, & Ferreira, 2010; Trancoso, Sano, & Menezes 2015).

Subsequently, the deforestation rate (TXD) of the analyzed time steps was ascertained as shown in Equation 1.

$$TXD = (AD2 - AD1) * 100/TA, \quad (1)$$

where:
TXD = deforestation rate;
AD1 = area deforested in Time 1 (year *X*) of analysis;
AD2 = area deforested in Time 2 (year *Y*) of analysis;
TA = total area

Table 4. Accuracy of images classification.

Year	Settlement project	Kappa coefficient
1990	Large-scale livestock farming region	0.8212
	Small-scale diversified farming region	0.9258
	Large-scale crop farming region	0.7798
2000	Large-scale livestock farming region	0.8180
	Small-scale diversified farming region	0.6003
	Large-scale crop farming region	0.9477
2010	Large-scale livestock farming region	0.8724
	Small-scale diversified farming region	0.8157
	Large-scale crop farming region	0.7938

Source: estimated by the authors.

This study analyzed deforestation, defined as the loss of any kind of native vegetation that occurred in the settlements and their surroundings. Once identified in the 1990 scene, the deforested polygons remained and were added to the deforested classified areas in the 2000 and 2010 scenes.

As a second step, a new classification of Landsat imagery was carried out only within the rural settlements[1] (perimeter of the settlements and their legal reserves provided by INCRA), in order to verify the occurrence of vegetation regrowth in the deforested areas including the areas of legal reserves. For this analysis, we used a segmentation algorithm created via the Feature Extraction tool available in the ENVI software, based on edge algorithms (edge parameter = 70.0) and the full lambda schedule (merge parameter = 70.0), with the texture kernel size equal to 3. In this stage, we also used the RapidEye satellite imagery from 2011, with 5-m spatial resolution for better discriminating the land use type within the settlements (as well as to validate the classification of the Landsat 5-TM imagery, http://geocatalogo.mma.gov.br) (see Figure 3).

As a third and final step of analysis, aiming to better discriminate between croplands and pastures in the study area, we applied the same approach described above in the second step (i.e. segmentation algorithm and respective parameters applied in the ENVI software), plus a visual interpretation only in areas previously classified as anthropic (croplands and pastures). We used the 2011 RapidEye imagery to validate the 2010 Landsat classification per the accuracy assessment presented in Table 5. Given the robust accuracy of 2010, we assumed that the 2000 and 1990 classifications had similar accuracy. This procedure allowed us to differentiate crop from pasture areas in all three settlements and their surroundings.

As already stated, for the visual interpretation, we used the following parameters: color, shape, texture, tone, and size of the objects in the images. This assisted in the visual interpretation of the Landsat 5-TM scenes in the rainy season (in this case, December–March) of each analyzed year, allowing a better view of agricultural activities.

For the analysis of 2010, we also added high spatial resolution images obtained from Google Earth platform (employed here to validate the classification of the Landsat 5 dataset, described above) and the sugarcane crops vector file (from National Institute for Space Research – INPE/CANASAT, http://www.dsr.inpe.br/laf/canasat/) (INPE, 2013).

In order to verify the actual land use and to identify other possible practices, fieldwork in each settlement was carried out between December 2014 and January 2015. This work aimed to

Table 5. Accuracy assessment for 2011 RapidEye for validating 2010 land use classification.

Settlement project	Land use class	Accuracy (%)
Large-scale livestock farming region	Croplands	77
	Pastures	96
Small-scale diversified farming region	Croplands	89
	Pastures	75
Large-scale crop farming region	Croplands	96
	Pastures	79

understand the agricultural production systems of the settlements and their environment implications, particularly for the legal reserves.

A survey was conducted with farmers in each settlement involving three to four key informants including presidents of associations and former residents. We used maps of the settlements, identifying each plot, the list of dwellers, and a map with the legal reserves overlapped on a RapidEye image from 2011. This material allowed the informants to identify every household in the settlement and the activities carried out in the plots, as well as to identify the status of the legal reserves. Afterward, specific plots were visited in order to check the environmental situation of the legal reserves.

3. Results

3.1. *Deforestation in the settlements and their surroundings*

Table 6 shows the deforestation that occurred in the three settlements and their surroundings in the three time frames examined (1990, 2000, and 2010). During these periods, the percentage of the area deforested was less in the three settlements than in their respective surroundings. The average percentage of the deforested area reached 67.71% in the settlements versus 78.31% in the surrounding areas in the last time frame (2010) analyzed.

Among the rural settlements, those with the greatest percentage of deforested area were the large-scale crop farming settlements, reaching 71.22% of the area in 2010. Similarly, these settlements' surroundings demonstrated the largest percentage of area deforested in 2010, at 81.21% deforestation. At the other end of the spectrum, the large-scale livestock farming region settlement and its surroundings demonstrated the least amount of deforestation in 2010, with 65.66% and 72.86%, respectively.

The small-scale diversified farming settlement presented a greater percentage of deforestation than the other regions only in 1990, before the settlement was created; these data are corroborated by what was observed in the surrounding area, which was also the most deforested in 1990. In the years 2000 and 2010, the large-scale crop farming settlements and their surroundings led in terms of proportion of deforested area.

The data in Table 7 demonstrate that over time, the deforestation rate decreased in all of the settlements and their surrounding areas. The rate of decrease in the second period analyzed is significant, dropping, for example, from 18.61% to 6.88% in the large-scale crop farming region settlements. The only exception was in the large-scale livestock farming region settlement, which reduced the deforestation rate by a mere percentage point. However, it was nonetheless the settlement with the least percentage of deforested area of the three studied.

The deforestation rate analyzed in the second period (2000), after the creation of the three settlements, was higher inside the settlements than in their respective surroundings. While the average deforestation rate reached 6.64% within the settlements in the second period, in the surroundings it was 4.98%. This reflects the settlers' early farming practices when their initial land activities were particularly intense.

Table 6. Deforested area in the settlements and their surrounding in the three time steps.

Settlement project	Deforestation 1990 (ha) and % of the area		Deforestation 2000 (ha) and % of the area		Deforestation 2010 (ha) and % of the area	
Large-scale livestock farming region	2,609.89	45.94	3,198.28	56.30	3,729.96	65.66
Small-scale diversified farming region	2,194.02	51.97	2,641.68	62.57	2,796.80	66.24
Large-scale crop farming region	744.90	45.74	1,047.94	64.34	1,160.01	71.22
Average	1.849.60	47.88	2.295.97	61.07	2.562.26	67.71
Surroundings						
Large-scale livestock farming region	184,590.04	48.44	247,701.82	65.01	277,674.98	72.86
Small-scale diversified farming region	257,593.84	69.54	286,364.99	77.26	299,631.96	80.87
Large-scale crop farming region	145,041.09	68.46	164,583.90	77.66	172,147.18	81.21
Average	195,741.66	62.15	232,883.57	73.31	249,818.04	78.31

Source: estimated by the authors.

Table 7. Deforestation rate within the settlements and their surroundings areas.

Settlement project	Deforestation rate 1990–2000 (%)	Deforestation rate 2000–2010 (%)
Large-scale livestock farming region	10.36	9.36
Small-scale diversified farming region	10.60	3.67
Large-scale crop farming region	18.61	6.88
Average	13.19	6.64
Surroundings		
Large-scale livestock farming region	16.56	7.78
Small-scale diversified farming region	7.76	3.58
Large-scale crop farming region	9.22	3.57
Average	11.18	4.98

Source: estimated by the authors.

3.2. *Native vegetation in the legally protected reserve areas*

Despite higher deforestation rates found within settlements after their establishment, the areas intended as legal reserves areas were, in general, respected by the land reform settlers. Figure 2(a) shows that in areas intended as legal reserves in the large-scale livestock farming settlement, native vegetation gradually increased between 1990 and 2010.

In fact, the native vegetation's regrowth in the legal reserve areas was more intense after the creation of the settlement in the large-scale livestock farming settlement. Between 2000 and 2010, the native vegetation growth was around 5.58%, versus 3.31% between 1990 and 2000. This indicates that the legal reserve areas were set aside (without crop-livestock farming use) by the settlers. In other words, the settlers respected the settlement's legal reserve areas and opened new areas only on their designated plots. Over 60% of the key informants reported that settled families also tended to maintain the legal reserves for fear of an inspection by federal agencies, which could result in penalties for the families in the case of illegal deforestation of the legal reserves.

In the small-scale diversified farming region, the amount of native vegetation within the legal reserves remained practically stable in the 20-year time span, as noted in Figure 2(b). This stability could be the result of the more rugged terrain largely dedicated to the legal reserves; however, it also points to the fact that the settlers respected the legal reserve boundaries, which were established when INCRA allotted the lands.

Figure 2(c) shows gradual deforestation in a part of the legal reserves; on the other hand, regrowth of native vegetation took place in other parts of these reserves, allowing, from a numerical point of view, the total area with native vegetation to be practically stable in the large-scale crop farming region settlement in the 20-year time span.

Comparison of the evolution of the native vegetation in the legal reserves can be seen in Figure 3, which shows the maintenance of more than 82% of the vegetation in the legal reserve areas in all cases (here, including another year of analysis in 2011). Therefore, recovery occurred in the legal reserve areas of the large-scale livestock farming region settlement, while the legal reserve areas remained stable in the small-scale diversified farming and the large-scale crop farming settlements, with percentages around 98% and 85%, respectively.

3.3. *Increase in agricultural activities in settlements and in their surroundings*

Data obtained from the classification of the agricultural areas are summarized in Table 8, showing the agricultural activities in the settlements in the three time frames analyzed. The data show that in the areas surrounding the large-scale livestock farming and the small-scale diversified farming settlements, the percentage of land dedicated to pasture was greater than land used for crop production. In the areas surrounding the large-scale crop farming region settlement, cropland dominated, reaching 73.85% of the area in 2010.

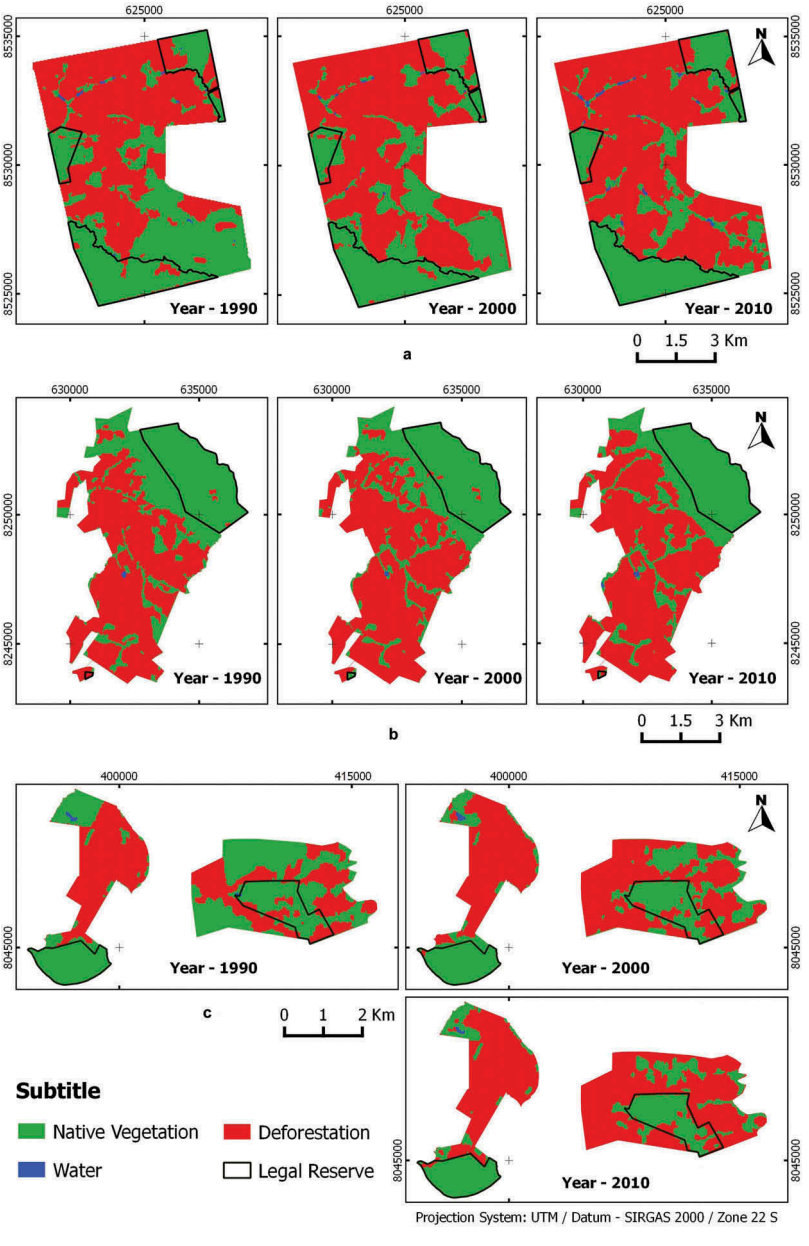


Figure 2. Progression of deforestation/vegetation recomposition in the settlements. (a) Large-scale livestock farming region (total area: 5.680 ha). (b) Small-scale diversified farming region (total area: 4.222 ha). (c) Large-scale crop farming region (total area: 1.628 ha). Source: INCRA and INPE.

In all settlements, there is a greater percentage of land dedicated to pastures than to crop production throughout the three time frames analyzed. This is explained by the activities undertaken (as described by the settlers), where dairy and beef cattle farming were underway well before the settlements were created, and were the way of life for the initial growth of the settler families.

The large-scale livestock farming and the small-scale diversified farming settlements' surrounding areas followed the same trends and had a greater percentage of pastures. Of these two regions, the large-scale livestock farming settlement (and its surroundings) had the greatest percentage of

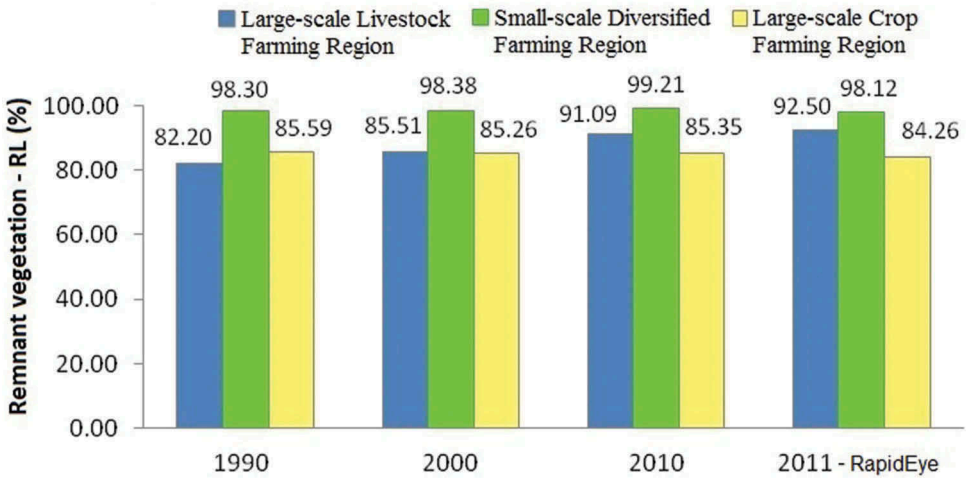


Figure 3. Progression of native vegetation in settlement legal reserve areas.

Table 8. Agricultural activities developed in the occupied areas in settlements and their surroundings.

	1990		2000		2010	
Settlement project	Cropland % area	Pasture % area	Cropland % area	Pasture % area	Cropland % area	Pasture % area
Large-scale livestock farming region	0.1	99.9	6.09	93.91	2.22	97.78
Small-scale diversified farming region	28.73	71.27	32.42	67.58	38.63	61.37
Large-scale crop farming region	4.15	95.85	14.06	85.94	32.70	67.30
Surroundings						
Large-scale livestock farming region	4.21	95.79	4.15	95.85	3.31	96.69
Small-scale diversified farming region	27.17	72.83	25.28	74.72	30.98	69.02
Large-scale crop farming region	60.52	39.48	63.84	36.16	73.85	15.26

Source: estimated by the authors.

pastures in all the time frames analyzed, resulting in 96.69% of pastures in the settlement area in 2010, confirming the region's livestock farming vocation.

The percentage of land used for crop production in the small-scale diversified farming region settlement was surprising as it was higher than the percentage of land used for this purpose in its surroundings in all three time frames analyzed. This demonstrates that even before the settlement's creation, the rural property already had substantial farming, and that after the settlement's establishment the agricultural potential continued to remain high, with 38.63% of its area as cropland in 2010. It is worth pointing out that this settlement is in a privileged location, close to a large agricultural center (municipality of Itaberaí – GO) and with easy access to the capital of Goiás, Goiânia.

The large-scale crop farming settlement did not follow the regional trend of crop production, and within the settlement, it had a higher percentage of pastures. Nevertheless, it appears that this is the settlement that increased the most in terms of farming use, increasing from only 4.15% of cropland area in 1990 to 32.70% of cropland in 2010, a growth of 28.55%.

This trend of developing cropland is also found in the areas surrounding the large-scale crop farming region settlement, but on a smaller scale (around 13%). Thus, it is noted that both (the settlement and its surroundings) grew in terms of the percentage of cropland.

This again demonstrates that the large-scale crop farming region settlements before they were founded were mainly used for livestock farming. After the creation of the settlements, the area of land used for cropland more than doubled, jumping from 14.06% in 2000 to 32.70% in 2010.

Figure 4 shows the land use and land cover inside the settlements and their surroundings, and confirms that the 'edges' of the study area in the large-scale crop farming settlements are predominantly dedicated to cropland, with cropland gradually moving into the center of the study area.

During the fieldwork at each settlement, it was possible to check the current land use of the occupied areas. Different agricultural activities carried out in the settlements' plots are summarized

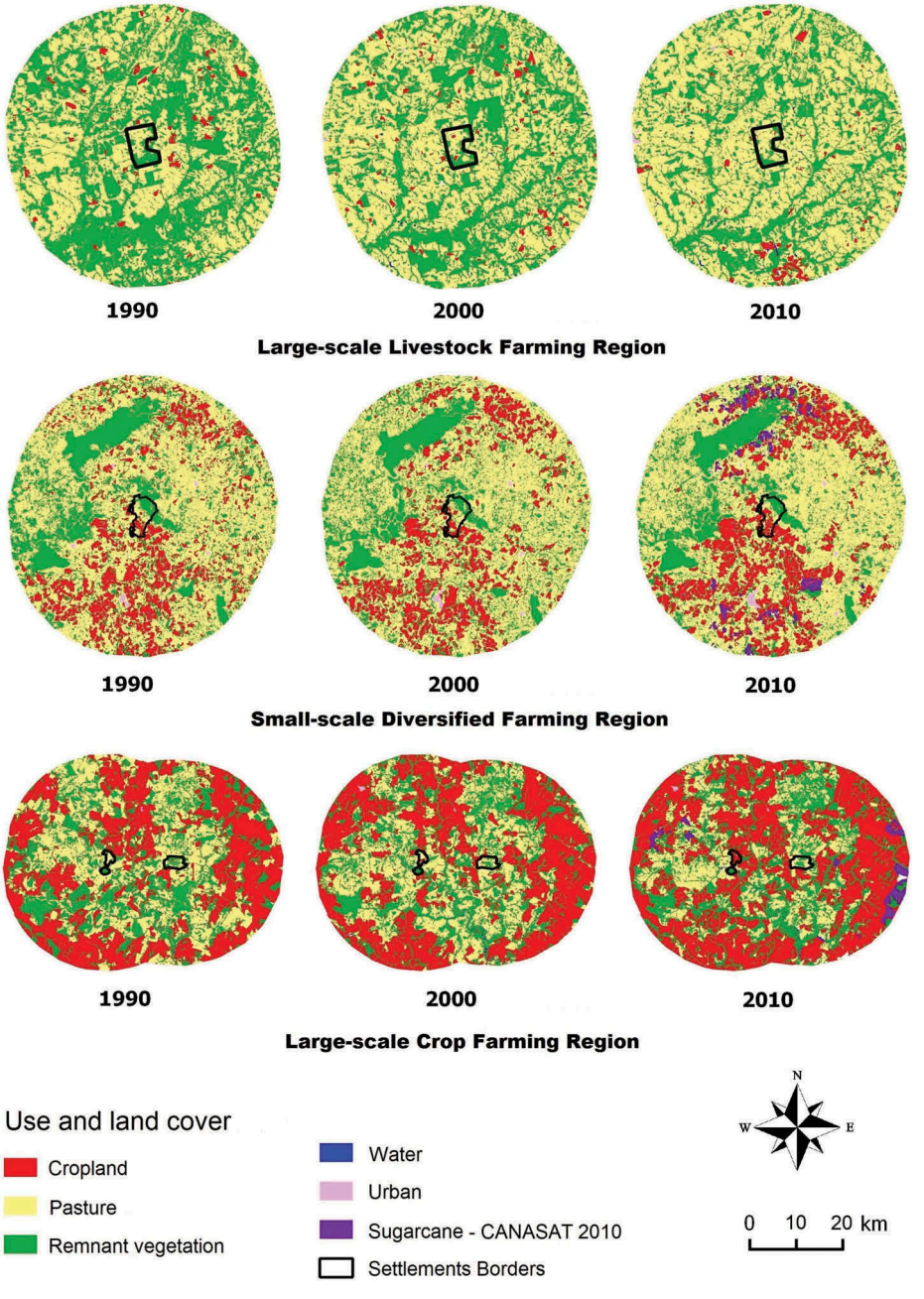


Figure 4. Progression of land use and land cover in the settlements and their surroundings. Source: INCRA and INPE.

Table 9. Percentage of number of plots and their main activities in pastures or cropland for the 2014/2015 harvest.

	% of Plots – Main activities	
Settlement project	Cropland	Pasture
Large-scale livestock farming region	15	93
Small-scale diversified farming region	55	87
Large-scale crop farming region	79	81

Source: estimated by the authors.

in Table 9 and grouped into two categories: activities with grazing (dairy and beef cattle) and activities with cropland.

It is also noted that the percentage of plots using pastures was greater in all of the settlements. The large-scale livestock farming settlement stands out because it had the highest percentage of plots with pastures (93%) and the lowest percentage of plots where crop production was practiced (only 15%, of which 11% were sesame).

4. Discussion

The main contribution of this study is to aid our understanding of the deforestation trend within rural settlements as well as its relationship to current agricultural activities. Our results reveal that although settlements tend to have high deforestation rates, particularly in the initial years, these contribute proportionately less to deforestation in the settlement regions compared to their neighboring farms. This is partly due to the maintenance of the legal reserves, even though deforestation patterns within rural settlements are greatly influenced by the agricultural activities undertaken regionally. The adopted methodology for imagery classification (see Tables 3, 4, and 5) has proven to provide accurate results that are appropriate for further study on land use cover change.

The first research question considered was the participation of the settlers in deforestation as these land holders are at times characterized as responsible for deforestation in the regions they occupy (see Batista, 2009; Brandão & Souza, 2006; Homma et al., 1998). Our results reveal that settlements contribute proportionately less to the deforestation in the regions where they are located in comparison to their neighboring farms. In the three time frames analyzed (1990, 2000, and 2010), the percentage of deforested area was less in the three settlements than in their respective surroundings. The average percentage of deforested area reached 67.71% in the settlements versus 78.31% in the surrounding areas in 2010 (Table 6). This result is similar to the one found in the study by Calandino et al. (2012), concluding that settlements had a deforestation index smaller than their surroundings.

Nonetheless, higher deforestation rates were observed inside the settlements compared to their surrounding areas. While the average deforestation rate reached 6.64% within the settlements in the second period, it was 4.98% in the surroundings at that time (Table 7). This may have been impacted by the greater (proportional) amount of existing native vegetation inside the settlements relative to their surroundings, by the high density of settled families per area relative to their surroundings, or by the need to open new areas for farming production in the first years of settlement.

This finding corroborates the following studies: Batista (2009), who, after analyzing 25 settlements in Amapá/Brazil, found that the highest rates of deforestation occurred in the early years of the settlements and Godar et al. (2012), who, in their study in Pará/Brazil, revealed that most of the deforestation observed in the initial phase of the settlement (mainly to prove the occupation and to secure title to the land) decreased after the initial stage. In addition, Santos et al. (2009) found that after the initial years, the annual rate of deforestation in studied settlements in Tocantins/Brazil decreased to around 3% per year.

Such studies suggest that deforestation rates found in the settlements are often part of the natural development of production processes, which are allowed by law. Agreeing with this view, Sparovek (2003) points out that deforestation in agrarian reform areas can be attributed to the need for vegetation removal in order to allow the establishment of agricultural activities.

The second research question considered was the conservation of the native vegetation in the settlements' legal reserve areas (Laris & Dembele, 2012). Figure 3 demonstrates the stability of the native vegetation in these reserves over the assessed time. Generally, the settlers respected the legal reserves, as observed in other studies of the Cerrado biome (Maywald & Marçal Júnior, 2013; Oliveira, 2013). Over 60% of the key informants reported that settled families tended to respect the legal reserves for fear of possible inspections by federal agencies, such as INCRA and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA)

This respect for the collective legal reserves contributed to the large proportion of native vegetation within the settlements. It contrasts with the limited protection of legal reserves in other areas of Brazil, as recent studies have shown for the states of Mato Grosso and Pará (Gibbs et al., 2015), both in the Amazon biome, where less than 10% of the farms maintain their legal reserves accordingly and more than 12% of the new deforestation is taking place within the legal reserves. However, this did not hinder all illegal deforestation in legal reserves, as there were occurrences of such in the large-scale crop farming settlements, where a part of the legal reserves was deforested and cleared. Based on information gathered from our interviews, the settlers appear to consider the legal reserve areas as conservation areas that cannot be used, and therefore, are not part of the families' economic context, leaving them vulnerable to illegal utilization by third parties.

A third research question considered was regarding the agricultural activities undertaken regionally and the deforestation found within the settlements and their surroundings. Table 6 shows that the north region of Goiás (large-scale livestock farming region) is the area with the least percentage of deforestation, whereas the central region of the state (small-scale diversified farming region) and the region southwest of Goiás (large-scale crop farming region) have high percentages of deforestation similar to each other.

This result suggests that settlements in regions with more intensive land use (the small-scale diversified farming region, with predominately small pastures, and the large-scale crop farming region, with predominately large-scale crop farms) tend to have higher deforestation rates.

However, regarding this question, the trends observed (Table 6) indicate that the percentage of area deforested in the settlements follows the percentage of deforestation in the surrounding areas. This finding is particularly relevant for the Brazilian savanna region where most land conversions relate to the export-oriented crop production and large-scale cattle farming (Ferreira et al., 2013; Rada, 2013).

Yet, based on Table 6, it can be said that the large-scale crop farming settlements and their surroundings were the most deforested in the years 2000 and 2010 in proportional terms, while the settlement of the small-scale diversified farming region and its surroundings showed the greatest percentages of deforested areas in 1990. These results indicate that from the environmental perspective, the rural settlements are highly influenced by the context in which they are embedded.

The large-scale livestock and small-scale diversified settlements and their surroundings mostly develop activities in pastures. However, the large-scale crop farming settlements did not follow the regional dynamics of predominance of cropland, since before the settlements were established there was an eminent livestock business. Thus, it turns out that both areas (settlements and their surroundings) are growing in terms of the percentage of agricultural activities, but in different proportions.

5. Conclusion

This research has shown that although the settlements generated a high deforestation rate just after their creation, they also contributed proportionately less to the deforestation in the regions

where they are located in comparison to their neighboring farms. On average, 67.71% of the settlements areas have been deforested, compared with 78.31% of the surrounding areas.

Respect for the collective legal reserves contributed to the largest proportional area of vegetation, even though this did not prevent illegal deforestation. In all of the settlements studied, more than 82% of the vegetation in the legal reserves was conserved.

We also found that the regions with the most intensive land use tended to have settlements with the greatest percentage of deforestation, as these settlements tended to have the same crop/livestock farming activities as their surrounding areas. The studied settlements have similar developments in the context in which they are embedded. Therefore, settled family farmers cannot be characterized as the main actors in regional deforestation as they tend to follow the environmental performance of the regions they are part of.

Note

1. It has not been possible to carry out such studies in the surroundings of the rural settlements because the vector files (shapefile) of the properties (and their legal reserves) are not yet public data in Brazil.

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