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LAND-USE AND LAND-COVER MAPPING OF THE BRAZILIAN CERRADO BASED MAINLY ON LANDSAT-8 SATELLITE IMAGES

Mapeamento de Uso e Cobertura de Terras do Cerrado com Base Principalmente em Imagens do Satélite Landsat-8

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ABSTRACT

The Brazilian Cerrado is one of the world´s biodiversity hotspot and hosts some of the most intensive agricultural activities for food production in the world. The objective of this study was to produce a land-use and land-cover (LULC) map of the Cerrado based on Landsat-8 Operational Land Imager (OLI) images. A set of 121 scenes from 2013 was processed using the image segmentation technique. The segments were exported in the shapefile format and interpreted visually in a geographical information system software using RGB/564 color composites. The following LULC classes were considered: annual croplands, perennial croplands, cultivated pasturelands, reforestation, mosaic of occupation, urban areas, mining areas, bare soil, forestlands, non-forestlands, water bodies, and non-identified (clouds and burned areas). The overall accuracy was estimated by an independent scientist with large experience in Cerrado´s image interpretation. The results showed that 43.4% of the study area (88.5 million hectares) were already converted into agricultural, urban and mining areas, 54.6% (111 million hectares) were still natural areas, and 1.9% (3.9 million hectares) was classified as non-identified. Cultivated pasturelands were the most representative land-use type (29.5%), followed by annual croplands (8.5%) and perennial croplands (3.1%). The overall accuracy of the final map was 80.2%.

Keywords: Tropical Savanna, Remote Sensing, LULC, Land Occupation.

RESUMO

O Cerrado brasileiro é um dos *hotspots* mundiais de biodiversidade e hospeda algumas das atividades agrícolas mais intensivas para a produção de alimentos no mundo. O objetivo deste estudo foi produzir um mapa de uso e ocupação de terras do Cerrado com base na análise de imagens do satélite Landsat-8 *Operational Land Imager* (OLI). Um conjunto de 121 cenas de 2013 foi processado por meio da técnica de segmentação de imagem. Os segmentos foram exportados para o formato *shapefile* e interpretados visualmente em um programa de sistema de informações geográficas utilizando composições coloridas RGB/564. As seguintes classes de uso e ocupação de terras foram consideradas: culturas anuais, culturas perenes, pastagens cultivadas, reflorestamento, mosaico de ocupação, áreas urbanas, áreas de mineração, solo exposto, cobertura florestal natural, cobertura não-florestal natural, corpos d´água e não-identificadas (cobertura de nuvens e queimadas). A exatidão da interpretação de imagens foi estimada por um cientista independente com larga experiência em análise de imagens de satélite do Cerrado. Os resultados mostraram que 43,4% da área de estudo (88,5 milhões de hectares) tinham sido convertidas para áreas agrícolas, áreas urbanas e de mineração, 54,6% (111 milhões de hectares) encontravam-se ainda com cobertura vegetal natural e 1,9% (3,9 milhões de hectares) foi classificada como não-identificada. Pastagens cultivadas foi o tipo de uso de terras mais representativo (29,5%), seguido por culturas anuais (8,5%) e culturas perenes (3,1%). A exatidão global do mapa final foi de 80,2%.

Palavras-chave: Savana Tropical, Sensoriamento Remoto, LULC, Ocupação da Terra.

1. INTRODUCTION

The Brazilian tropical savanna (Cerrado) is the second largest biogeographical region in Brazil (~ 204 million hectares; 24% of the nation´s area) and occupies the central part of the country. It extends from the northern part of Maranhão State to the northern part of Paraná State, a variation of 22.4 degrees in latitude (SANO *et al.*, 2010). The elevation ranges from sea level to 1,800 m. Varying proportions of grasses, shrubs and trees are found in the Cerrado´s different physiognomies, which range from grasslands to forestlands.

Several regions in the Cerrado contain large and flat terrains that are known as *chapadão*. Most of the high-tech and mechanized grain production (mainly soybean, maize and cotton) are found in this type of terrain despite its low soil fertility and high soil acidity. This became possible due to the use of liming, chemical fertilizers, improved management practices and crop varieties adapted to the local soil and climate conditions (RADA, 2013). This is the case of Luis Eduardo Magalhães in the Bahia State, Jataí in the Goiás State and Lucas do Rio Verde in the Mato Grosso State (SANO *et al.*, 2008, 2010).

Livestock is another important and well-established economic activity in the Cerrado, which is primarily based on the African *Brachiaria* grass species. In contrast to grain production, cattle ranchers do not use input fertilizers and work with low levels of productivity (~ 1 animal unit per hectare) and varying levels of degradation. There are also significant numbers of cattle ranchers in the natural grasslands and more open Cerrado shrublands.

Land-use and land-cover (LULC) mapping of the Brazilian Cerrado based on remote sensing data is challenging because of its geographical extent, marked climatic seasonality, varying mosaics of trees, shrubs and grasses in terms of structure and cloud cover conditions during most of the satellite overpasses, especially during the wet season. Nevertheless, producing accurate LULC maps of the Cerrado is important for several issues. They are one of the first steps in estimating biomass changes and related CO_2 emissions due to habitat conversion and degradation. Multitemporal LULC maps can provide estimates of rates of conversion, as well as the magnitude of replacement of pastures by crops, which is a common practice in this region.

LULC maps can be overlaid with vector-based farm boundaries to evaluate whether farmers are following the Federal Law of Native Vegetation Protection (old Forest Code of Brazil - Law Nº.. 12,651, May 25, 2012) (SOARES FILHO *et al.*, 2014). The maps are also important to support the selection of priority areas for biodiversity conservation and water resources because only 2.2% of the region are permanently protected in terms of federal conservation units (KLINK & MACHADO, 2005). The objective of this study was to produce a new LULC map of the Brazilian Cerrado based on Landsat-8 Operational Land Imager (OLI) scenes from 2013. This map will be the basis for a long-term LULC monitoring program that will cover at least 73% of the country (Amazon and Cerrado regions), called of Brazilian Biomes Enviromental Monitoring National Program (PMABB) (BRASIL, 2017; IBGE, 2004).

2. MATERIALS AND METHODS

The study area (Brazilian Cerrado) covers 203.92 million hectares. Because of the high levels of floristic diversity and endemism, this region is considered to be one of the world´s 25 hotspots for biodiversity conservation (MYERS *et al.*, 2000). Seasonality is one of the most prominent features of the Cerrado; it includes a six-month dry season (April-September) and a six-month wet season (October-March) and average annual precipitation ranging from 800-1,800 mm (PEREIRA *et al.*, 2011).

This study was based on Landsat-8 OLI satellite scenes from 2013. This sensor was selected because of its radiometric and geometric qualities as well as its 30-meter spatial resolution and relatively large 185 km swath, which are compatible with the size of the study area. A set of 121 scenes was considered (paths: 217-229; rows: 62-77). The images were obtained from the U.S. Geological Survey homepage (*Earth Explorer* platform) with the following specifications: processing level: 1T; cloud cover: < 10%; projection system: Universal Transverse of Mercator (UTM); datum: WGS84; and data format: geotiff. The majority of the scenes (93%) was acquired in July and August (dry season).

The images were converted to top-of-atmosphere (TOA) reflectance in order to minimize the influence of different solar illumination conditions which is overpass-specific. According to Jensen (2009), variations in the solar zenith and azimuth angles often add more difficulty in the interpretation of scenes obtained at different overpasses. First of all, digital numbers (*DN*) were converted to radiance (L_λ) using the gain (*G*) and offset (*OS*) values, which are specific to the individual scenes (Eq. 1). They are available in the header files. Next, the radiance was converted to TOA reflectance (ρ_λ) (Eq. 2).

$$L_\lambda = G * DN + OS \quad (1)$$

$$\rho_\lambda = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * cos\theta_s} \quad (2)$$

where d is the Earth-Sun distance, $ESUN_\lambda$ is the mean solar exoatmospheric irradiances during the satellite overpass and θ_s is the solar zenith angle during the satellite overpass. These conversions were made using the *ENVI 4.5* image processing software.

Bands 4 (0.64 – 0.67 µm), 5 (0.85 – 0.88 µm) and 6 (1.57 – 1.65 µm) were selected for image segmentation using a region growing algorithm that is available in *SPRING 4.0* geographical information system (GIS) software (CAMARA *et al.*, 1996). The algorithm identifies regions or segments in an image with spectrally uniform pixels. Initially, it considers each pixel as having its own region. The adjacent pixels are then grouped step-by-step according to the user-defined similarity and minimum area (OUMA *et al.*, 2008). The minimum area was set at 70 pixels (~ 6.25 hectares) to match the minimum area of the Monitoring Brazilian Amazon Forest by Satellite (PRODES) project, which is an operational project to detect annual rates of deforestation in the Brazilian Amazon. Several tests indicated that the most appropriate similarity was 0.015. The algorithm produced an average of more than 120,000 segments per scene.

The segments were exported in *shapefile* format and interpreted visually on a computer screen by overlaying them on the corresponding RGB/564 color composites. The mapping scale on the computer screen was set to ~ 1:50,000. The following LULC classes were considered in the visual interpretation: annual croplands, perennial croplands, urban areas, mining areas, mosaic of occupations, cultivated pastures, reforestations, bare soils, forestlands, non-forestlands, natural non-vegetated, water bodies and non-identified (clouds and burned areas).

Annual croplands include large plantations of soybean, maize and cotton. Perennial croplands include coffee, citrus, sugarcane and rubber tree plantations. Cultivated pasturelands correspond to planted pastures, most of which contain African *Brachiaria* species. Mosaic of occupations refer to polygons that are composed of a mixture of varying LULC classes (e.g., houses, orchards, native vegetation, bare soils and pastures) of relatively small areas, which cannot be defined as specific polygons. Bare soils correspond to areas that are usually found between croplands, pasturelands and reforestations and are difficult to classify as land prepared for grain production, pasture renewal or harvested areas of reforestations.

Forestlands include the dense Cerrado (dominant tree cover with continuous canopy), riparian forests, deciduous and semi-deciduous forests on the border of the Amazon and Atlantic forests and deciduous forests (dry forests) found mainly over limestones. The grasslands and shrublands were grouped as non-forestlands. In this study, natural grasslands outside conservation units were classified as natural vegetation because the original cover is maintained in the terrain. Natural non-vegetated areas are natural areas without or very few grasses in sand banks found near the coast of Maranhão or along major rivers.

The first step of the image analysis was the classification of the segments into the following classes: natural, anthropic, water bodies and non-identified (clouds, shadow or burned areas). For the anthropic polygons, we first identified the polygons related to the annual croplands. The remaining anthropic polygons were classified step-by-step in the following sequence: perennial croplands; reforestations; urban areas, mining areas and mosaics of occupations; bare soils; and cultivated pastures. The classification of annual croplands was based on time series of the Normalized Difference Vegetation Index (NDVI) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor (Huete *et al.*, 2002) and smoothed by a conservative filter proposed by Wardlow *et al.* (2006). Typical temporal signatures of annual croplands available in the spectral library at the Embrapa Agriculture Informatics in Campinas/SP were used to derive the MODIS-based annual cropland map (2012/2013). This map was then overlaid on the Landsat images and on the vector-based segmentation files.

The perennial croplands, which included plantations of coffee, citrus, sugarcane and rubber trees, were mapped using RapidEye scenes with a pixel size of 5 m, time-series of MODIS NDVI, high spatial resolution images when they were available in the *Google Earth*™ program, the sugarcane mapping project led by Rudorff *et al.* (2010), the coffee and citrus mapping project led by Moreira *et al.* (2010), and municipality-based agricultural production information provided by the Brazilian Institute for Geography and Statistics (IBGE) (EMBRAPA, 2016).

Because cultivated pastures were mapped last, all remaining unidentified anthropic polygons were set as cultivated pastures. Misinterpretations were corrected by visual inspection of the Landsat images. Finally, the polygons that were defined as natural vegetation were classified into forest and non-forest (grasslands and shrublands) classes. The accuracy of the final map was evaluated based on a validation provided by a senior researcher with extensive experience in satellite image interpretation in the Cerrado and who was not directly involved in the image analysis of the project (Dr. Roberto Rosa).

A set of 3,207 sampling points that were randomly distributed using Neyman´s optimal allocation method (CONGALTON & GREEN, 2009) was made available in a webpage (ADAMI *et al.*, 2012). In this web interface, we provided the portion of the Landsat-8 image of the project around the selected sampling point, the corresponding vector-based polygon, temporal series of the MODIS Enhanced Vegetation Index (EVI2) (2000-2013), portions of 5-meter spatial resolution RapidEye images and access to Google Earth™ images. The validation expert independently identified the LULC class, which was then compared to the Cerrado LULC map for accuracy assessment in terms of the overall accuracy and omission/commission errors.

3. RESULTS AND DISCUSSION

Approximately 54.6% (111 million hectares) of the Cerrado are covered by natural vegetation (Figure 1). In this study, all areas that are primarily covered by natural species and physiognomies of the Cerrado, regardless of the presence of land use activities (e.g., livestock activities, extensive grazing in natural pastures or manual exploitation of native fruits for local consumption), were considered to be natural vegetation. Regenerating areas (secondary vegetation) that were mainly located along the border of the Brazilian Amazon (northwestern Cerrado) were also included as natural Cerrado (forest or non-forest depending upon the stage of regeneration).

The remaining preserved areas of the Cerrado are mainly located in the northernmost part of the region, mainly because of the relatively poor road network and lack of large urban areas. This also reflects the history of land occupation of this region, which began in the south and intensified after the beginning of the construction of Brasilia in 1958, the capital of the country since 1960. Federal government subsidies for farmers that were interested in purchasing lands in the Cerrado and the development of crop varieties more adapted to the climate and soil conditions (strong acidity and low levels of soil nutrients) also accelerated the occupation of the Cerrado (SANO, 2016).

The coexistence of high food and energy productions with ~ 50% natural environment (Table 1) offers a unique opportunity to promote land use and biodiversity conservation policies to optimize both perspectives and reconcile biodiversity and ecosystem services conservation with sustainable agricultural development. According to IBGE (2006), this region produced 22.3 million tons of soybeans in 2006 (48.9% of the national production, the most important agricultural commodity in Brazil). The region also produces approximately 2.5 million tons of beef per year, which represents ~ 40% of the national supply (Ferreira *et al.*, 2012). At the same time, this region presents high biodiversity, with many endemic plant species (RIBEIRO *et al.*, 2011). The idea that the Cerrado has poor faunal diversity is a misinterpretation, mostly due to the lack of a good registration system (FERRO *et al.*, 2010).

Cultivated pastures represent the most dominant anthropic class; they occupy 29.5% of the region (~ 60 million hectares), followed by annual croplands (8.5%; 17 million hectares). Pasturelands are found in most of the states in the Cerrado region (Figure 2) but mainly in Goiás (~ 14 million hectares), Mato Grosso do Sul (12 million hectares), Minas Gerais (~ 12 million hectares) and Mato Grosso (8 million hectares) (Table 2). Mato Grosso and Mato Grosso do Sul highlight one of the greatest contrasts in terms of meat and grain production. In Mato Grosso, there is a balance between the pasturelands and croplands, which cover 57% and 42% of the total anthropic areas in the state, respectively. In contrast, in Mato Grosso do Sul, 83% of the total anthropic areas are pasturelands, and only 12% are croplands.

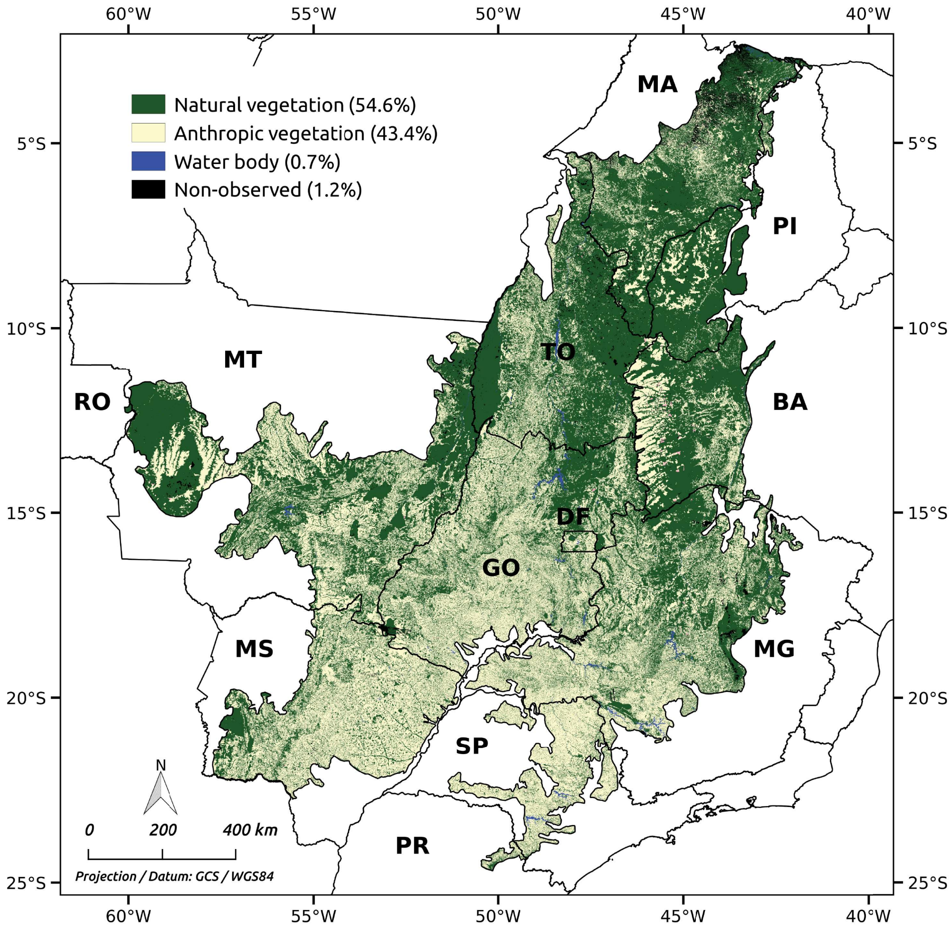

Fig. 1 - Spatial distribution of natural and anthropic classes of the Brazilian Cerrado in 2013. State identification: BA = Bahia; GO = Goiás; MA = Maranhão; MG = Minas Gerais; MS = Mato Grosso do Sul; MT = Mato Grosso; PI = Piauí; PR = Paraná; RO = Rondônia; SP = São Paulo; TO = Tocantins; and DF = Distrito Federal.

Around the beginning of this decade, Cerrado was responsible by the majority of Brazil's planted area in soy (61%), maize (61%), and cotton (99%) (IBGE, 2013). In 2014 approximately 12% (24M ha) of the Cerrado was covered by annual and perennial croplands and soybeans represent 90% (15.6 million hectares) of all annual agriculture in this region, representing more than half (52%) of the soybeans produced in Brazil (CARNEIRO FILHO & COSTA, 2016). Some of the annual croplands utilize double cropping systems, which are mainly soybean/maize or soybean/cotton (SPERA *et al.*, 2014). The annual croplands tend to be located in restricted areas of the Cerrado because of their dependence on flat terrains. This is the case in western Bahia (Luís Eduardo Magalhães municipality), southwestern Goiás (Jataí and Rio Verde municipalities) and the central part of Mato Grosso (Lucas do Rio Verde municipality), as was described previously (Figure 3

Table 1: Area and percentage of each land use and land cover class in the Cerrado region in 2013

Land cover	Class	Area (ha)	Percentage (%)
Anthropic	Cultivated pasture	60,084,000	29.5
	Annual cropland	17,417,900	8.5
	Perennial cropland	6,423,700	3.2
	Reforestation	3,060,700	1.5
	Urban area	885,200	0.4
	Bare soil	360,900	0.2
	Mosaic of occupation	234,400	0.1
	Mining area	28,000	0
	SUBTOTAL	**88,494,800**	**43.4**
Natural	Non-forestland	69,237,700	34.0
	Forestland	41,884,000	20.5
	Non-vegetated	263,000	0.1
	SUBTOTAL	**111,384,700**	**54.6**
Water body		1,502,500	0.7
Non-observed		2,542,100	1.2
	TOTAL	**203,924,100**	**100**

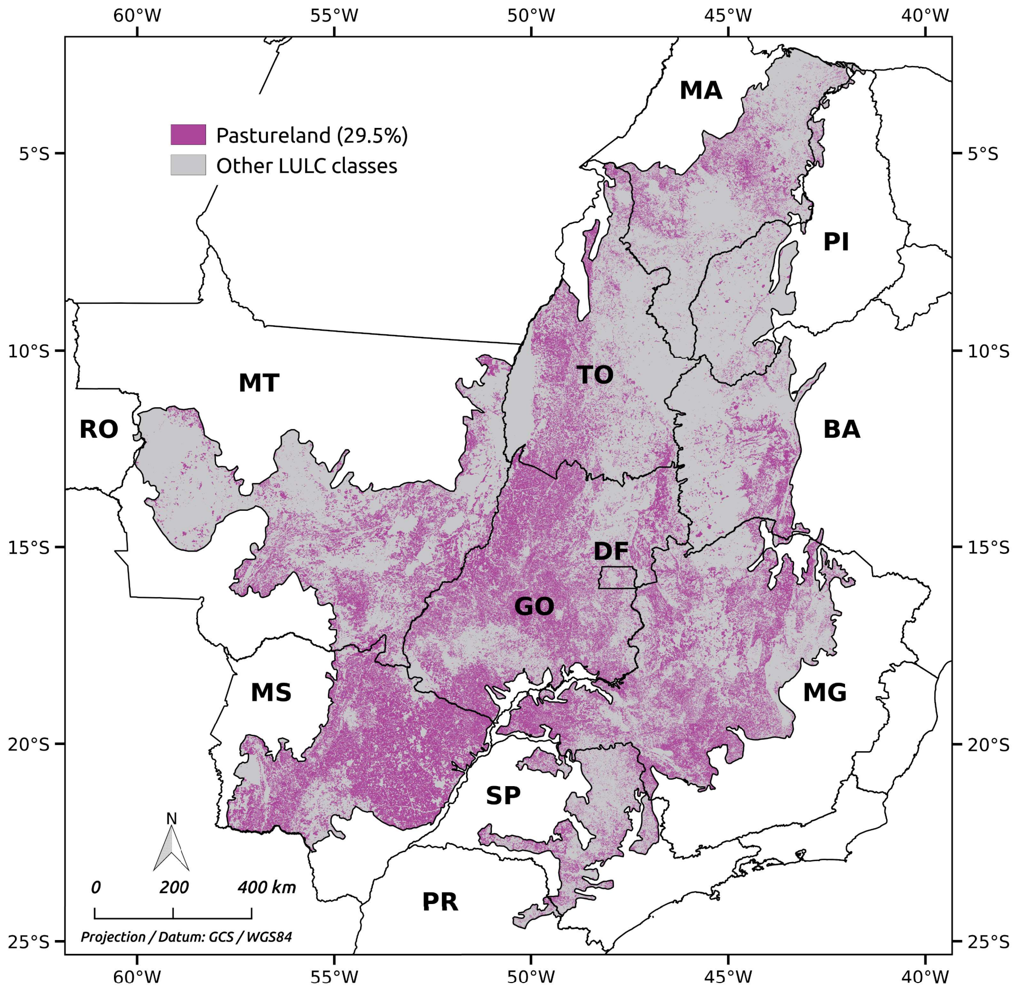

Fig. 2 - Spatial distribution of cultivated pasturelands in the Brazilian Cerrado in 2013. See Figure 1 for state identification.

Table 2: Areas of land-use and land-cover classes in the states covered by the Brazilian Cerrado in 2013 (units: hectares x 10,000). See Figure 1 for state identification. CP = cultivated pasturelands; AC = annual croplands; PC = perennial croplands; RE = reforestation; UA = urban areas; BS = bare soil; MO = mosaic of occupation; MA = mining areas; NV = natural vegetation; nV = natural non-vegetated areas; WB = water bodies; and NO = non-observed.

State		Class												
		CP	AC	PC	RE	UA	BS	MO	MA	NV	nV	WB	NO	TOTAL
MT	Area (ha)	791.1	566.8	17.1	10.1	6.0	4.5	1.8	0.4	2,153.5	0.3	17.4	19.3	**3,588**
	Percent (%)	22.0	15.8	0.5	0.3	0.2	0.1	0.1	0	60.0	0	0.5	0.5	**100**
MG	Area (ha)	1,187.6	187.8	124.2	145.2	19.8	4.7	1.4	1.0	1,597.1	2.3	35.9	30.2	**3,337**
	Percent (%)	35.6	5.6	3.7	4.4	0.6	0.1	0	0	47.9	0.1	1.1	0.9	**100**
GO	Area (ha)	1,397.7	349.2	94.0	15.3	17.9	2.9	2.3	0.8	1,375.2	1.4	30.0	9.5	**3,296**
	Percent (%)	42.4	10.6	2.9	0.5	0.5	0.1	0.1	0	41.7	0	0.9	0.3	**100**
TO	Area (ha)	547.7	71.8	3.6	8.0	3.8	5.7	1.0	0.1	1,826.4	1.8	28.3	33.6	**2,532**
	Percent (%)	21.6	2.8	0.1	0.3	0.2	0.2	0	0	72.1	0.1	1.1	1.3	**100**
MS	Area (ha)	1,218.1	133.4	47.8	54.7	6.1	2.1	7.0	0.1	679.2	0	4.5	6.9	**2,160**
	Percent (%)	56.4	6.2	2.2	2.5	0.3	0.1	0.3	0	31.4	0	0.2	0.3	**100**
MA	Area (ha)	337.4	74.8	6.2	9.5	3.7	1.9	2.5	0.2	1,514.9	9.3	12.2	148.2	**2,121**
	Percent (%)	15.9	3.5	0.3	0.4	0.2	0.1	0.1	0	71.4	0.4	0.6	7.0	**100**
BA	Area (ha)	245.0	219.7	2.5	5.0	2.0	12.1	0.5	0	1,007.8	10.3	4.9	2.6	**1,513**
	Percent (%)	16.2	14.5	0.2	0.3	0.1	0.8	0	0	66.6	0.7	0.3	0.2	**100**
PI	Area (ha)	60.3	81.3	1.7	1.3	2.5	0.4	1.8	0	778.0	1.0	3.3	2.5	**934**
	Percent (%)	6.5	8.7	0.2	0.1	0.3	0	0.2	0	83.3	0.1	0.4	0.3	**100**
SP	Area (ha)	202.2	38.4	345.3	49.3	20.4	1.7	2.7	0.2	137.9	0	12.9	0.5	**811**
	Percent (%)	24.9	4.7	42.6	6.1	2.5	0.2	0.3	0	17.0	0	1.6	0.1	**100**
DF	Area (ha)	14.2	9.6	0	0.9	6.2	0	2.5	0	23.6	0	0.7	0.1	**58**
	Percent (%)	24.6	16.6	0	1.6	10.7	0	4.3	0	40.8	0	1.2	0.2	**100**
PR	Area (ha)	7.2	8.9	0	6.8	0.2	0.1	0	0.	14.1	0	0.1	0	**37**
	Percent (%)	19.3	23.8	0	18.2	0.5	0.3	0	0	37.7	0	0.3	0	**100**
RO	Area (ha)	0.1	0	0	0	0	0	0	0	4.4	0	0	0	**5**
	Percent (%)	2.2	0	0	0	0	0	0	0	97.8	0	0	0	**100**
TOTAL	Area (ha)	6,009	1,742	642	306	89	36	23	3	11,112	26	150	254	20,392
	Percent (%)	29.6	8.5	3.1	1.5	0.4	0.2	0.1	0	54.6	0.1	0.7	1.2	100

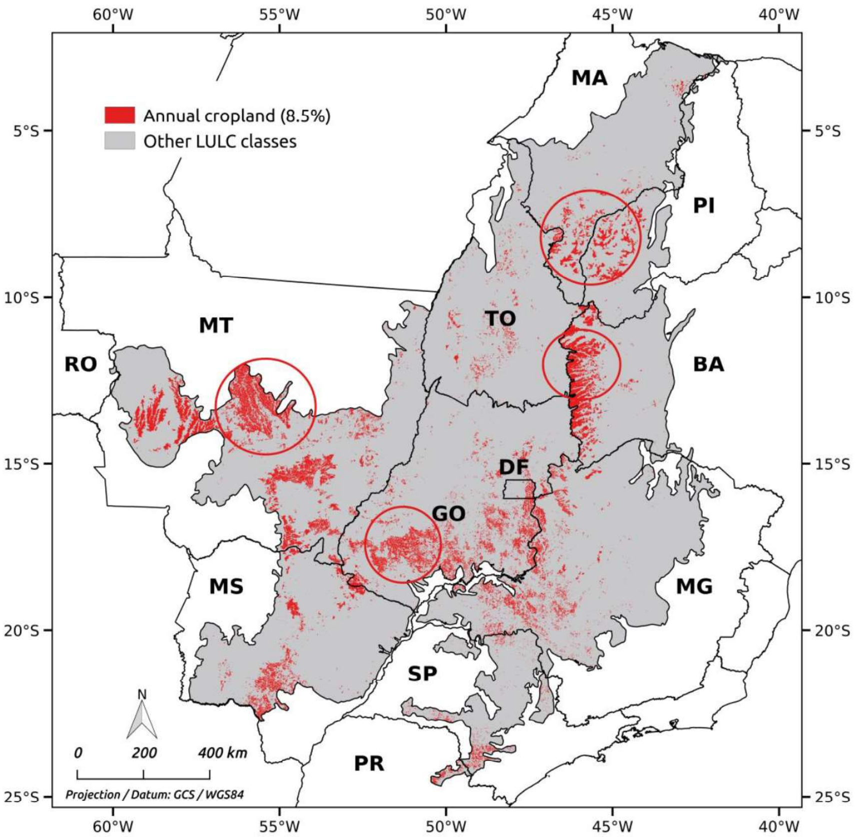

Fig. 3 - Spatial distribution of annual croplands in the Brazilian Cerrado in 2013. See Figure 1 for state identification. Red circles indicate traditional agricultural frontiers of the Cerrado, namely western Bahia, southwestern Goiás and the central part of Mato Grosso. The circle in southern Maranhão and Piauí is the newest agricultural frontier in the Brazilian Cerrado.

These regions have traditionally produced soybeans, maize and cotton, mainly for exportation, and have the highest productivities in the country (~ 3,200 kg/ha, 6,600 kg/ha and 3,800 kg/ha of soybean, maize and cotton, respectively). A new agricultural frontier, which is known as MATOPIBA, is located along the boundaries of the states of Maranhão, Tocantins, Piauí and Bahia. Between 2010 and 2014, the agricultural areas in this region expanded by 43% (ESQUERDO *et al.*, 2015). The impact of these changes was reported by Gibbs *et al.* (2015) and is related to biodiversity loss and biogeochemical cycles. The perennial croplands (mainly sugarcane) are mostly concentrated in São Paulo, western Minas Gerais and southern Goiás.

The overall accuracy of the final map was 80.2%. Three classes had higher levels of agreement (≥ 80%) (Figure 4): water bodies and natural non-vegetated areas, annual croplands and reforestations. The cultivated pasturelands and perennial croplands classes had levels of agreement between 70-80%. The two groups with the highest omission errors were: a) mining areas, mosaic of occupation and urban areas (61%) and b) bare soils and non-observed areas (39%). The groups composed of the bare soils and non-observed, forested natural vegetation and non-forested natural vegetation classes had the highest commission errors of 23%, 22% and 24%, respectively. The omission and commission errors for the forested and non-forested classes show that the natural vegetation mapping procedure overestimated these classes.

Comparing with the previous LULC map produced in 2002 by the Project of Conservation and Sustainable Utilization of Brazilian Biological Diversity (PROBIO) (SANO *et al.*, 2010), the land use in the Cerrado region increased 4.5%, from 38.9% in 2002 (about 80 million hectares) to 43.4% in 2013 (about 88.5 million hectares). Cultivated pastures increased from 54 million hectares in 2002 to 60 million hectares in 2013 while croplands increased from 22 million hectares in 2002 to 24 million hectares in 2013.

4. CONCLUSIONS

A long term LULC monitoring program for the Cerrado region is one of the 9 key components of policy mix to swerve a business as usual scenario for land use dynamics with a series of negative socioenviromental impacts to a sustainable scenario where agriculture expansion is reconciled with conservation of the remaining Cerrado (STRASSBURG *et al*., 2017).

In the time period of 2002-2013, land use in the Cerrado biome increased 4.5%.The set of Landsat-8 images used was able to generate LULC map of the Cerrado with an overall accuracy larger than 80%. The development and the use of a web service to estimate the accuracy of the final LULC map was very efficient and important. The improvement of this service should be pursued as part of a adoption of the accuracy estimates as basic procedures in official LULC mapping initiatives.

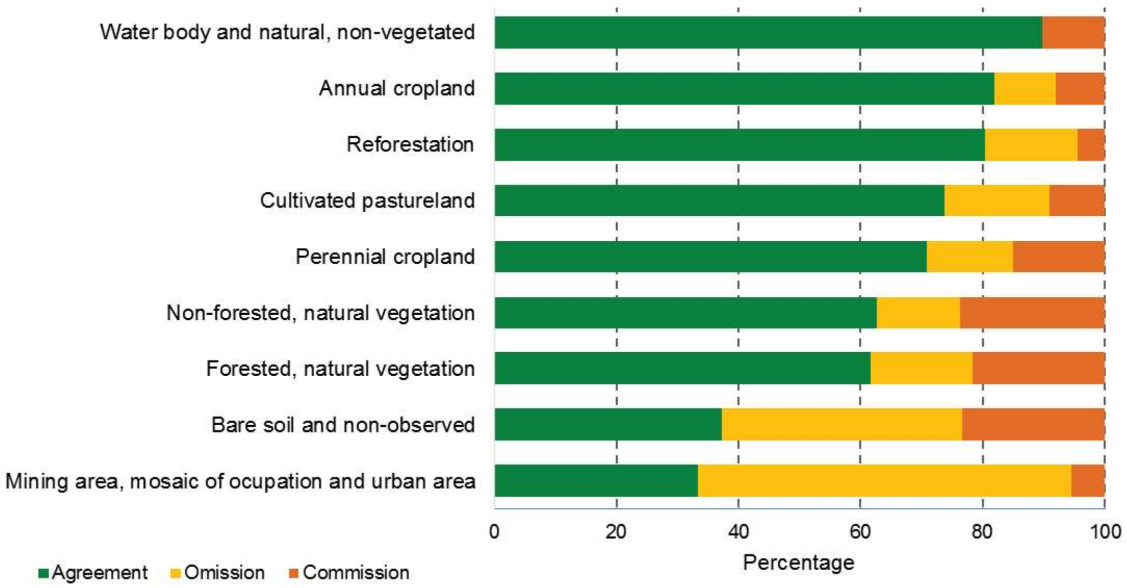

Fig. 4 - Levels of agreement, omission and commission for the land-use and land-cover classes.

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