Assessing land cover changes in the Brazilian Cerrado between 1990 and 2010 using a remote sensing sampling approach

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Abstract. We present a remote sensing sampling approach to assess land cover changes between years 1990 and 2010 for the Cerrado biome. Despite the fact that natural vegetation cover of this biome has been heavily converted into agricultural lands over the past decades, there is still a lack of detailed and historical information about vegetation cover changes at the biome scale. The sampling design and image processing techniques were developed by the Joint Research Centre (JRC) Tropical Ecosystem Environment Observation by Satellite (TREES-3) project. A set of 175 regularly distributed sample units (with10 km x 10 km size) located at every full degree confluence point of latitude and longitude were assessed. For each sample unit, (E)TM Landsat images from three target years (1990, 2000 and 2010) were selected, pre-processed, segmented and classified into five land cover classes (Tree Cover - TC, Tree Cover Mosaic - TCM, Other Wooded Land - OWL, Other Land Cover - OLC and Water -W). The results showed that the Cerrado had a net loss of natural vegetation (TC + OWL) of about 12 million hectares between 1990 and 2010, or an average rate of change of -0.6% y^{-1}. However, the rates of change decreased from the first (1990-2000) to the second (2000-2010) decade. By 2010, the percentage of natural vegetation cover remaining in the Cerrado was 47%.

Keywords: Change detection, Landsat, Brazilian savannas, sampling approach.

1. Introduction

Anthropic pressures on vegetation resources, especially through the conversion of vegetation cover into agriculture, have been the major driver of transformation of the Cerrado biome in the past decades (Silva *et al.,* 2006). The Cerrado (Brazilian tropical savanna) occupies an area of approximately 203 million hectares (IBGE, 2004). It is the second most extensive biome in South America (Sano *et al.,* 2010). Despite the importance of this region, recognized as one of the world's biodiversity hotspots (Myers *et al.,* 2000), and the fact it has undergone heavy losses of natural vegetation recently, the biome still lacks detailed and historical information about vegetation cover changes at the biome scale. Although some study cases have focused on assessing land cover changes in the Cerrado based on medium-resolution satellite imagery (Jepson, 2005; Brannstrom *et al.,* 2008; Grecchi *et al.,* 2013), previous assessments at the biome scale have either assessed land cover status at one point in time rather than the changes (Mantovani & Pereira, 1998; MMA, 2007), or used coarser spatial resolution satellite imagery (Machado *et al.,* 2004; Ferreira *et al.,* 2007; Rocha *et al.,* 2011). The project Monitoramento do Desmatamento dos Biomas Brasileiros por Satélite (PMDBBS) used the results of PROBIO - a biome scale mapping for year 2002 based on Landsat images (MMA, 2007) - as a baseline to map new cleared areas from 2002-2008, 2009 and 2010. However, this project has assessed only gross loss of natural vegetation. Moreover, there is a lack of information on rates and trajectories of changes prior to 2002. Thus, there still are gaps in the knowledge about land cover changes in these highly transformed landscapes. In this context, and considering the extent of this biome and the necessary resources for carrying out an assessment based on a "wall-to-wall" mapping, we present a change detection approach based on a systematic sampling of Landsat images for years 1990, 2000 and 2010 used to assess land cover changes over the entire biome.

2. Material and Method

Study area

The selected study area is the Cerrado biome, which is located in central Brazil and cover an area of approximately 203 million hectares (IBGE, 2004) (Figure 1). This Brazilian biome encompasses a mosaic of shrublands, woodlands and grasslands (Coutinho, 2000; Sano & Ferreira, 2005), creating complex habitats for fauna (Chhabra *et al.,* 2006). According to the Köppen climate classification, the predominant climatic class in this region is Equatorial savannah with dry winters (Aw) (Kottek *et al.,* 2006).

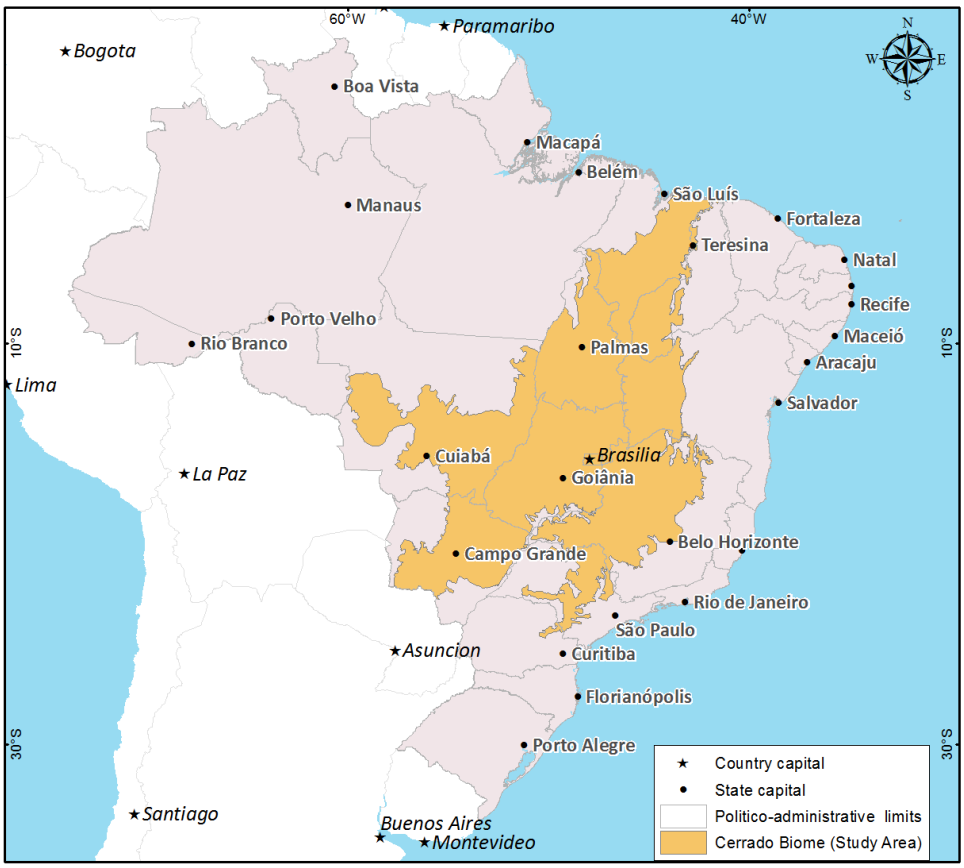


Figure 1. Location of the study area (Cerrado biome) in the Brazilian territory.

Methodological approach

The assessment of land cover changes in the Cerrado was performed based on a systematic sampling scheme with each sampling unit covering an area of 10 km x 10 km, located at every full degree confluence point of latitude and longitude (Figure 2). For each sample unit, ortho-rectified (E)TM Landsat images were obtained for three target years (1990, 2000 and 2010) from the Global Land Survey (GLS) archives (Gutman *et al.*, 2013) of the United States Geological Survey (USGS). A total of 175 sample units were processed for the Cerrado in order to estimate land cover and land cover changes between 1990 and 2010. The sampling design and image processing techniques were developed by the Joint Research Centre (JRC) TREES-3 project (Mayaux *et al.*, 2005; Eva *et al.*, 2012; Achard *et al.*, 2014).

The selected images underwent an extensive pre-processing (Bodart *et al.*, 2011) and processing through a multi-date image segmentation approach using eCognition software (Trimble©). On basis of membership functions, image objects were classified into five land cover classes (Tree Cover - TC, Tree Cover Mosaic - TCM, Other Wooded Land - OWL, Other Land - OL, and Water - W). The classification and change detection methods are fully described in Raši *et al.* (2011, 2013). The classification results of the TREES-3 project underwent an extensive process of correction by national experts. In addition, a consistency assessment based on the interpretation of an independent interpreter was carried out, similar to the approach used by Bodart *et al.* (2013).

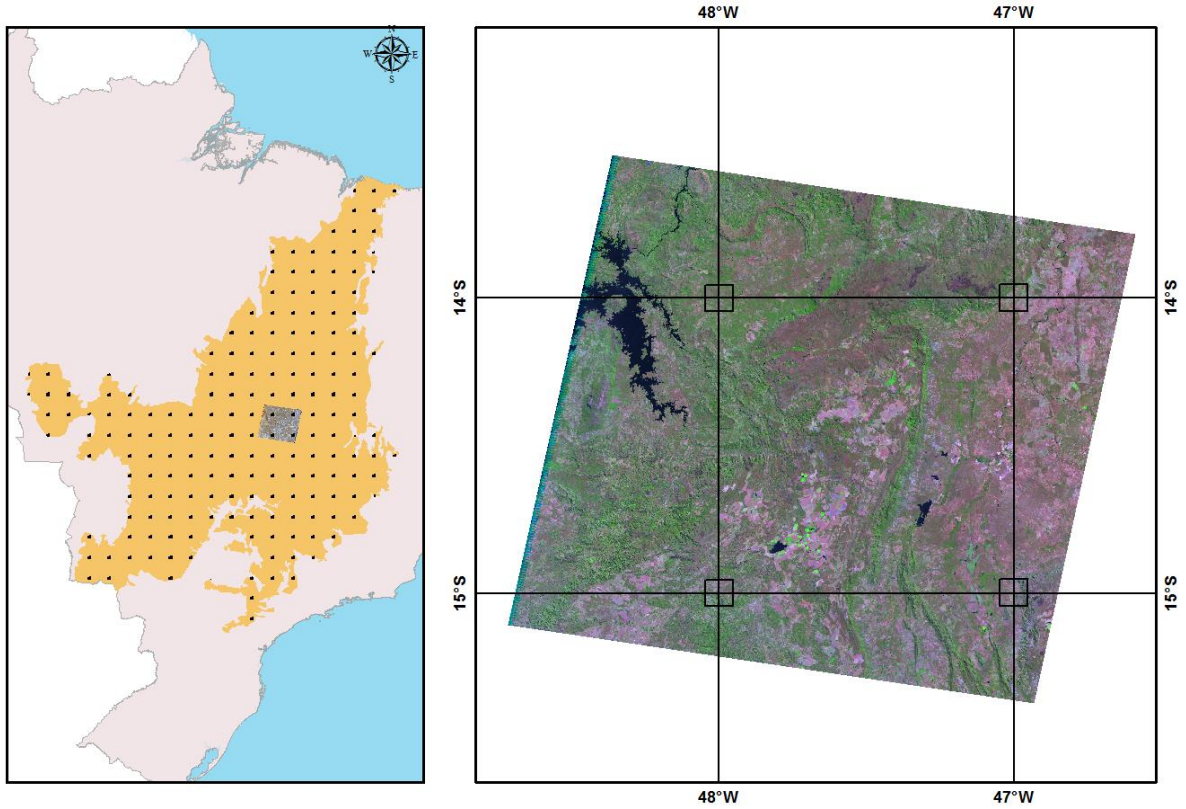


Figure 2. (a) Cerrado biome and the sample units; (b) Landsat scene 221-070 encompassing four sample units (S14W048, S14W047, S15W48, S15W47).

3. Results and discussion

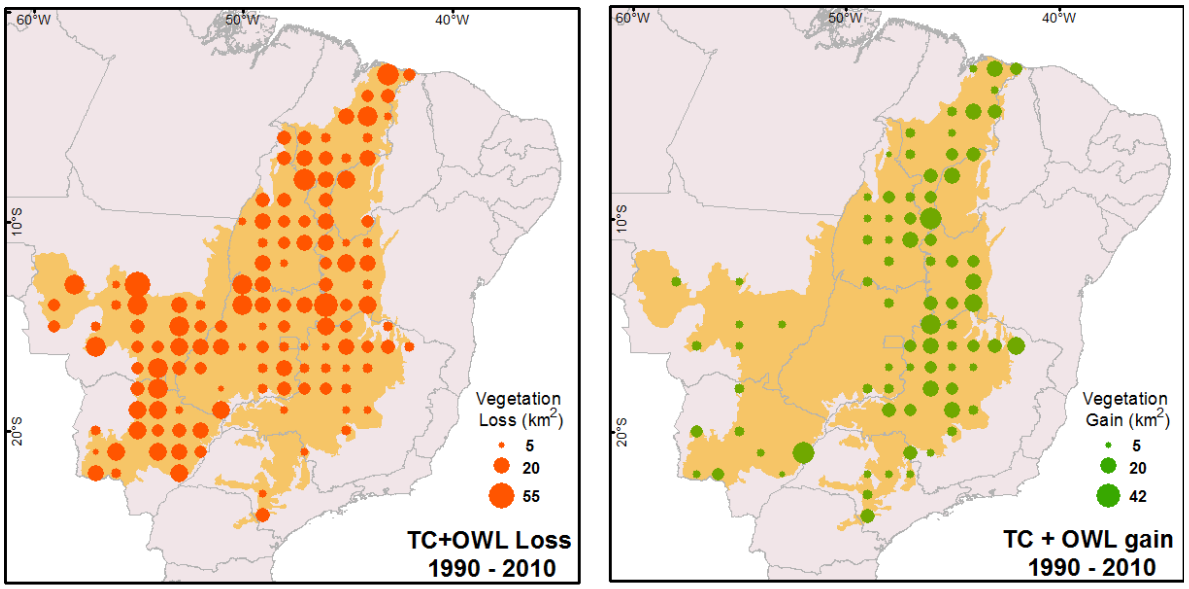
The results were attained with an overall agreement of 85-90% with the interpretation of independent experts considering a broader legend of "natural vegetation" (TC + OWL) and Other Land Cover (OLC). The results indicate that land cover changes in the Cerrado occurred at an average annual rate of -0.61% between 1990 and 2010. In this period, the biome had a net loss of approximately 12 million hectares of natural vegetation. The rates of vegetation loss decreased from the first (-0.79% y^{-1}) to the second (-0.44 % y^{-1}) decade. By 2010, the percentage of remaining Cerrado´s natural vegetation cover was 47% (Table 1).

Table 1. Percentage of land cover (LC) classes in the Cerrado biome in the years 1990, 2000 and 2010.

LC classes (%)/Year	1990	2000	2010
Natural vegetation	53.1	49.1	47.0
Other land cover	46.2	50.2	52.2
Water body	0.7	0.8	0.8

Although the results show a significant loss of natural vegetation over the two decades, we also identified vegetation cover gain for some regions of the Cerrado (predominantly Other Wooded Land) (Figure 3). Gain of Tree Cover is mostly related to tree plantations, mapped as tree cover in this study.

A comparison of our results with those of PROBIO (MMA, 2007; Sano *et al*., 2010) and PMDBBS (MMA, 2009, 2011a, 2011b) (Table 2) showed that this study identified a lower percentage of remaining natural vegetation cover in this biome. Such discrepancy can be partially explained by the differences in the legends (for example, natural grasslands were not mapped as natural vegetation in this study as they were in PROBIO) as well as by methodological aspects.



(a) (b)

Figure 3. (a) Loss of natural vegetation (TC + OWL) per sampling unit between 1990 and 2010 (b) Increase of vegetation cover in some regions of Cerrado (TC + OWL) in the same period.

Table 2. Comparison among the results obtained by this study and those obtained by PROBIO and PMDBBS projects.

	This study		PROBIO	PMDBBS			This study
LC classes (%)/Year	**1990**	**2000**	**2002**	**2002**	**2008**	**2009**	**2010**	**2010**
Natural vegetation	46.2	50.2	38.9	43.7	47.8	48.2	48.5	52.2
Other land cover	53.1	49.0	60.5	55.7	51.6	51.2	50.8	47.0
Water bodies	0.7	0.8	0.6	0.6	0.6	0.6	0.6	0.8

Conclusions

Our method has provided consistent, recent and historical estimates of land cover changes over the Cerrado biome on basis of medium resolution satellite imagery. By 2010, more than 50% of the Cerrado´s original vegetation was already converted into agricultural lands. However, we also identified that some areas experienced gains of Tree Cover and Other Wooded Land.

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