



Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach



René Beuchle^{a, *}, Rosana Cristina Grecchi^a, Yosio Edemir Shimabukuro^{a, b}, Roman Seliger^c, Hugh Douglas Eva^a, Edson Sano^d, Frédéric Achard^a

^a Joint Research Centre of the European Commission, Institute for Environment and Sustainability, Via E. Fermi 2749, 21027 Ispra, VA, Italy

^b Brazilian National Institute for Space Research (INPE), Caixa Postal 515, 12245-970 São José dos Campos, SP, Brazil

^c Universität Leipzig, Institut für Geographie, Johannisallee 19, 04103 Leipzig, Germany

^d Embrapa Cerrados, Caixa Postal 08223, 73301-970 Planaltina, Distrito Federal, Brazil

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ABSTRACT

The main objective of our study was to provide consistent information on land cover changes between the years 1990 and 2010 for the Cerrado and Caatinga Brazilian seasonal biomes. These areas have been overlooked in terms of land cover change assessment if compared with efforts in monitoring the Amazon rain forest. For each of the target years (1990, 2000 and 2010) land cover information was obtained through an object-based classification approach for 243 sample units (10 km × 10 km size), using (E)TM Landsat images systematically located at each full degree confluence of latitude and longitude. The images were automatically pre-processed, segmented and labelled according to the following legend: Tree Cover (TC), Tree Cover Mosaic (TCM), Other Wooded Land (OWL), Other Land Cover (OLC) and Water (W). Our results indicate the Cerrado and Caatinga biomes lost (gross loss) respectively 265,595 km² and 89,656 km² of natural vegetation (TC + OWL) between 1990 and 2010. In the same period, these areas also experienced gain of TC and OWL. By 2010, the percentage of natural vegetation cover remaining in the Cerrado was 47% and in the Caatinga 63%. The annual (net) rate of natural vegetation cover loss in the Cerrado slowed down from $-0.79\% \text{ yr}^{-1}$ to $-0.44\% \text{ yr}^{-1}$ from the 1990s to the 2000s, while in the Caatinga for the same periods the rate increased from $-0.19\% \text{ yr}^{-1}$ to $-0.44\% \text{ yr}^{-1}$. In summary, these Brazilian biomes experienced both loss and gains of Tree Cover and Other Wooded Land; however a continued net loss of natural vegetation was observed for both biomes between 1990 and 2010. The average annual rate of change in this period was higher in the Cerrado ($-0.6\% \text{ yr}^{-1}$) than in the Caatinga ($-0.3\% \text{ yr}^{-1}$).

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Introduction

Consistent information on vegetation cover, and more specifically on forest cover, and its dynamics over time is critical for managing and protecting forest and supporting related political decisions. In South America, historically, most of the efforts for estimating forest cover changes have been focused on the tropical rain forests, with far less attention dedicated to the less humid seasonal regions (Pennington, Lewis, & Ratter, 2006; Portillo-Quintero & Sánchez-Azofeifa, 2010; Santos, Leal, Cortez, Fernandes, & Tabarelli, 2011). Although the Neotropics encompass

considerable areas of savannas and seasonally dry tropical forests (SDTF), research and conservation efforts focussing on these tropical seasonal ecosystems are still very limited (Barreda-Bautista, López-Caloca, Couturier, & Silván-Cárdenas, 2011; Pennington et al., 2006).

The Cerrado and Caatinga Brazilian biomes, which together cover an area of circa 2.8 million km² (IBGE, 2004) or approximately 35% of the Brazilian territory, are placed among the most endangered eco-regions on Earth due to high rates of conversion and few protected areas (Hoekstra, Boucher, Ricketts, & Roberts, 2004). The Cerrado (Brazilian savannas) is the second most extensive biome in South America (Sano, Rosa, Brito, & Ferreira, 2010) and has been identified as one of the world's biodiversity hotspots (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Since the

* Correspondence author.

E-mail address: rene.beuchle@jrc.ec.europa.eu (R. Beuchle).

1970s, this region has suffered heavy losses of natural vegetation due to agricultural expansion (Fearnside, 2001; Silva, Farinas, Felfili, & Klink, 2006). According to Pennington et al. (2006) the areas cleared in the Brazilian Cerrado are greatly exceeding the clearing of the Amazon rain forest. The Caatinga is a heterogeneous biome consisting of a mosaic of shrubs and areas of seasonally dry forest (Leal, Silva, Tabarelli, & Lacher, 2005; Santos et al., 2011), occurring mainly under semi-arid conditions. According to Queiroz (2006), the Caatinga encompasses the largest areas of SDTF in South America. Regardless of the land cover changes and of the unsustainable use of its land resources, the Caatinga has been indicated as one of the least known and most neglected of Brazilian biomes (MMA, n.d.; Santos et al., 2011).

The current understanding of land cover changes in the Cerrado and the Caatinga biomes is still limited. The Brazilian territory is divided into six continental biomes (Amazônia, Cerrado, Caatinga, Mata Atlântica, Pantanal and Pampa) (IBGE, 2004), from which only the Amazônia and Mata Atlântica biomes have been targeted by permanent monitoring initiatives since the 1980s, such as PRODES (Monitoring Brazilian Amazon Forest by Satellite), DETER (Detecting Deforestation in Real Time) for the Amazon or the SOS Mata Atlântica to monitor deforestation over the Mata Atlântica biome (MMA, 2014). Although some study cases have focused on assessing land cover changes in the Cerrado and Caatinga biomes based on medium-resolution satellite imagery (Brannstrom et al., 2008; Coelho et al., 2014; Grecchi, Gwyn, Béné, Formaggio, & Fahl, 2014), only recently biome-scale mapping for these biomes has been carried out by the PROBIO program (Projeto de Conservação e Utilização Sustentável da Diversidade Biológica), in which the percentage of vegetation cover was estimated using Landsat imagery from year 2002 (MMA, 2014). Subsequently, using PROBIO as a baseline, the project *Monitoramento do Desmatamento dos Biomas Brasileiros por Satélite* (PMDBBS) mapped newly cleared areas for 2008 and 2009 for both biomes and for 2010 for the Cerrado biome only. The project estimated deforestation rates for the 2002–2008, 2008–2009 and 2009–2010 periods (MMA, 2009, 2010, 2011a, 2011b, 2011c). PMDBBS has assessed only gross vegetation losses, since vegetation regrowth was not considered. Moreover, there are no data available on annual deforestation rates prior to 2002 for the two biomes (MMA, 2011).

Other initiatives for estimating and monitoring land cover change in these regions include the study of Mantovani and Pereira (1998). They assessed the Cerrado biome's "degrees of anthropization" based on Landsat imagery, mostly from 1992/1993, finding that there were approximately 35% of undisturbed areas, 35% of disturbed Cerrado vegetation (e.g. natural grasslands mixed with pasture) and 30% of heavily disturbed Cerrado vegetation (e.g. intensive agriculture, urban areas). Their results have been reported as difficult to use either because of irreproducible categories (Brannstrom et al., 2008) or for the lack of spatial information (Sano, Rosa, Brito, & Ferreira, 2007). Machado et al. (2004) assessed the entire biome using a MODIS image mosaic (at 1 km × 1 km spatial resolution) for the year 2002 and estimated that approximately 55% of the original (natural) Cerrado vegetation were already converted to other land cover. For the Caatinga, Castelletti, Silva, Tabarelli, and Santos (2003) focused on answering the question "how much of the Caatinga is still remaining?" by assessing the 1:5,000,000 scale Brazilian vegetation map (IBGE, 1993) within the limits of the biome, combined with other auxiliary data (e.g. road maps).

The main initiatives for estimating and monitoring land cover change in the Cerrado and Caatinga biomes are summarized in Table 1.

Many studies claim these biomes have suffered heavy losses (Castelletti et al., 2003; Klink & Machado, 2005; Machado et al.,

2004). However, considerable vegetation gain in these areas has also been reported. Aide et al. (2012), for example, assessed the deforestation and reforestation in Latin America and the Caribbean region between 2001 and 2010 using 250-m Moderate Resolution Imaging Spectroradiometer (MODIS) data and detected that Brazil has experienced both loss and gain of woody vegetation, the gain occurring mainly in the dry areas of northeast Brazil (Caatinga biome). Redo, Aide, and Clark (2013), assessed land cover changes in the Brazil's "dryland ecoregions" (Cerrado, Caatinga and Mato Grosso seasonal forests) based on MODIS data from 2001 to 2009, and reported increases in woody vegetation both in the Cerrado and the Caatinga biomes. However, these dynamics of loss and regrowth of natural vegetation has neither been assessed through medium resolution satellite imagery (e.g. Landsat (E) TM), nor prior to year 2000.

While remote sensing technology has been the major provider of cost-effective, high-quality datasets for land surface monitoring in the past decades (Lunetta, Ediriwickrema, Johnson, Lyon, & McKerrow, 2002), mapping large forest areas continuously ("wall-to-wall") with medium to high resolution satellite imagery (e.g. with 30 m × 30 m resolution Landsat images) is still challenging and also often unrealistic for large areas due to the lack of resources. Lately, an attempt of global wall-to-wall mapping of tree cover and tree cover changes (between the years 2000 and 2012) has been made by Hansen et al. (2013). However, the usability and the consistency of the results is under question in particular for the seasonal tropical domain (Bellot, Bertram, Navratil, Siegert, & Dotzauer, 2014; Hansen et al., 2014; Tropek et al., 2014). Sampling approaches have been proposed (Mayaux et al., 2005; Ridder, 2007) and used as an alternative, implying advantages such as reducing costs and efforts while providing accurate estimates of forest cover and forest cover changes (Achard et al., 2002; Hansen et al., 2008; Potapov et al., 2011). In this context, the aim of the present work is to provide consistent information on historical and recent vegetation cover changes in the Brazilian Cerrado and Caatinga biomes based on the analysis of Landsat imagery acquired over a systematic sample of 10 km × 10 km size units.

Materials and methods

Study area

The Cerrado and Caatinga biomes are seasonal ecosystems characterized by distinct dry and wet seasons. They are located in the centre and the Northeast of Brazil, covering nearly 35% of the Brazilian territory (Fig. 1).

The Caatinga biome occupies an area mostly coincident with the region called "Brazilian semi-arid", which is described as the most biodiverse and the most populated semi-arid region in the world (MMA, 2011). The Caatinga vegetation ranges from the deciduous low shrub to small patches of tall dry forests, often fragmented, with a height of up to 20 m (Prado, 2003). This region receives from 240 to 1500 mm annual rainfall, but mostly it receives less than 750 mm/year (Leal et al., 2005; Prado, 2003). Rainfall in this region is extremely irregular, in both its temporal and geographical distribution; usually more than 75% of the total annual rainfall occurs within three months (Prado, 2003). The annual variations are large; droughts can last for years (Leal et al., 2005). The climatic conditions of the Cerrado are less extreme compared to those of the Caatinga: the rainy season is longer (6–7 months) and the overall amount of rain is higher with 800–2000 mm/year (Ratter, Ribeiro, & Bridgewater, 1997). The typical Cerrado vegetation (outside the often tall and dense evergreen gallery forests) ranges from closed or open canopy deciduous and semi-deciduous forest with a

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