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Land use and land cover changes in the Brazilian Cerrado: A multidisciplinary approach to assess the impacts of agricultural expansion

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A B S T R A C T

Expansion of agricultural lands have shaped Brazilian Cerrado landscapes in recent decades; however, the environmental consequences of these transformations are still poorly assessed. This paper presents a multidisciplinary approach used to assess historical land-use and land-cover (LULC) changes and their impacts on the environment in southeast Mato Grosso State, a region where the Cerrado has been intensively converted into agricultural lands. The methodology encompassed three main stages: (1) quantifying LULC changes using remote sensing data, (2) assessing LULC change impacts on vulnerable lands (e.g. erosion prone areas and wetlands), and (3) summarizing preceding information into key environmental indicators, assessed within the Pressure-State-Response framework (PSR) of the Organization for Economic Co-operation and Development (OECD). The results indicated a drastic landscape transformation in the selected area, which evolved from predominantly vegetated to a consolidated agricultural region. Crops expanded at high rates from 1985 to 1995, occupying the majority of the lands suited for agriculture. In the following decade, crops continued to expand and encroached into fragile environments (e.g. wetlands and more erodible soils). As a result, from 1985 to 2005, the area lost approximately 42% of its natural vegetation and erosion risks increased significantly. Our integration of land-use change information with intrinsic environmental vulnerabilities allowed a deeper understanding of LULC changes consequences and provided environmental indicators. This offered a synoptic view of how LULC changes occurred and how they affected the environment at a landscape scale. Furthermore, the assessment of the indicators using the PSR framework, helped to clarify cause–effect relationships thus furnishing key information of value to decision-makers and future comparisons with other areas.

Introduction

Land-use and land-cover (LULC) changes are reshaping landscapes all over the world at unprecedented rates, affecting environmental processes at multiple scales (Ellis & Pontius, 2007). The ever increasing demand for land resources (e.g. food, fresh water, fuel) together with unsustainable land management practices have resulted in increasing environmental degradation, which is seriously menacing the world's food production capability (Nellemann et al., 2009). Therefore, understanding man-induced landscape changes and providing decision makers with reliable information on the status of the environment have become crucial.

Cultivated systems constitute the single greatest type of anthropic land use (Cassman et al., 2005). While agriculture is unquestionably important, as it constitutes the “ultimate provider of food, fiber and shelter for the human population” (Smith & McDonald, 1998, p. 15), the massive cultivation of land in order to obtain ecosystem goods often has impacts on other ecosystem services, for example freshwater provisioning, climate and biogeochemical cycles regulation, and soil fertility maintenance

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(DeFries, Foley, & Asner, 2004). The impacts of LULC changes on the environment vary according to the type of change (e.g. forest clearing for agriculture or urban expansion; wetland drainage) and the biophysical and ecological settings (DeFries et al., 2004). Thus, a starting point to understand the effects of LULC changes is by obtaining detailed and accurate information about the characteristics of changes (e.g. rates and trends) (Loveland & Defries, 2004). Subsequently, coupling land-use changes with bioclimatic and edaphic characteristics allows a deeper understanding of the consequences and can serve to signal places which are more at risk of degradation (Asner, DeFries, & Houghton, 2004).

As landscapes rapidly change, land-use decisions have to deal with difficult choices concerning the balance between the satisfaction of human needs and the unintended environmental consequences (DeFries et al., 2004). Environmental indicators have been used for the purpose of providing and exchanging information about the environmental quality and are an important approach in dealing with environmental changes. They can provide policymakers with information on environmental issues that can assist in the evaluation of their seriousness or the definition of priority actions (Smeets & Weterings, 1999). Although indicators are regularly employed for economic and social issues, for example gross national product as an indicator of total wealth, or life expectancy and literacy rates as indicators of social well-being, they are used far less often to assess, monitor, and evaluate the impact of anthropic interventions in the landscape (Dumanski, Gameda, & Pieri, 1998). Moreover, in order for indicators to be developed, reliable environmental data are required. However, Segnestam (2002, p. 66) called attention to the fact that in practice, the relationship between primary data and indicators/indices is inverted, with indicators being developed with less data than is statistically desirable.

Remote sensing has played a key role in the past decades, providing cost-effective ways to detect and monitor changes at various scales (Lunetta, Ediriwickrema, Johnson, Lyon, & McKerrow, 2002) and have a great potential for deriving indicators, which respect elementary requirements of science and specifically statistical requirements. Still, understanding the dynamics, causes, and consequences of man-induced land changes requires interdisciplinary approaches, which combine for example, land observation and spatially explicit modeling, assessment of vulnerability, resilience, among others (Turner, Lambin, & Reenberg, 2007). A great deal of research has used remote sensing techniques for mapping and assessing land use/cover changes within a temporal window, from global to local scales, for example Kamusoko and Aniya (2007), Brannstrom et al. (2008), Schulz, Cayuela, Echeverria, Salas, and Rey Benayas (2010), Abd El-Kawy, Rød, Ismail, and Suliman (2011), Bodart et al. (2013), Grecchi, Gwyn, Bénié, and Formaggio (2013), Achard et al. (2014). Some studies, in addition to LULC changes, have characterized landscape fragmentation (Kamusoko & Aniya, 2007; Pôças, Cunha, & Pereira, 2011; Sivrikaya et al., 2007). Others, such as Chaplin and Brabyn (2013), have combined remote sensing change detection with GIS techniques to assess the impacts of tourism on forest. Dewan and Yamaguchi (2009) used satellite images together with socioeconomic variables for assessing land use/cover changes and urban expansion in Greater Dhaka, Bangladesh. Agyemang, McDonald, and Carver (2007) applied the Driving-Force–Pressure–State–Impacts–Response (DPSIR) framework to assess environmental degradation in northern Ghana, coupling remote sensing change detection (for state indicators) with community validation to derive the other indicators.

The present study focuses on the highlands of central Brazil, the area of occurrence of the Cerrado biome (Brazilian savannas). This Brazilian biome, the second in extent after the Amazonian, has undergone profound landscape transformations recently, being among the world's hotspots of cultivated land expansion in the past 50 years (Ramankutty, Foley, & Olejniczak, 2002). This region carries a “double burden” of being a complex and rich natural environment, placed among the world's biodiversity hotspots (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000), and at the same time being perceived as favorable land for agricultural expansion, which has emerged as a key factor transformation for this region. The Cerrado was long considered unsuitable for agriculture because of its poor soils; however, agronomical and technological advances, government incentives, together with physiographic characteristics (favorable to mechanization) and the low price of land all contributed to transforming the Cerrado into a booming agricultural region (Bickel & Dros, 2003; Goedert, 1983). This drastic transformation has many potential negative consequences (e.g. biodiversity loss, invasive species, soil erosion, water pollution) (Klink & Machado, 2005), which are still poorly assessed.

There is a general lack of integrated assessments of the Cerrados for the purpose of understanding and quantifying the changes the biome has undergone due to anthropic pressures, and how these pressures are reflected in changes in the quality and quantity of the natural resources at a landscape scale. These understandings are urgent, and can greatly contribute to devise strategies for a more sustainable future for this region. In this context, the aim of this study was twofold: (1) linking land-use and land-cover changes to terrain vulnerabilities through a remote sensing/GIS modeling approach in order to assess their impacts on the environment at a landscape scale, and (2) summarizing these information on land-use and environmental changes into key environmental indicators and assessing them using the OECD's Pressure-State-Response framework.

The study area

The selected area of interest (AOI) is located in the southeast portion of Mato Grosso State (MT) in Brazil, the Primavera do Leste region, a place where the Cerrado biome has been intensively converted into agricultural lands. It consists of part of the upper Mortes river basin, totaling 15,550 km^2 in area (Fig. 1). This area is part of the Planalto dos Guimarães geomorphologic unit and encompasses extensive areas of flat to gently rolling relief, which favors the expansion of mechanized agriculture. The main municipalities in this region, Primavera do Leste and Campo Verde, are among the highest producers of soybean, corn and cotton in Mato Grosso State, using highly intensive cropping systems (CONAB, n.d.). Agriculture in this region started in the 1970s, initially with the cultivation of rice crops on newly cleared areas, followed by pasture. In the 1980s soybean crops expanded with the implementation of soil acidity correction practices and the availability of better-adapted crop varieties to the Cerrado conditions (Wallis, 1997). Other important crops in the area are maize (introduced in the 1990s in rotation with soybean), and cotton (cultivated since 1996) (Portillo, 2007, p. 117). Currently, the remaining natural vegetation, dominated by the Cerrado physiognomies and gallery forests, is concentrated mainly in the Sangradouro/Volta Grande Indigenous Protected Area and along the rivers.

The region has a climate marked by a distinct dry season from May to September, which is classified as tropical wet-dry or savanna climate (Aw) according to the Köppen classification (Moreno & Higa, 2005). The main soils in the area are the Latossolos (equivalent to Haplustox in the USA Soil Taxonomy (USDA, 2006)), which are deep, well-drained, non-hydromorphic mineral soils. They occur in 67% of the AOI. In general, Latossolos are resistant to surface erosion under natural conditions or when managed