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Deforestation analysis in protected areas and scenario simulation for structural corridors in the agricultural frontier of Western Bahia, Brazil

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ABSTRACT

The aim in this paper was to evaluate the spatial distribution of protected areas defined by law and their importance as structural corridors. The study area was 7,559,783.69 ha located in Western Bahia (Northeast Brazil), restricted to the limits of the Urucuia Group (Upper Cretaceous), where there is strong agribusiness growth. Currently, a major dilemma in Brazilian public policy arises from the conflicting interests of environmental conservation and increased food production. Brazilian environmental protection policies include the implantation of Protected Areas (Full Protection Units and Sustainable Use Units) and the adoption of the National Forest Act (Permanent Preservation Areas and Legal Reserves). In this context, we delimited illegal land-use in Permanent Preservation Areas (PPAs) adopting the intersection between land-use/land-cover data from PRISM/ALOS image classification for the years 2007–2010 and PPA vectors. We performed the temporal analysis in PAs considering land-use/land-cover data from Landsat TM image classification for the years 1988, 1992, 1996, 2000, 2004, 2008 and 2011. Finally, we performed a Morphological Spatial Pattern Analysis (MSPA) to evaluate whether PPAs alone are sufficient as structural corridors. Hypothetical scenarios were simulated to increase the potential of PPAs as structural corridors. The calculation of MSPA attributes was conducted considering 3 edge widths: 15 m (1 pixel), 510 m (34 pixels), and 1005 m (67 pixels). Four scenarios were simulated, considering a gradual increase in preserved areas. The results show that illegal land use is contained within PPA and protected areas. The scenario simulations present alternatives to increase the connectivity of the fragments and ensure the maintenance of ecological and hydrological services. Rapid agricultural expansion without proper landscape planning can compromise the sustainability of ecosystem services and the recharge zone of the Urucuia aquifer.

1. Introduction

Brazilian agriculture has achieved high productivity levels, becoming important in the global market and contributing greatly to its economic development (Abbade, 2014; Figueiredo et al., 2012). Over the past three decades (since 1990), the farming sector has shown significant growth, doubling agricultural production volume and tripling livestock production (OECD/FAO, 2015). In 2013, Brazil reached the following production level: world's second largest agricultural exporter; together with the agri-food industries earned more than $86 billion (36% of total exports); largest supplier of soybeans, sugar, orange juice and coffee; a major exporter of tobacco and poultry; and high production of maize, rice and beef for the domestic market (OECD/FAO, 2015).

The growth of Brazilian agriculture is widely credited to expansion in the use of the Brazilian *Cerrado* or savanna (Rada, 2013). Over recent decades, public policy has encouraged agricultural growth in this region. Since the 1970s, the Brazilian government has created funding programs for irrigation and modernization of agriculture; expansion of rural credit; investment in research and

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technology; significant export-led growth; and reduction in government intervention and trade barriers (Ávila et al., 2010; Pereira et al., 2012; Castro and Teixeira, 2012). These government policies resulted in increased migration of farmers from the southern region of the country, causing rapid expansion of mechanized agriculture (Brannstrom and Brandão, 2012; Oliveira et al., 2014) and increased landscape fragmentation (Oliveira et al., 2015).

Therefore, the success of agriculture has promoted economic growth, but has also been associated with the widespread devastation of *Cerrado* ecosystems. Economic development policies have taken precedence over environmental protection policies (Martha Jr et al., 2010). The implantation of Protected Areas (PA) according to the National System of Conservation Units (NSCU) (Brazil, 2000) and the adoption of National Forest Act (NFA) (Brazil, 1965) were the main strategy for environmental conservation in the Brazil, having great influence over land use (Metzger, 2010; Metzger et al., 2010; Sparovek et al., 2012; Payés et al., 2013). The NFA is an important policy for ecosystem conservation establishing: (a) Permanent Preservation Areas (PPA), ecologically sensitive areas designed for mandatory conservation; and (b) Legal Reserves (LR), minimum percentage of native vegetation that the landowner should maintain preserved; specifically for the *Cerrado* this value is 20% of the area. According to Law 12,727, October 17, 2012 (Brazil, 2012a,b), LRs should be defined individually and attached to rural property documentation, hindering the systematization of information in a database.

The NSCU, Law 9985 promulgated on July 18, 2000 (Brazil, 2000), establishes the criteria for creation of Protected Areas (PA), which can be subdivided into twelve categories, grouped into Full Protection Units (FPU) and Sustainable Use Units (SUU). The FPUs aim to preserve nature with indirect use of natural resources (e.g. scientific research, environmental education, and visitation), while SUU aim to reconcile conservation and sustainable use of natural resources. The main objectives of PAs are the following factors (Brazil, 2000): (a) conservation of varieties of biological species and genetic resources; (b) protection of endangered species; (c) preservation and restoration of the diversity of natural ecosystems; (d) protection of natural scenic beauty; (e) restoration of degraded ecosystems; (f) promotion of scientific research.

In addition, this region is located on the large Urucuia aquifer and at the headwaters of the São Francisco and Parnaíba Rivers, which are the most important fluvial systems that serve Northeast Brazil. This is the poorest region of the country and long subject to problems with drought and underdevelopment in the neighboring semi-arid Caatinga biome to the east, which once again is being castigated by a periodic drought now into its fifth year. These environmental and social functions by themselves more than justify preserving the natural vegetation of the Urucuia Aquifer recharge zone.

Brazil possesses the world's largest PA system with 1930 protected areas (1,513,828 km^2) (MMA, 2015), and 585 Indigenous Lands (1,135,182 km^2) (FUNAI, 2015). However, the Brazilian *Cerrado* contains only 8.2% of the natural area and, of this, only 2.9% are FPU (MMA, 2015). Moreover, even with specific environmental legislation, illegal land use continues in protected areas of Brazil (Sparovek et al., 2010; Nolte et al., 2013). At present, a major dilemma in public policy arises from the conflicting interests of environmental conservation and the need for increased food production, which is necessary due to population growth and malnutrition worldwide (Alarcon et al., 2015). In this context, landscape planning can establish mechanisms of increased food production minimizing environmental damage. One of the main challenges is to understand the effectiveness of law for ecosystem services under different policy scenarios, identifying strategies for better arrangement of preserved areas.

Protected areas, in many cases, do not a proper nature conservation design because they are not connected to each other. Thus, wildlife corridors can minimize both the consequences from human impact and interconnectivity. They are fundamental for biological conservation and allow for connecting wildlife separated by anthropological actions, such as agricultural activities, to aid in inhibiting adverse effects and enable biological fluxes (Uezu et al., 2005). Fragment size and connectivity make up a structural corridor to maintain species in disjointed landscapes (Crooks et al., 2001) in which connected patches are the best sites for reestablishment (Schultz and Crone, 2005). In landscape planning, the structural corridors are essential for biodiversity assessment and maintaining landscape permeability.

Currently, the Western Bahia region on the geological formation of the Urucuia Group (Upper Cretaceous) is one of the main areas of agricultural expansion in the *Cerrado* biome. In a short time, the mechanized farming has replaced traditional agriculture (before 1970) characterized as ultra-extensive, containing low stocking rate of native pastures and interventions based on local rural experience of the natural system (Pierson, 1972). The main driving forces for agribusiness growth in this region are the environmental factors characterized by flat topography and deep soils (Oxisols) adequate for agricultural mechanization and water availability from the rainfall, rivers, and groundwater. Precipitation is concentrated in the rainy season (from November to April) and annual rainfall ranges from 800 mm in the east to 1600 mm in the west. However, agricultural growth caused intense Cerrado deforestation, increasing from 795,502.61 ha in 1988 to 2,804,679.75 ha in 2011 (Oliveira et al., 2015). The annual deforestation rate (approximately 1.16% per year or 87.355,53 ha per year) in this region is higher than the 0.6% per year registered for the Brazilian *Cerrado* Biome in the period 2002–2010 (MMA-IBAMA, 2010). In addition, this region is located on the large Urucuia aquifer and headwaters of the São Francisco and Parnaíba rivers, which are the most important fluvial systems that serve the Brazilian Northeast region, which undergoes serious problems of drought and poverty. Natural vegetation preserves Urucuia Aquifer recharge zone, which regulates the flow of the tributaries from the left bank of the center region of the São Francisco River and has its groundwater used in the supply of farms, villages and irrigation projects (Gaspar and Campos, 2007; Gaspar et al., 2012). Because of the high anthropogenic pressure and environmental relevance, the remaining vegetations of Western Bahia have become priority areas for conservation (MMA, 2002).

In this article we aim to evaluate the spatial arrangement in conservation areas defined by law and their importance as structural corridors. The study area is Western Bahia region (7,559,783.69 ha), covering nine municipalities of Bahia State: Formosa do Rio Preto, Riachão das Neves, Barreiras, Luís Eduardo Magalhães, São Desidério, Baianópolis, Correntina, Jaborandi, and Cocos (Fig. 1). In this context, we performed a Morphological Spatial Pattern Analysis (MSPA) under agriculture intensification and the studied role of PAs and PPAs. The analysis evaluates whether the PPAs alone are sufficient as structural corridors among PAs and investigates hypothetical scenarios considering the use of LR to increase the connection potential of PPAs.

2. Material and methods

2.1. Mapping of the permanent preservation areas

In the study area, the PPAs contain plateau edges and water bodies (drains, rivers, springs, lakes, and artificial reservoirs). The hydromorphic soils were also mapped to establish alternative scenarios for conservation. The PPA delimitation used a buffer according to the width specified in the NFC (Table 1).