CERRADO NATIONAL PARKS BEYOND BIODIVERSITY
CONSERVATION: CULTURAL ECOSYSTEM SERVICES AND
ENVIRONMENTAL RISKS

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A thesis submitted to the faculty at the University of Brasilia in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Program in Environmental Sciences.

Area of Concentration: Structure, Dynamics and Environmental Conservation

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PARQUES NACIONAIS DO CERRADO PARA ALÉM DA CONSERVAÇÃO DA BIODIVERSIDADE: SERVIÇOS ECOSSISTÊMICOS CULTURAIS E RISCOS AMBIENTAIS

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ARIANE DE ALMEIDA RODRIGUES

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ABSTRACT

Buffer zones around protected areas can minimize negative human impacts and stimulate the sustainable use of natural resources. Conversely, land-use in these zones can potentially deteriorate ecological processes and biodiversity conservation inside the area under protection. In this study, we address human-environment interaction in the buffer zones of 13 Brazilian Cerrado National Parks, with a twofold perspective: as vulnerable ecosystems under land-use change pressure, and as important sources of services that sustain human wellbeing. Two analyses were conducted. The first one was aimed at revealing opportunities to expand and complement the touristic attractions around eight Cerrado National Parks opened for visitation, by taking advantage of their scenic views. The methods were based on remote sensing derived landscape biophysical attributes, three key categories related to visual and ecological qualities and six indicators. Results identified profiles of the selected parks, relating their biophysical characteristics to their main touristic potential. Strong hilly topographies, in general, were associated with wide visual scale and high complexity while flat topographies favored water related recreational services. The second analysis investigated protected areas more sensitive to land use and land cover change disturbances carried by hydrologic flows. Three factors that influence natural areas sensitivity, encompassing soil and hydrologic natural characteristics, and measures of exposure from land use and land cover change in the buffer zone were obtained from remote sensing data. The results revealed three groups of parks to be targeted for prevention and mitigation measures. The group classified as high risk sustains high rates of conversion in their buffer zones and additional characteristics that aggravate potential impacts. The group classified as high land-use exhibited the highest rates of conversion in their buffer zones, and should also be prioritized for adaptive management. Another group of parks exhibited high sensitivity to disturbances from hydrologic flows and should be targeted for prevention of land use and land cover change in the buffer zone. Although our research focused on National Parks located in the Brazilian Cerrado, the studied area is representative of tropical ecosystems with relevant specie richness and high land use conversion pressure.

**Keywords:** scenic view, tourism, erosion, savanna, contamination.
RESUMO EXPANDIDO

As zonas de amortecimento no entorno de unidades de conservação podem minimizar os impactos antrópicos negativos e estimular o uso sustentável dos recursos naturais. Por outro lado, o uso da terra nessas zonas pode potencialmente deteriorar os processos ecológicos e a conservação da biodiversidade dentro da área protegida. Neste estudo, abordamos a interação homem-ambiente nas zonas de amortecimento de 13 Parques Nacionais do Cerrado Brasileiro, sob dupla perspectiva: como ecossistemas vulneráveis sob intensa pressão de conversão do uso da terra e como importantes fontes de serviços que sustentam o bem-estar humano. Foram realizadas duas análises. A primeira teve como objetivo apontar oportunidades para expandir e complementar as atrações turísticas em torno de oito Parques Nacionais abertos para visitação, aproveitando suas vistas panorâmicas. Os métodos foram baseados em atributos biofísicos derivados de sensoriamento remoto, três categorias principais relacionadas à qualidade visual e ecológica e seis indicadores. Os resultados identificaram perfis para os parques selecionados, relacionando suas características biofísicas com seu principal potencial turístico. As topografias mais acidentadas, em geral, foram associadas a maior amplitude de escala visual e complexidade, enquanto topografias planas favorecem serviços recreativos relacionados à água. A segunda análise investigou áreas protegidas mais sensíveis a distúrbios de mudanças do uso e cobertura do solo transportadas por fluxos hidrológicos. A partir de dados de sensoriamento remoto, foram identificados três fatores que influenciam a sensibilidade ambiental, abrangendo características naturais pedológicas e hidrológicas, bem como medidas de exposição à conversão do uso e cobertura do solo na zona de amortecimento. Os resultados revelaram três grupos de parques a serem priorizados para aplicação de medidas de mitigação e prevenção. O grupo classificado como de alto risco sustenta altas taxas de conversão em suas zonas de amortecimento e outras características que agravam os impactos potenciais. O grupo classificado como de alto uso da terra mostrou as maiores taxas de conversão em suas zonas de amortecimento e também deveria ser priorizado para manejo adaptativo. Outro grupo de parques exibiu grande sensibilidade a perturbações nos fluxos hidrológicos e deveria ser direcionado para prevenção de mudanças de cobertura e uso da terra na zona de amortecimento. Embora o estudo tenha focado em Parques Nacionais localizados no Cerrado brasileiro, a área de estudo é representativa de ecossistemas tropicais com relevante riqueza de espécies e alta pressão de conversão do uso da terra.

Palavras-chave: vista cênica, turismo, erosão, savana, contaminação.
To my supporting and loving family,
To my dear husband,
To my brilliant advisors,
To all the friends from the University of Brasília,
Thank you!
I am deeply grateful to have you in my life.
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<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS</td>
<td>Advanced Land Observing Satellite</td>
</tr>
<tr>
<td>ANA</td>
<td>Brazilian National Water Agency (Agência Nacional de Águas)</td>
</tr>
<tr>
<td>BA</td>
<td>Bahia State, Brazil</td>
</tr>
<tr>
<td>CDB</td>
<td>Convention of Biological Diversity</td>
</tr>
<tr>
<td>CES</td>
<td>Cultural Ecosystem Service(s)</td>
</tr>
<tr>
<td>CONAMA</td>
<td>National Environmental Council (Conselho Nacional de Meio Ambiente)</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>DF</td>
<td>Distrito Federal, Brazil</td>
</tr>
<tr>
<td>DSM</td>
<td>Digital Surface Model</td>
</tr>
<tr>
<td>ES</td>
<td>Ecosystem Services</td>
</tr>
<tr>
<td>FUNATURA</td>
<td>Fundação Pró-Natureza (Fundação Pró-Natureza)</td>
</tr>
<tr>
<td>GO</td>
<td>Goiás State, Brazil</td>
</tr>
<tr>
<td>IBGE</td>
<td>Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)</td>
</tr>
<tr>
<td>ICMBIO</td>
<td>Chico Mendes Institute for Biodiversity Conservation (Instituto Chico Mendes de Conservação da Biodiversidade)</td>
</tr>
<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
</tr>
<tr>
<td>JAXA</td>
<td>Japan Aerospace Exploration Agency</td>
</tr>
<tr>
<td>LULCC</td>
<td>Land Use and Land Cover Change</td>
</tr>
<tr>
<td>MA</td>
<td>Maranhão state, Brazil</td>
</tr>
<tr>
<td>MATOPIBA</td>
<td>Maranhão, Tocantins, Piauí and Bahia Cerrado region</td>
</tr>
<tr>
<td>MEA</td>
<td>Millennium Ecosystem Assessment</td>
</tr>
<tr>
<td>MG</td>
<td>Minas Gerais state, Brazil</td>
</tr>
<tr>
<td>MMA</td>
<td>Brazilian Ministry of Environment (Ministério do Meio Ambiente)</td>
</tr>
<tr>
<td>MODIS</td>
<td>Moderate-Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>MS</td>
<td>Mato Grosso do Sul state, Brazil</td>
</tr>
<tr>
<td>MT</td>
<td>Mato Grosso state, Brazil</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NP(s)</td>
<td>National Park(s)</td>
</tr>
<tr>
<td>PA(s)</td>
<td>Protected Area(s)</td>
</tr>
<tr>
<td>PI</td>
<td>Piauí State, Brazil</td>
</tr>
<tr>
<td>SNUC</td>
<td>National System of Conservation Units (Sistema Nacional de Unidades de Conservação)</td>
</tr>
<tr>
<td>SRTM</td>
<td>Shuttle Radar Topography Mission</td>
</tr>
<tr>
<td>TNC</td>
<td>The Nature Conservancy</td>
</tr>
<tr>
<td>TO</td>
<td>Tocantins State, Brazil</td>
</tr>
<tr>
<td>UNEP-WCMC</td>
<td>United Nations Environment World Conservation Monitoring Centre</td>
</tr>
</tbody>
</table>
Societies are not isolated systems, they are connected to broader ecological systems from which they withdraw goods and services for their maintenance. The benefits that people obtain from natural systems are ecosystem services (ES) (MEA 2005a), characterized by stocks and flows of matter and energy. Although demands of society for ES are often determined by political and socio-economical decisions, the capacity of ecosystems to supply these services is governed by the laws of thermodynamic and mass conservation (Burger et al. 2012).

The supply of ES corresponds to the ecosystem’s ability to provide a group of services and products beneficial to society in a given location and period (Burkhard et al. 2012). The calculation of the current supply depends on the demand, which corresponds to the total services consumed by the social group in a given area, in the same period (Burkhard et al. 2012). In general, there is a separation between places that produce ES and places where these services are consumed. In globalized markets, this separation includes international displacements of nutrients, biomass, and extensive socio-environmental impacts, that feedback reducing the capacity of ecosystems to sustain the production in the long term (Foley et al. 2005, Burger et al. 2012, Austin et al. 2013, Godar et al. 2016). The scenario in Brazil is illustrative of that vicious circle. Brazil is a leading exporter of agricultural products (Martinelli et al. 2010), a position sustained with high levels of land concentration and deforestation (Lapola et al. 2014). There is a current focus on short-term over long-term needs that produces extensive environmental imbalances worldwide, representative of our current era, the Anthropocene (Foley et al. 2005).

The Anthropocene is characterized by deep human influence on the planet, including the lithosphere, atmosphere, hydrosphere and biosphere (Crutzen 2002, Zalasiewicz et al. 2011, Richter et al. 2015). Human activities have pushed the planet outside the expected range of variability for key ecological processes and increased the risk of abrupt planetary environmental changes (Rockström et al. 2009). Land use and land cover change (LULCC) is one of the human-determined environmental modifications that have scaled from local to global influence. LULCC is a driver of global environmental change with cascading effects. It impacts climate, water
balance, air quality, biogeochemical cycles, biological diversity, transmission of diseases and many other ecological processes, with possible long term decline in human wellbeing (Foley et al. 2005).

Nevertheless, among the subset of global ecosystem boundaries, land-use change is below the zone of high risk (Steffen et al. 2015). This perspective on LULCC boundaries, however, considers major tropical, temperate and boreal forests controls over climate (Steffen et al. 2015). Non-forest ecosystems are underestimated, encompassing some of the biodiversity hotspots, Earth’s most biologically rich and threatened areas (Myers et al. 2000). This is the case of the Cerrado, the Brazilian savanna biome, one of the 36 current world hotspots for biodiversity conservation (Critical Ecosystem Partnership Fund 2017).

The Cerrado is Brazil’s second largest biome, after the Amazon. It occupies an area of over 2 million km$^2$ (IBGE 2004) which is comparable to the combined area of England, France, Germany, Italy and Spain (Lahsen et al. 2016). The heterogeneity of relief, soils, climate and fire regimes along the Cerrado create a vast array of vegetation cover or plant physiognomies, establishing a gradient of grasslands, savannas and forests (Eiten 1972, 1977, Ribeiro and Walter 1998, Oliveira-Filho and Ratter 2002). Climate variability is one of the major controls over the ecosystem processes. Cerrado’s climate is characterized by strong seasonality, with five to six months of water deficit throughout the year (from April/May until September/October) (Eiten 1972, Silva et al. 1998).

The heterogeneity of habitats sustains the most biologically rich savanna in the world (Klink and Machado 2005). The Cerrado concentrates one third of Brazilian biodiversity (Silva and Bates 2002, Klink and Machado 2005), with high endemism for some groups, such as lizards (45%), upper plants (44%), amphibians (50%) and herbaceous plants (70%) (Machado et al. 2008). The biological diversity is highly threatened by the loss of habitats. The intense LULCC process in the Cerrado started in the early 1970s, to make way for the expansion of Brazilian agricultural production, driven by the demands of the international markets (Klink and Moreira 2002, Mueller and Martha Júnior 2008). About 43% of its original natural vegetation cover was suppressed in a very short time span and converted to cultivated pasture (25.5%), annual (8.5%) and perennial (3.1%) crops (MMA 2015).

Nowadays, the Cerrado remains highly threatened. Despite the tendency towards decoupling agricultural production and LULCC (Lapola et al. 2014),
deforestation still advances around 6,000 km² per year in the Cerrado (MMA 2015). Native vegetation loss is higher in the northern region, in areas suitable for agriculture that still hold large extents of Cerrado, mostly in the states of Maranhão, Tocantins, Piauí and Bahia, a region known as MATOPIBA (Spera et al. 2016). The accumulated and ongoing LULCC in the Cerrado threatens not only the rich biodiversity, but also the far-reaching benefits that societies obtain from this ecosystem (MEA 2005b) and that have been overlooked (Lahsen et al. 2016).

The hydrological services provided by the Cerrado for freshwater recharge and distribution are critical for Brazil and South America. The biome feeds water for eight of the 12 major Brazilian hydrologic basins, contributing to 94% of the São Francisco, 71% of the Tocantins-Araguaia and 71% of the Paraná-Paraguai basins (Lima and Silva 2005). The extensive presence of deep and well-drained Oxisols (46% of the Cerrado) (Reatto and Martins 2005), along with native vegetation root systems, provide an essential service to recharge national aquifers (Oliveira et al. 2005). Cerrado’s vegetation deep roots reach the water table in deep soil horizons and return water to the atmosphere through evapotranspiration, maintaining the water balance in the dry season and in dryer years (Oliveira et al. 2005, Bucci et al. 2008, Cabral et al. 2015). Agricultural expansion replaces the Cerrado with shallow rooted vegetation, reducing evapotranspiration and changing the water balance (Arantes et al. 2016, Spera et al. 2016), while producing increased runoff and erosion (Oliveira et al. 2015). Albedo and surface roughness are also modified, with predicted impacts of higher temperature and longer dry periods in the future (Hoffman and Jackson 2000).

The Cerrado also maintain substantial carbon stocks, with a high fraction of its biomass stocked underground (Miranda et al. 2014). Original carbon stocks in the biome are estimated to be around 21.3 ± 7.5 PgC (Leite et al. 2012). Although savannas can be accounted as carbon sinks under undisturbed conditions (Grace et al. 2014), Cerrado’s carbons stocks have been quickly mobilized, mainly through LULCC and increased fire regimes (Grace et al. 2006). Carbon emissions from LULCC vary considerably depending on the management practices adopted, that may include the use of fire (Bustamante et al. 2012), crop rotations and tillage practices (Batlle-Bayer et al. 2010, Bustamante and Ferreira 2011). Nevertheless, deforestation and agriculture activity have historically been the largest contributors to Brazilian CO₂ emissions (Fig. 1).
Food provision is another important ES provided by the Cerrado. According to Rudorff et al. (2015), in 2013/2014, the Cerrado was responsible for 51.9% of the Brazilian cultivated soy area (15.66 Mha) (Fig. 2). Pasturelands occupied 26.4% of the Cerrado area in the beginning of the 2000’s (Sano et al. 2010). Crop farming and cattle ranching contributed with 23% of 2016 national gross domestic product (GDP) (Oliveira and Cieglinski 2016), but social equity and environmental degradation outcomes are excluded from the economic equation (Lahsen et al. 2016).

Fig. 2. Cultivated area (in Mha) with soy, corn and cotton in the Brazilian Cerrado. The values refer to the first harvest, in three different periods (2000/2001, 2006/2007 and 2013/2014), in the whole Cerrado (first), and separately for the MATOPIBA region and other states within the Cerrado. Source: Rudorff et al. (2015), with adaptations.
On top of being severely threatened, the biome is poorly protected, since strictly protected areas (PAs) cover approximately 3% of the Cerrado, and that proportion is possibly lower if taken into account the deforestation inside PAs (Françoso et al. 2015). Brazil defines PAs according to the National System of Protected Areas (SNUC in Portuguese), that has similarities with the International Union for Nature Conservation (IUCN) system (Table 1). The terrestrial protected area network cover 28.94% (2.5 million km$^2$) of the Brazilian territory (UNEP-WCMC and IUCN 2016). Those areas, however, are unequally distributed along the country (Fig. 3). Compared to the Amazon, the Cerrado contains fewer PAs with smaller average sizes (Overbeck et al. 2015).

Table 1. Correspondence between protected areas categories according to the Brazilian system (SNUC Category) and the International Union for Nature Conservation system (IUCN Category). The area covered by each category in the Brazilian territory is also showed, according to governance type (Federal Government or State Government). Source: ISA (2017), with adaptations.

<table>
<thead>
<tr>
<th>Type</th>
<th>SNUC Category</th>
<th>Management objectives</th>
<th>IUCN Category</th>
<th>Federal (km$^2$)</th>
<th>State (km$^2$)</th>
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<tbody>
<tr>
<td>Strictly protected</td>
<td>Ecological Station</td>
<td>Research</td>
<td>Ia</td>
<td>73,902.68</td>
<td>46,402.79</td>
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<td></td>
<td>Biological Reserve</td>
<td>Biodiversity protection</td>
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<td>43,390.86</td>
<td>12,616.50</td>
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<td></td>
<td>National/State Park</td>
<td>Ecosystems protection and recreation</td>
<td>II</td>
<td>269,384.28</td>
<td>70,524.52</td>
</tr>
<tr>
<td></td>
<td>Natural Monument</td>
<td>Unique natural features protection</td>
<td>III</td>
<td>447.34</td>
<td>324.10</td>
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<td></td>
<td>Wildlife Refuge</td>
<td>Wildlife protection</td>
<td></td>
<td>2,697.81</td>
<td>1,107.40</td>
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<tr>
<td>Sustainable use</td>
<td>Environmental Protection Area</td>
<td>Human occupation ordering</td>
<td>V</td>
<td>106,916.48</td>
<td>210,887.85</td>
</tr>
<tr>
<td></td>
<td>Natural Heritage Private Reserve</td>
<td>Biodiversity conservation in private area</td>
<td>IV</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td>Area of Relevant Ecological Interest</td>
<td>Local ecosystems protection</td>
<td></td>
<td>450.79</td>
<td>250.00</td>
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<td></td>
<td>National/State Forest</td>
<td>Sustainable use of forest resources</td>
<td>VI</td>
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<td>134,945.01</td>
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<td>Extractive Reserve</td>
<td>Maintenance of sustainable traditional communities</td>
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<td></td>
<td>Fauna Reserve</td>
<td>Sustainable economic management of wildlife resources</td>
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<td></td>
<td>Sustainable Development Reserve</td>
<td>Maintenance of traditional cultures</td>
<td></td>
<td>1029.12</td>
<td>113,760.87</td>
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<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>787,472.40</td>
<td>622,615.21</td>
</tr>
</tbody>
</table>
Fig. 3. Map of original vegetation cover in the Brazilian biomes. Original forest area is depicted in green and original non-forest vegetation area in yellow. Small inset graphs indicate the proportion of converted (red) and protected (blue) areas until 2009. Protected areas include IUCN categories I–VI and Indigenous Reserves. The Conservation Risk Index (CRI) given for each biome is the ratio of converted to protected percentages. At the bottom left, recent conversion rates (2002–2009) for each biome are shown (CE = Cerrado, CA = Caatinga, PA = Pampa, PL = Pantanal, AM = Amazon, AF = Atlantic Forest). Source: Overbeck et al. (2015).

Along the Cerrado, the existing PAs are also unevenly distributed, with larger areas in the northwest and small, fragmented and isolated areas in the southeast (Garcia et al. 2011). In addition, most PAs (64.13%) are located in marginal lands, with rugged terrain (Garcia et al. 2011). Protected areas suitable to agricultural activities are under heavy pressure of conversion (Garcia et al., 2011). Large scale activities of mining, dam and road building also submit the PA network to pressing threats (Bernard et al. 2014, Ferreira et al. 2014).

There is a long way ahead to reach the 17% goal of PA coverage in the Cerrado (BRASIL 2000). PA creation policies have stagnated and there is a trend towards downgrading, downsizing, degazettement and reclassification, undermining previous conservation achievements (Bernard et al. 2014, Ferreira et al. 2014). In this rapid-vanishing biome, there is a urgent need to understand the importance of PAs and develop mechanisms to reduce conversion, following the footsteps of the deforestation decrease in the Amazon (Nepstad et al. 2014).
Beyond the well-recognized goal of biodiversity conservation, PAs are identified as cornerstones to ES provision, including provisioning, regulating, cultural and supporting services (Fig. 4). Different studies have demonstrated the role of PA networks in climate change mitigation and adaptation strategies, water supply, protection of wild crop relatives, sustainable fisheries, disaster mitigation and maintenance of cultural diversity (Lopoukhine et al. 2012). Close to a third of the world’s largest cities depend on PAs for their freshwater supply (Dudley and Stolton 2003). As a result, the expansion of PA network and improvements in their governance models have gained importance as cornerstones to adaptation and mitigation strategies, in response to global warming and land conversion (Dudley et al. 2010). A better understanding of the ES provided by the Cerrado PAs has potential to highlight social and economic benefits of investing in the expansion and management improvement of in situ conservation networks.

![Fig. 4. Ecosystem services categories according to the Millennium Ecosystem Assessment. Source: MEA (2003 p. 57).](image)

PAs offer opportunities for people to interact with nature through various recreational, aesthetical and other cultural ecosystem services (CES) (MEA et al. 2005a, Ament et al. 2016, De Vos et al. 2016). People who experience more frequent contact with nature are more likely to manifest positive feelings, attitudes and behavior toward the natural environment and its value (Soga and Gaston 2016), which may be an essential step towards a more sustainable society. Furthermore,
CES can provide revenues to enable the maintenance and expansion of PA networks by means of ecotourism activities (Maciejewski et al. 2015, Souza 2016). Although nature-based tourism has been a long debated issue, only recently it has been integrated in the ecosystem services framework as an activity that encompasses multiple bundles of CES provision (Ament et al. 2016). Studies about CES are limited compared to the number of publications on other ES categories, especially in Latin America (Martín-López et al. 2012).

In this study, we investigated the aesthetic services provided by PAs, a topic not yet well elucidated for the Cerrado. We also identify PAs under higher pressure from anthropogenic activities, considering diverse degrees of sensitivity to these activities. Therefore, we address human-environment interaction regarding the Cerrado biome, with a twofold perspective: (1) as a fragmented and vulnerable ecosystem under land-use change pressure; and (2) as an important natural system that provides services to sustain human wellbeing. The focus lies on the dynamic relationship between PAs and their surroundings, where positive and negative interactions are concurrent. More specifically, our study objective was to evaluate scenic view services, along with sensitivity and exposure to disturbances disseminated through hydrologic flows in Cerrado National Parks and their buffer zones. We tested two hypotheses:

1. Biophysical characteristics can predict different opportunities to obtain benefits from the scenic panoramic views of PAs.
2. Soil and hydrologic characteristics can reveal PAs that are more sensitive to LULCC disturbances transmitted through water flows.

Both hypotheses, concerning scenic view and exposure/sensitivity to disturbance, were applied to Cerrado National Parks. Eight parks were accessed in chapter two and thirteen in chapter three. Since they are common subjects for the analysis carried out in the following chapters, before moving forward it is important to present our study area.

1.1. Study area: Cerrado National Parks

Among the PA management categories, National Park was selected for this study based on its distinguished effectiveness to protect the Cerrado, along with its management objectives to promote ecotourism and protect scenic beauty (Carranza
et al. 2014, Françoso et al. 2015). According to Brazilian system, National Parks are strictly PAs, created to promote the preservation of natural ecosystems of great ecological importance and scenic beauty, enabling scientific research and activities of education and environmental interpretation, recreation in contact with nature and ecological tourism (Brazil 2000). Brazilian National Parks are analogous to IUCN-I category (Fig. 3, above) and they constitute the largest proportion of strictly PAs in the Cerrado, with estimated 1.42% coverage (Table 2).

Table 2. Protected areas cover in the Cerrado, by category and jurisdiction. Jurisdiction encompasses federal, state and municipal protected areas. Categories are divided according to land use restriction intensity, between integral protection (IP) and sustainable use (SU). Number, area, cover and natural vegetation remnant for each category is also depicted. Source: Françoso et al. (2015)

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Remnant (%)</th>
<th>Use</th>
<th>Category</th>
<th>N</th>
<th>Area (ha)</th>
<th>Cover (%)</th>
<th>Remnant (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>88.60</td>
<td>IP</td>
<td>EE</td>
<td>5</td>
<td>1,112,149</td>
<td>0.55</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PARK</td>
<td>15</td>
<td>2,891,980</td>
<td>1.42</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>REIBO</td>
<td>1</td>
<td>3,449</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RVS</td>
<td>1</td>
<td>128,049</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLONA</td>
<td>7</td>
<td>29,023</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APA</td>
<td>11</td>
<td>1,457,864</td>
<td>0.71</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RESEX</td>
<td>6</td>
<td>81,621</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ARIE</td>
<td>3</td>
<td>2,312</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>State</td>
<td>75.19</td>
<td>IP</td>
<td>EE</td>
<td>25</td>
<td>48,687</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PARK</td>
<td>43</td>
<td>1,326,444</td>
<td>0.65</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>REIBO</td>
<td>4</td>
<td>10,501</td>
<td>0.01</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RVS</td>
<td>5</td>
<td>134,725</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MN</td>
<td>4</td>
<td>31,468</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLONA</td>
<td>10</td>
<td>30,766</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RDS</td>
<td>1</td>
<td>58,780</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APA</td>
<td>56</td>
<td>9,057,087</td>
<td>4.44</td>
<td>3.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ARIE</td>
<td>7</td>
<td>4,446</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Municipal</td>
<td>29.94</td>
<td>IP</td>
<td>PARK</td>
<td>16</td>
<td>7,972</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MN</td>
<td>11</td>
<td>124,806</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APA</td>
<td>54</td>
<td>408,579</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>285</td>
<td></td>
<td></td>
<td>16</td>
<td>16,950,708</td>
<td>8.31</td>
<td>6.50</td>
</tr>
</tbody>
</table>

Our study examines the Cerrado National Parks as representatives of areas with low anthropogenic impact (Françoso et al. 2015), and therefore are expected to provide increased levels of ecosystem services (Lopoukhine et al. 2012). They function as important protectors of water springs, streams and geological and biological diversity. Furthermore, National Parks combine preservation of ecologically important sites with scenic beauty and ecotourism, one of the dimensions evaluated in this study that can possibly fuel social and economical support to the PA maintenance (Souza 2016).
Thirteen National Parks located in the Cerrado were selected (Fig. 5). Lençóis Maranhenses and Serra das Confusões Parks, although located in the Cerrado biome, were not included in this study because vegetation in these parks is not typical of Cerrado. In fact, Lençóis Maranhenses present vegetation from three biomes – Amazonia, Cerrado and Caatinga – and ~2/3 of the park corresponds to sandy dunes. Vegetation from the Serra das Confusões is typical of Caatinga biome. Due to the several difficulties to compare data from different biomes, we also disregarded the Chapada Diamantina and Sete Cidades Parks. They are mostly composed of Cerrado vegetation, but are located outside of the Cerrado biome.

![Map of Cerrado National Parks](image)

**Fig. 5.** Map of the study area encompassing 13 National Parks located in the Brazilian Cerrado biome. Sources: Polygon of Brazil and the Cerrado from IBGE (2004) and polygons of parks from ICMBIO (2016a).

The parks are distributed in nine states, 11 ecoregions, under varying environmental conditions (Table 3). Serra do Cipó Park National Park, located in the Minas Gerais State, is the smallest one, with 316 km² (Table 2). Conversely, Nascentes do Rio Parnaíba National Park, located in the states of Maranhão, Piauí
and Bahia, is the largest one, with 7,497 km². Eight parks are officially opened to public visitors according to ICMBIO (2017a).

In 1959, it was created the first National Park in the Cerrado: The Araguaia Park, located in Tocantins State and now in the list of Wetlands of International Importance (Ramsar site). Brasilia, Chapada dos Veadeiros and Emas Parks were created in 1961 as part of the project to stimulate economic development in the central part of Brazil. Chapada das Mesas, located in the Maranhão State, is the most recent National Park in the Cerrado, created in 2005. Its creation is coincident with the recent expansion of the agricultural frontier up to the north of the country, to the MATOPIBA region.

Table 3. Main characteristics of 13 Cerrado National Parks selected as study area.

<table>
<thead>
<tr>
<th>National Park</th>
<th>States*</th>
<th>Ecoregions</th>
<th>Year of creation/alteration</th>
<th>Area (km²)</th>
<th>Number of visitors in 2015</th>
<th>Main characteristics</th>
<th>Main threats</th>
<th>Touristic attractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Araguaia</td>
<td>TO</td>
<td>Bananal</td>
<td>Created in 1959, reduced in 1971/1973, with limits defined in 1980</td>
<td>5,555.24</td>
<td>Unregistered</td>
<td>Wetland of International Importance (Ramsar Site), more than 60% of the total area overlaps indigenous territories, located in the Cerrado/Amazon transition</td>
<td>Livestock farming, agricultural expansion, fire, irrigation systems, contamination from agrochemicals, hunting, fishing, roads, waterways</td>
<td>Biggest river island in the world, seasonal river beaches, ponds, extensive river network, fishing, camping, animal observation, indigenous cultures</td>
</tr>
<tr>
<td>Brasilia</td>
<td>DF</td>
<td>Planalto Central</td>
<td>Created in 1991, extended in 2006</td>
<td>423.56</td>
<td>294,682</td>
<td>Located inside an urban area, contains springs and streams that provide water to the city of Brasilia, helps to control the urban climate</td>
<td>Urban expansion, pollution, fire, landfill, biological invasion, fishing, tourism impact, gravel extraction</td>
<td>Natural swimming pools, trails, recreation infrastructure</td>
</tr>
<tr>
<td>Cavernas do Perusú</td>
<td>MG</td>
<td>Undetermined</td>
<td>Created in 1999</td>
<td>564.49</td>
<td>2,938</td>
<td>Located in the Cerrado/Caatinga transition, characterized by karst topography, and an abundance of caves and archaeological sites</td>
<td>Livestock farming, fire, agricultural expansion, deforestation, wood extraction, invasive species, roads, excessive use of water resources, irrigation systems, dams, erosion, sedimentation, contamination from agrochemicals, sewage disposal</td>
<td>Prehistorical rock paintings, trails, scenic outlooks, archaeological sites, colonial caves, canyons, geological monuments, speleothems, cerrado rupestre (rocky cerrado)</td>
</tr>
<tr>
<td>Chapada das Mesas</td>
<td>MA</td>
<td>Bico do Parapagio</td>
<td>Created in 2005</td>
<td>1,599.53</td>
<td>Unregistered</td>
<td>Contains more than 400 springs, located within Legal Amazon limits</td>
<td>Agricultural expansion, steel industry expansion, fire, delay in the expropriation process</td>
<td>Sandstone plateaus, scenic outlooks, waterfalls, archaeological rock paintings</td>
</tr>
<tr>
<td>Chapada dos Guimarães</td>
<td>MT</td>
<td>Parand-Guimarães</td>
<td>Created in 1989</td>
<td>326.46</td>
<td>174,855</td>
<td>Composed by notable landform diversity and geological sites, protects springs of the Curitiba River (main contributor to the Paraná), and springs of the Guairá Aquifer</td>
<td>Livestock farming, agricultural expansion, fire, roads, roadkill, delay in the expropriation process, recreational activities</td>
<td>Trails, waterfalls and rivers, scenic outlooks, cycling, sandstone walls, caves, geological sites</td>
</tr>
<tr>
<td>Chapada dos Veadeiros</td>
<td>GO</td>
<td>Planalto Central</td>
<td>Created in 1981, extended in 1981, reduced in 2001 (which was reversed in 2003), extended in 2017</td>
<td>647.26 (new area is 2,408.11)</td>
<td>56,629</td>
<td>UNESCO World Heritage Site, contain a high number of fauna and flora endemic species</td>
<td>Fire, livestock farming, agricultural expansion, roads and urban expansion, tourism expansion, wood extraction, plant gathering, mining, dams</td>
<td>Diversity of Cerrado formations, rivers, waterfalls and rip currents, natural pools, trails, canyons, scenic outlooks</td>
</tr>
<tr>
<td>Emas</td>
<td>MS, GO</td>
<td>Parand-Guimarães</td>
<td>Created in 1961, with limits defined in 1972</td>
<td>1,327.87</td>
<td>1,681</td>
<td>UNESCO World Heritage Site, divide Araguaia and Paraná basins</td>
<td>Agricultural expansion, livestock farming, contamination from agrochemicals, dams, roads, railway, invasive species, fire, erosion, sedimentation, habitat fragmentation and isolation, increased floods</td>
<td>Bioluminescence of termite nests, trails, cycling, car expedition (safari), ponds, tubing</td>
</tr>
<tr>
<td>Grande Sertão Veredas</td>
<td>BA, MG</td>
<td>Chapadão do São Francisco</td>
<td>Created in 1989, extended in 2004</td>
<td>2,308.56</td>
<td>570</td>
<td>Located in the Cerrado/Caatinga transition, contains high biodiversity, abundant water resources and cultural importance</td>
<td>Delay in the expropriation process, fire, agricultural expansion, contamination from agrochemicals, livestock farming, degraded pastures, roads, wood and straw extraction</td>
<td>Diversity of Cerrado formations, Veredas formations, scenic outlooks, waterfalls, trails, meeting of rivers</td>
</tr>
<tr>
<td>Nascentes do Rio Pamaiba</td>
<td>MA, PI, BA</td>
<td>Chapadão do São Francisco, Depressão do Paranaguá and Alto Parnaiba</td>
<td>Created in 2002, extended in 2015</td>
<td>7,497.74</td>
<td>Unregistered</td>
<td>Located in the Cerrado/Caatinga/Amazon transition, partially inside the Legal Amazon, in the Cerrado agriculture frontier (MATOPIBA); contains the springs to the Parnaiba river, that supply water to 50 cities in the Northeast Located in the Mata Atlântica/Caatinga transition, within the Espinhoca Ridge, a biodiversity conservation priority (high endemism); it is a center of genetic diversity of Erica species plant family; contains important springs and streams</td>
<td>Delay in the expropriation process, fire, livestock farming, wood and straw extraction, wild animals traffic</td>
<td>Waterfalls</td>
</tr>
<tr>
<td>Sempere-Vivas</td>
<td>MG</td>
<td>Serra do Cópia</td>
<td>Created in 2002</td>
<td>1,241.55</td>
<td>26</td>
<td>Atlantic/Caatinga transition, within the Espinhoca Ridge, a biodiversity conservation priority (high endemism); it is a center of genetic diversity of Erica species plant family; contains important springs and streams</td>
<td>Livestock farming, fire, forestry, hunting, fishing, mining, plant gathering for handicrafts, wood extraction, land disputes</td>
<td>Terrain diversity, rivers and waterfalls, diversity of Cerrado vegetation formations, fields of sempere-vivas and other small flowers, animal diversity, historical and cultural human heritage sites (such as archeological rock paintings, caves and historical ruins)</td>
</tr>
<tr>
<td>National Park</td>
<td>States*</td>
<td>Ecoregions</td>
<td>Year of creation/alteration</td>
<td>Area (km²)</td>
<td>Number of visitors in 2015</td>
<td>Main characteristics</td>
<td>Main threats</td>
<td>Touristic attractions</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>------------</td>
<td>-----------------------------</td>
<td>------------</td>
<td>--------------------------</td>
<td>---------------------</td>
<td>--------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Serra da Bodoquena</td>
<td>MS</td>
<td>Complexo Bodoquena</td>
<td>Created in 2000</td>
<td>789.73</td>
<td>389</td>
<td>Located in the border zone between Paraguay and Brazil (with military presence), in the Pantanal/Mata Atlântica/Cerrado transition, with important springs and streams, inside the Bodoquena-Pantanal State Geopark, due to its high geodiversity</td>
<td>Livestock farming, fire, invasive species, water contamination by cattle, riparian forest suppression, wetlands drainage, springs and streams destruction, sedimentation, hunting, fishing, agriculture expansion, use of agrochemicals (possibly products banned from Brazil, that enter illegally from Paraguay), gravel and limestone extraction, roads, increased population density due to rural settlements</td>
<td>Diversity of Cerrado formations, geosites (including sites with geomorphological, tectonic- stratigraphic, sedimentological, paleontological, speleological, mineralogical and hydrogeological importance)</td>
</tr>
<tr>
<td>Serra da Canastra</td>
<td>MG</td>
<td>Serra da Canastra</td>
<td>Created in 1972</td>
<td>1,970.71</td>
<td>52,673</td>
<td>Encompasses main springs for the São Francisco River.</td>
<td>Land use and land cover change in the buffer zone, with livestock farming, agriculture in slopes, use of pesticides, forestry, mining, fire, roads, energy transmission lines, uncontrolled tourism, invasive species, delay in the expropriation process</td>
<td>Archaeological and prehistorical heritage sites, historical buildings, trails, rivers and waterfalls</td>
</tr>
<tr>
<td>Serra do Cipó</td>
<td>MG</td>
<td>São Francisco Velhas</td>
<td>Created in 1984 (converted from State Park to National Park)</td>
<td>316.39</td>
<td>53,660</td>
<td>Located in the Mata Atlântica/Castiga transition, within the Espinhaço Range, which it is a biodiversity conservation priority, with high endemism</td>
<td>Cattle ranching, fire, plant gathering, biological invasion, uncontrolled tourism, fishing, motor biking</td>
<td>Waterfalls, trails, scenic outlooks, ponds, rivers, canyons, cycling, archeological sites</td>
</tr>
</tbody>
</table>

CONCLUDING REMARKS

The two proposed hypothesis were confirmed by our results. Biophysical measures of visual scale (panoramic view area), topographic heterogeneity (roughness and slope variability) and biological diversity (Shannon’s Diversity and Evenness Indexes) proved to be appropriate (in terms of objectivity) indicators of touristic and scenic potentials. We were able to create biophysical profiles to the studied parks revealing differences in their aptitude to offer cultural ecosystem services. Limitations of the proposed model are mostly related to the absence of other variables, such as built infrastructure and socioeconomic factors, that strongly influence visitation potential, and could not be integrated in the analysis.

Additionally, soil (sand content) and hydrologic (drainage density and direction) characteristics were able to define parks under higher sensitivity to LULCC disturbances transmitted through water flows. The indicators provided qualitative measurements of risk to identify areas for priority management, focusing on different land-use degradation drivers and tendencies. Main limitations are the difficulty to rank those aspects and integrate them with other mechanisms that potentially impact protected areas. In order to reach a vulnerability measure, adaptive capacity was the missing component in our analysis.

Our main contributions are methodological, covering two aspects of protected areas rarely mentioned in the scientific literature. Although this study focused only on National Parks located in the Brazilian Cerrado biome, the proposed approaches can be extended to other tropical areas with species-rich ecosystems under high pressures of land use conversion.
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Table S1. Values for scenic view indicators, related to biophysical characteristics in eight National Parks located in the Cerrado, opened for visitors.

<table>
<thead>
<tr>
<th>Cerrado National Park</th>
<th>Viewshed proportional area (%)</th>
<th>Terrain Roughness (m)</th>
<th>Slope variability (%)</th>
<th>Shannon's Diversity Index</th>
<th>Shannon's Equitability Index</th>
<th>Drainage density (km/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brasília</td>
<td>32.48</td>
<td>3.63</td>
<td>68.39</td>
<td>0.93</td>
<td>0.84</td>
<td>1.02</td>
</tr>
<tr>
<td>Cavernas do Peruaçu</td>
<td>31.86</td>
<td>3.14</td>
<td>56.70</td>
<td>0.54</td>
<td>0.78</td>
<td>0.94</td>
</tr>
<tr>
<td>Chapada dos Guimarães</td>
<td>39.76</td>
<td>5.27</td>
<td>136.59</td>
<td>1.02</td>
<td>0.93</td>
<td>1.01</td>
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<tr>
<td>Chapada dos Veadeiros</td>
<td>34.29</td>
<td>5.86</td>
<td>106.98</td>
<td>0.44</td>
<td>0.40</td>
<td>1.00</td>
</tr>
<tr>
<td>Emas</td>
<td>16.25</td>
<td>1.38</td>
<td>23.70</td>
<td>0.94</td>
<td>0.86</td>
<td>1.20</td>
</tr>
<tr>
<td>Grande Sertão Veredas</td>
<td>10.93</td>
<td>1.43</td>
<td>23.49</td>
<td>0.41</td>
<td>0.60</td>
<td>1.06</td>
</tr>
<tr>
<td>Serra da Canastra</td>
<td>20.52</td>
<td>10.75</td>
<td>139.60</td>
<td>0.83</td>
<td>0.76</td>
<td>0.85</td>
</tr>
<tr>
<td>Serra do Cipó</td>
<td>47.62</td>
<td>6.24</td>
<td>141.93</td>
<td>0.69</td>
<td>0.63</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Fig. S1. Bar chart with the values and standard deviation of biophysical scenic view indicators in eight National Parks located in the Cerrado, opened for visitors.
Fig. S2. Stacked bar chart with the bioprofiles of scenic potential in eight National Parks located in the Cerrado, opened for visitors. The objective environmental and ecological indicators depicted in the chart indicate different opportunities to explore touristic activities in each park. Flat parks register higher drainage density and offer more opportunities for water recreational activities, inside the park. Hilly parks can offer panoramic views to viewers in the surroundings of the park.

Fig. S3. Variation of radar chart in Fig. 13, displaying the biophysical scenic view profiles for the eight selected National Parks located in the Cerrado biome and opened for visitation. Five visual and ecological indicators can be seen: Shannon Evenness Index (SEI), slope variability, drainage density, terrain roughness and viewshed area.