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Research article

Landscape changes in a neotropical forest-savanna ecotone zone in central Brazil: The role of protected areas in the maintenance of native vegetation

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ABSTRACT

In the Amazon-savanna ecotone in northwest Brazil, the understudied Araguaia River Basin contains high biodiversity and seasonal wetlands. The region is representative of tropical humid-dry ecotone zones, which have experienced intense land use and land cover (LULC) conversions. Here we assessed the LULC changes for the last four decades in the central portion of the Araguaia River Basin to understand the temporal changes in the landscape composition and configuration outside and inside protected areas. We conducted these analyzes by LULC mapping and landscape metrics based on patch classes. During this period, native vegetation was reduced by 26%. Forests were the most threatened physiognomy, with significant areal reduction and fragmentation. Native vegetation cover was mainly replaced by croplands and pastures. Such replacement followed spatial and temporal trends related to the implementation of protected areas and increases in population cattle herds. The creation of most protected areas took place between 1996 and 2007, the same period during which the conversion of the landscape matrix from natural vegetation to agriculture occurred. We observed that protected areas mitigate fragmentation, but their roles differ according to their location and level of protection. Still, we argue that landscape characteristics, such as suitability for agriculture, also influence landscape conversions and should be considered when establishing protected areas. The information provided in this study can guide new research on species conservation and landscape planning, as well as improve the understanding of the impacts of landscape composition and configuration changes.

1. Introduction

Human influence over pristine landscapes has increased significantly in the past century. Rapid population growth and increasing consumption are the primary factors that induce land use changes worldwide by creating economic opportunities. Infrastructure implementation along with improvements in production systems drive land use regionally, leading to the shrinkage and fragmentation of habitats. The expansion of agriculture, pasturelands, and urban areas are the major causes of deforestation and habitat fragmentation, representing a serious threat to biological diversity (Foley et al., 2005), as observed in tropical regions (Fahrig, 2001; Gibbs et al., 2010). Moreover, deforestation is also related to several other alterations, such as an increase in runoff, loss of superficial soil and water quality, climate destabilization (Costa and Pires, 2010; Coe et al., 2011), and biogeochemical changes in surface waters (Krusche et al., 2005; Neill et al., 2006).

In Brazil, the flat topography, infrastructure advances, relatively low price of land, and construction of most cities, such as Brasília, the federal capital since 1960, were the major factors that led the Cerrado (the largest savanna environment in South America) to become one of the world's main agricultural areas (Costa et al., 2003; Klink and Machado, 2005; Lambin et al., 2013). During the mid-1990s, approximately 40% of Brazilian livestock production took place in this biome (Sano et al., 2000). Despite the current prevalence of cultivated pastures, large areas of the Cerrado, particularly the open physiognomies, are still used as native

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pasture. This type of anthropism results in environmental impacts, such as soil compaction, and annual burning because fire remains a tool for managing or expanding areas for cattle ranching (Quesada et al., 2004).

To support this transformation (initiated intensively in 1970), approximately 50% of the Cerrado has been replaced by agriculture (15% by croplands and 35% by pastures) through 2013 (see Terra-Class Cerrado project - MMA, 2015). In 2002, for instance, the number was approximately 40% of this biome (or 800,000 km^2), illustrating a dynamic process of occupation, especially in border areas in the north of the country (MMA, 2009; Ferreira et al., 2012). Such changes have resulted in an average deforestation rate of ~3500 km^2 per year, reaching 4500 km^2 in 2014/2015 (see Warning Deforestation System - SIAD dataset in the LAPIG interactive research platform: https://www.lapig.iesa.ufg.br). As a consequence of this intense occupation, the Cerrado is currently one of the most threatened biomes in Brazil and even in the world, with a deforestation rate higher than that of the Amazon Rainforest (MMA, 2009; INPE, 2015a) in some periods. Additionally, natural fields or savannah within the rainforest may present even higher conversion rates.

To protect natural resources and undermine intense land use conversion, federal and state protected areas (PAs) were established by the Brazilian Protected Areas System (SNUC) and the National Indian Foundation (FUNAI) (Silva, 2005). There are three main types of PAs: indigenous lands (IL), strictly protected areas (strictly PAs), and protected areas for sustainable-use (sustainable-use PAs) (Silva, 2005). ILs are areas of use for indigenous people, where they can live and use natural resources, which maintains their physical and cultural reproduction (FUNAI, 2015). IL is established by FUNAI and is thus not subject to the rules of the SNUC. According to the Brazilian Protected Areas System (Brazil, 2000), strictly PAs are areas for ecosystem maintenance, free from disturbances caused by human interference, allowing only indirect use of its natural attributes. On the other hand, sustainable-use PAs allow environmental exploitation to ensure the continuity of renewable environmental resources and ecological processes, which maintains biodiversity and other ecological attributes, in a socially fair and economically viable manner.

Ecological maintenance relies on native vegetation cover and on how it is spatially distributed. Fragmentation affects the abiotic conditions in the landscape and, consequently, species distribution. Thus, the interactions between organisms can be eliminated and new processes can be created (Hadley and Betts, 2012). Landscape metrics have been increasingly used to estimate fragmentation effects due to a variety of activities to integrate fragmentation into landscape planning and to design ecological networks (Uuemaa et al., 2013). The calculation of landscape metrics is based on remote sensing methods, and the choice of the metric to be used depends on the ecological process of interest (Lausch and Herzog, 2002).

Evaluating land use and land cover changes (LULC) can be an important tool in planning new conservation areas that are in ecoregions that are not covered by existing conservation areas as well as in evaluating already established conservation areas, which helps improve the understanding of the temporal dynamics of natural and anthropic landscapes in Brazil. It can also help promote a more sustainable use of the region and increase the understanding of deforestation dynamics and their impact on carbon balance, nutrient cycling, water resources, and biodiversity (Asner et al., 2005). Therefore, the aim of this study was to evaluate the LULC changes and role of protected areas on the maintenance of native vegetation cover in the Middle Araguaia River Basin (MARB). Using landscape metrics as indicators of the landscape composition and configuration in the last four decades (between 1975 and 2013), we evaluated the temporal variation of the entire landscape as well as within different types of PAs established in the basin.

2. Methods

2.1. Study area

The study area encompasses 166,000 km^2 of the Middle Araguaia River Basin, including Bananal Island - the largest fluvial island in the world. The region is a transition zone between the Amazon and Cerrado biomes, dominated by Cerrado (Fig. 1, Appendix S1 for further description). The population of the MARB has experienced continuous growth and urbanization. Currently, the population is estimated at 1 million people (IBGE, 2015). Livestock is the major regional economic activity, with planted pastures predominant over native pastures. Native grasslands in flooded areas of the Bananal lowland maintain a reasonable capacity for cattle raised during the dry season due to the shallow water table and fertilization caused by sediment deposition during flood episodes (Diegues, 2002). Nearly 50,000 km^2, or approximately 30% of the study area, consists of conservation units and indigenous lands (see Appendix S2 for further information), including 8 indigenous lands (IL), 2 strictly protected areas (strictly PAs), and 3 protected areas for sustainable use (sustainable-use PAs).

2.2. Land use and land cover mapping

Land use and land cover (LULC) maps were obtained from two sources. The first dataset, from 1975 to 2007, was created by Sawakuchi et al. (2013) and was derived from the digital classification of Landsat 2 - MSS scenes for 1975 and Landsat 5 - TM scenes

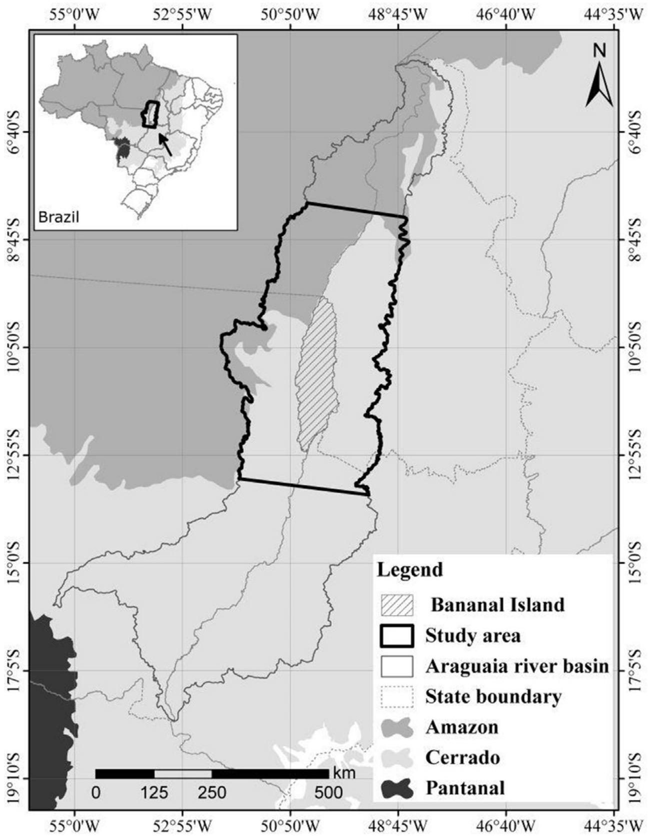

Fig. 1. The study area location at the Middle Araguaia River Basin, encompassing the transition zone between the Amazon and Cerrado biomes in Brazil.

for 1985, 1996, and 2007. The authors acquired the images from the Brazilian National Institute of Space Research (INPE, 2008). Digital classification was performed using an ISODATA unsupervised classification to obtain different groups of classes with similar spectral responses, reducing misunderstanding errors. Then, mixed target classes were separated by a maximum likelihood supervised classification (Sawakuchi et al., 2013). The legend was composed of the following land cover classes: (1) Forest, a combination of riverine, transitional forest, and cerrado woodland - higher tree density; (2) Cerrado, representing physiognomies with a wood layer but lower tree density; (3) Grassland, open fields composed of native species; (4) Agriculture, pasturelands and crop fields; (5) Urban areas; (6) Burned areas; and (7) Cloud. Second, the 2013 LULC map was obtained by merging TerraClass products for the Cerrado (MMA, 2015) and Amazon biomes (INPE, 2015b). We adapted the legends according to the first classification scheme and resampled all of the raster images to a 250-m pixel spatial resolution. See Appendix S3 for a full description on the methodology carried out by Sawakuchi et al. (2013), TerraClass products description, and reclassification scheme applied to classified images obtained from those two specified sources.

2.3. Landscape configuration analysis

The effects of LULC changes on the landscape structure were evaluated inside and outside the protected areas using a temporal analysis of landscape metrics obtained from LULC maps from 1975, 1985, 1996, 2007, and 2013. To assess the landscape composition, we calculated the class area (CA), percentage of class area (PLAND), and patch density (PD). For analysis of landscape configuration, we calculated the class level index using the 8-neighbor rule: the largest patch index (LPI), mean patch area (AREA_MN), edge density (ED), mean perimeter-area ratio (PARA_MN), mean core area (CORE_MN), and mean proximity index (PROX_MN). We chose these metrics based on the target aspect of the landscape that considered important to describe fragmentation (edge and core areas, patches shape and isolation), the capacity of singular information, and their availability in the literature to compare our results. All of the chosen metrics were calculated using FRAGSTATS 4.0 (Appendix S4 for description). Considering a variety of landscape studies in the Cerrado and Amazon and their respective land use maps scales, we established that the patch edge depth parameter was equal to 250 m and the search radius was 1000 m (Laurance, 2007, 2011; Dodonov et al., 2013).

To compare results between the fragmentation process throughout the study area and the different types of PAs, we selected metrics that were not affected by the total landscape size. We used the PD, LPI, ED, and PROX_MN metrics to calculate how fragmentation differs among PA types using the Kruskal-Wallis rank sum test and a Spearman correlation index to observe which type of PAs presented a similar fragmentation process (Zar, 2010a). We compared fragmentation inside and outside PAs by analyzing the buffers zones in the respective areas through a paired Wilcoxon signed rank test (Zar, 2010b). We built such zones by extracting 10 km buffers inside the boundary of each PA and another zone surrounding each PA.

With the aim of understanding the landscape dynamics of the MARB, we assessed the demography and agricultural production dataset from the Brazilian Institute of Geography and Statistics (IBGE, 2015). Available historical datasets on human demography, cattle herds, cultivated areas, and wood extraction were compiled to compare with the observed landscape changes derived from satellite images. The available data represent groups of counties, called micro-geographic regions. All of the micro regions within the studied area were used in these analyses.

3. Results

3.1. Landscape composition change

Temporal analyses of the area showed a strong substitution of native vegetation by agriculture (Table 1 and Appendix S5). In 1975, the landscape matrix was dominated by forest (39%), followed by grassland (26%) and cerrado (23%), amounting to 88% native cover. In 1985, a decrease of forest and cerrado to 34% and 21% of the landscape, respectively, was observed, while grassland and agriculture increased to 29% and 12% of the landscape, respectively. The increase in grassland was mainly found in areas that were previously classified as cerrado, which is probably related to the degradation of the woody layer and burned areas. From 1985 onward, agriculture increased sharply in the MARB. In 1996, the total amount of native cover dropped to 76% of the study area, while the proportion of agricultural areas (22%) was already equivalent to grassland (23%) and cerrado (20%). In 2007, agriculture represented 32% of the landscape – the most abundant cover. Such a transition represents a landscape matrix inversion, despite the 67% of native coverage. In 2013, agricultural areas encompassed 37% of the landscape, while natural cover was 62%.

Thus, over the 38 years analyzed, there was a substitution of approximately 48,000 km^2 of native vegetation by agriculture, increasing the agricultural area by 366%. Although all of the native vegetation classes decreased, forest was identified as the most endangered physiognomy, with a 33% reduction, followed by a reduction of 30% in cerrado and 25% in grassland. Overall, the substitution rate of native vegetation by agriculture in the study area had a mean of 1122 $\text{km}^2\ \text{yr}^{-1}$. However, this rate was not constant over time. From 1996 to 2007, the deforestation rate reached 1405 km^2 year^{-1}, with a total reduction in native vegetation of 12%, the highest rate observed in this study.

In 2007, there was approximately 5% agricultural use inside conservation units and indigenous lands (Fig. 2). Most of these activities were already established when the majority of the protected areas were created; between 2007 and 2013, there was no substantial change. However, by analyzing those units separately, a tenure-related pattern was found, with agricultural areas declining inside strictly PAs and IL, while increasing in sustainable-use PAs (Fig. 2). Additionally, comparing the proportion of land cover classes along the outside buffer of the PAs to along the inside buffer, sustainable-use PAs presents higher similarity between both buffers than other types of PAs.

3.2. Landscape structure change

The low patch density (PD) and the largest patch index (LPI) are considered to be good indicators of landscape fragmentation. Resulting from the division of large patches of natural or human induced perturbations, a highly fragmented landscape presents increasing patches per area and a decrease in the size of large and

Table 1
Cover area (%) at the Middle Araguaia River Basin by each land use and land cover class of the analyzed years (1975, 1985, 1996, 2007, and 2013).

	1975	1985	1996	2007	2013
Forest	39	34	33	29	26
Cerrado	23	22	20	17	16
Grassland	26	30	23	20	20
Agriculture	8	12	22	32	37
Urban areas	0	0	0	0	0
Burned areas	3	1	0	0	0
Water	1	2	1	1	1

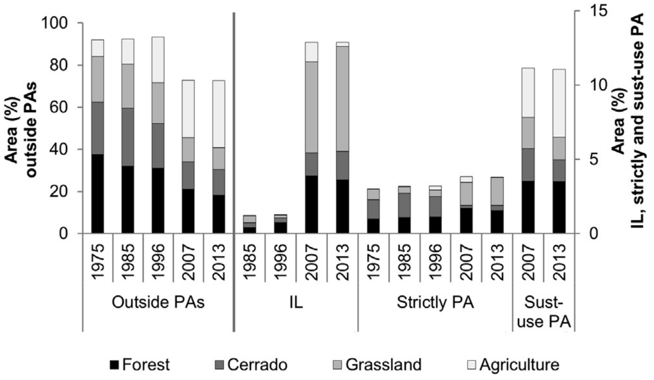

Fig. 2. Area of coverage (%) of the main land cover classes at the Middle Araguaia River Basin (MARB) by analyzed years (1975, 1985, 1996, 2007, and 2013), and land tenure - outside PAs, indigenous lands (IL), strictly protected areas (Strictly PAs), and protected areas for sustainable use (Sust-use PAs).

continuous patches. Throughout the landscape, forest was the most affected land cover class in the MARB when considering both parameters (Appendix S6). The same pattern was observed in the landscape outside Pas. On the other hand, our results show that, after the creation of IL and strictly Pas, cerrado and forest PD increased inside of those PAs (Fig. 3a), although the cerrado PD decreased by 0.01 patches 100 ha^{-1} in sustainable-use PAs. Grassland and agriculture presented a decline in PD until 2013 in all types of protected areas. From 2007 to 2013, grassland patches presented an increase in large patch index (LPI) in IL (3.5%) and strictly PAs (0.36%) and a slight decrease in the percentage of cerrado, both 0.01%, in the same period. Sustainable-use PAs presented constant and low values for both cerrado (0.05%) and grassland LPI (0.24%) (Fig. 3b). The largest growth in LPI was observed for agriculture, increasing by 9.2-fold over time inside sustainable-use PAs and outside PAs. Forest patches became more concentrated in sustainable-use PAs and outside PAs, but no substantial variation was observed inside IL or strictly PAs.

Regarding landscape quality, we also observed contrasts between IL and strictly PAs compared to sustainable-use PAs (Fig. 3c and d). The proximity among fragments (PROX_MN) decreased for forest by almost 40% within the first two types of protected areas, but increased inside sustainable-use PAs (+80%). Between 2007 and 2013, grassland fragments became closer to each other inside IL (+162%), strictly PAs (+100%), and sustainable-use PAs (+2%). Both forest and grassland presented an increase in PROX of 80% outside PAs. We observed no significant variation in cerrado in any protected area for this index, but there was an increase (60%) in distance between cerrado patches outside PAs. However, the edge density for this class almost doubled in IL and strictly PAs and decreased by one-third inside sustainable-use PAs and outside PAs (Fig. 3c). Grassland ED presented no significant change inside IL and strictly PAs and decreased in sustainable-use PAs and outside PAs by 0.4 m ha^{-1}. Forest ED presented no significant change in all protected areas.

We compared the fragmentation pattern along a surrounding buffer outside the PAs and inside the PAs based on the PD, ED, LPI and PROX metrics. The relationship between the outside and inside buffers is presented in Fig. 4. Sustainable-use PAs present the same fragmentation pattern along the outside of the PAs and the inside based on the paired Wilcoxon Signed Rank Test for the PD, ED, LPI and PROX metrics ($p > 0.05$). IL and strictly PAs presented significant differences between both buffers ($p < 0.01$) for PD and ED (Fig. 4a and c). Those results indicate that the landscape surrounding IL and strictly PAs presents a more complex configuration pattern, with higher patch and edge densities. Additionally, in testing the variance of metrics calculated inside PAs, we observed a distinction between IL/strictly PAs and sustainable-use PAs related to both PD and ED (see Appendix S6 for graphics).

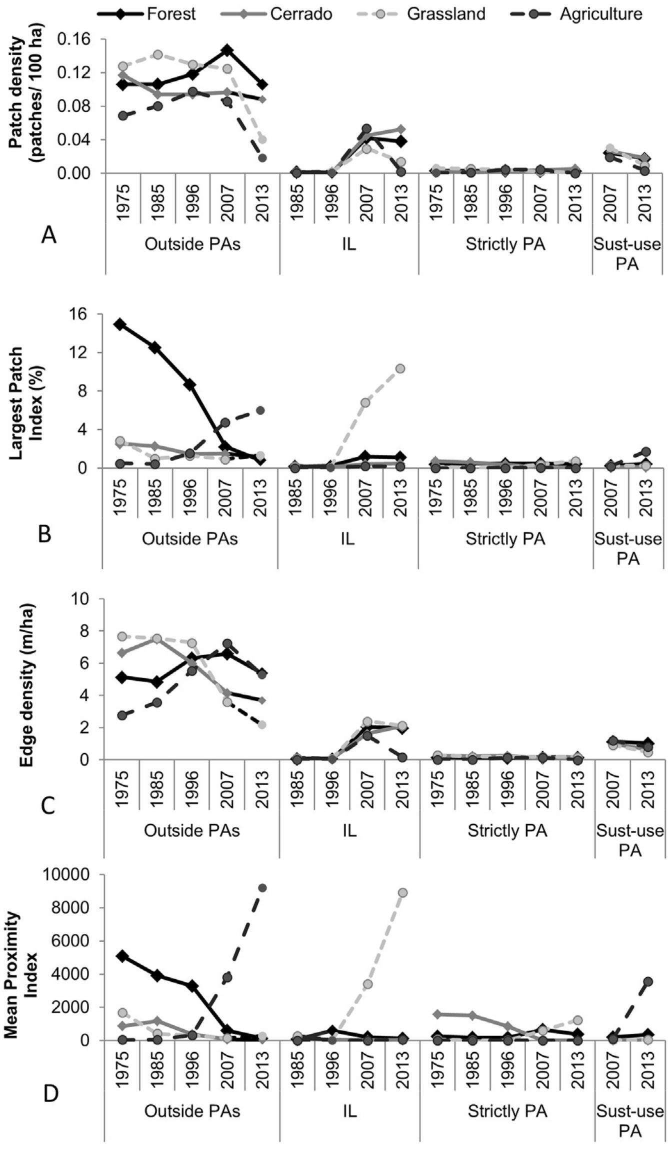

Fig. 3. Evolution of the Patch Density (panel A), Largest Patch Index (panel B), Edge Density (panel C), and Mean Proximity Index (panel D) by analyzed year (1975, 1985, 1996, 2007, and 2013) and land tenure - outside PAs, indigenous lands (IL), strictly protected areas (Strictly use), and protected areas for sustainable-use (Sust-use). Note that PROX_MN is an index and does not present a specific unit of measurement (Appendix S4).

Considering each type of protected area, we found different patterns of fragmentation. IL were highly correlated to strictly PAs for landscape indices ($R^2 = 0.80$, $p < 0.05$), which indicates fragmentation (PD, LPI, ED and PROX_MN). However, sustainable-use PAs were poorly correlated to IL ($R^2 = 0.07$, $p < 0.05$) and strictly PAs ($R^2 = 0.55$, $p < 0.05$). The correlation test for each landscape metric is shown in Appendix S6. In this case, the fragmentation inside IL and strictly PAs decreased after their creation, followed by a small increase or maintenance of the native vegetation cover.

Nevertheless, analyzing comparable landscape metrics among indigenous land, conservation units, and the whole landscape in 2007 and 2013, we found that indigenous land and strictly PAs presented a smaller fragmentation rate for forest and grassland

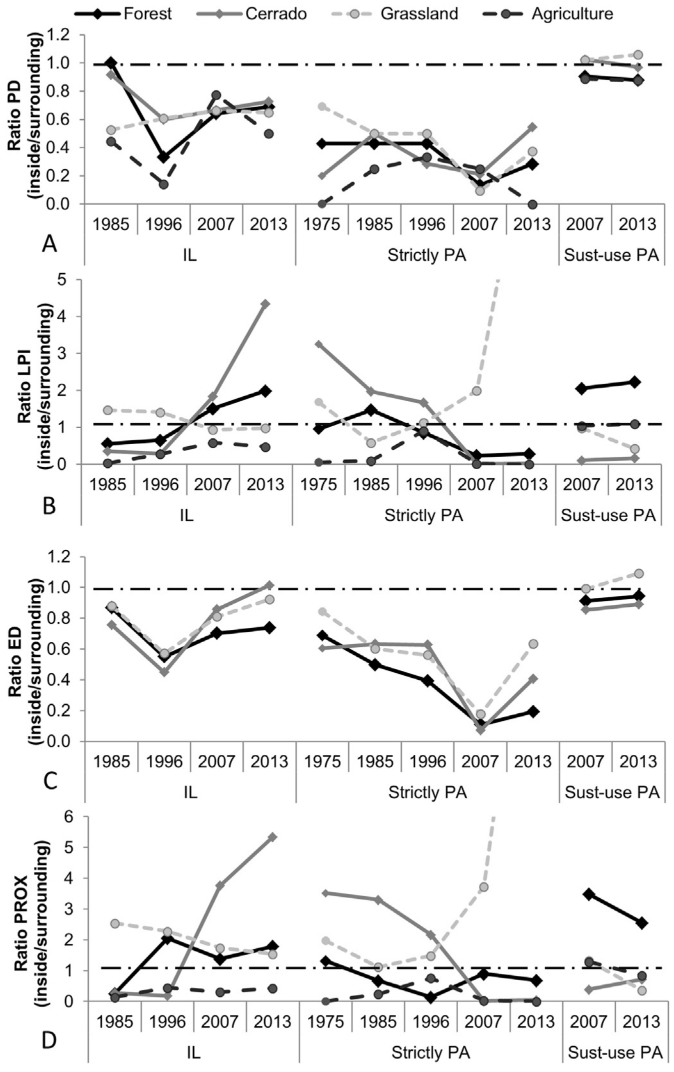

Fig. 4. Evolution of landscape metrics in buffer zones inside and surrounding PAs. We calculated the ratio between inside and surrounding zones to create comparisons. Values near 1 show similar metric behavior for both zones; values near zero show higher metric values for surrounding zones; and metrics higher than 1 show higher metric values for inside zones. The figure contains Patch Density (PD – panel A), Largest Patch Index (LPI – panel B), Edge Density (ED – panel C), and Mean Proximity Index (PROX – panel D) ratios by analyzed year (1975, 1985, 1996, 2007, and 2013), and land tenure - outside PAs, indigenous lands (IL), strictly protected areas (Strictly use), and protected areas for sustainable-use. Note that in panel B and D, grassland in strictly PAs present very high values, out of the scale of the graphic.

areas. These areas had a decreasing PD (−17%) associated with an increasing LPI (23%) and area cover (8%) as well as a decreasing ED (−3%) associated with an increasing PROX (31%) compared to the total landscape (PD = −32%, LPI = −7%, AREA = −8%, ED = −19%, PROX = 2%). The landscape metrics showed that sustainable-use PAs had undergone lighter fragmentation compared with the total landscape (PD = −32%, LPI = 25%, AREA = −9%, ED = −19%, PROX = 28%).

4. Discussion

4.1. Landscape composition change

Over the last four decades, the Brazilian Amazon has lost almost 15% of its tropical rain forest (INPE, 2015a), while the Cerrado biome has had approximately 46% of its natural coverage cleared (MMA, 2015). During this period, land use changes in our study area accounted for a net loss of 26% of the original natural vegetation. This value reflects the landscape dynamic at the transition boundary between these two biomes, where larger areas have been cleared at higher rates in the Cerrado.

In the MARB, the spatial and temporal conversion trends (from native to agriculture cover) were similar to those generally reported in the Amazon and Cerrado. Until 1996, native vegetation was replaced by agriculture, mainly at the western portion of the basin, including areas in the states of Mato Grosso and Pará. Such a pattern represents both the preference for land covered by forest and land with a lack of conservation units in this region. However, at the eastern portion (Tocantins and Goiás states), conversion of native areas to agriculture took place later, spreading significantly after 1996. A similar regional trend was also found at the northern portion of the Araguaia Basin (Cardille and Foley, 2003), in areas where Cerrado was the dominant land cover, with a lower preference for agriculture due to a predominance of low fertility soils (Hecht, 1993; Wassenaar et al., 2007). Grassland physiognomy had the lowest conversion rates of the three native vegetation types, corresponding to areas that were less fit for agriculture as well as the presence of integral protection areas and indigenous lands.

Considering the entire Cerrado biome, Tocantins, Piauí, and Maranhão states present the largest and most preserved remnant vegetation. The long distance of these states from major consumption centers, such as Brasília and São Paulo, is the main reason for this vegetation pattern (Sano et al., 2010). Specifically, in Tocantins state, Bananal Island is a large remnant of a Cerrado physiognomy area, where low fertility soils, a flooding regime, and several protected areas have restricted land cover conversion (Sawakuchi et al., 2013).

The expansion of deforestation in the Amazon and Cerrado has been associated with the expansion of agriculture and local population growth (Morton et al., 2006; Barona et al., 2010; Sano et al., 2010). Areas converted from native vegetation into productive areas are related to biophysical characteristics and infrastructure establishment or improvement (Soares-Filho et al., 2006; Ferreira et al., 2013; Sawakuchi et al., 2013; Garcia and Ballester, 2016). These patterns represent higher land, water, and food demands, as well easier access (Ballester et al., 2003). Thus, since native vegetation and economic activities compete for space, we assumed that increases in population, cultivated area, cattle herd, and wood extraction might present a relationship with the temporal dynamics of land cover.

According to agricultural and demographic census data (IBGE, 2015), from 1970 to 2013, the number of inhabitants, livestock, and planted areas in the sub regions of our study area increased. In contrast, wood extraction for firewood, round wood, and charcoal has decreased since 1990. The growth in the number of inhabitants was related to the 1650% increase in urban areas (Appendix S7). While the urban population grew by approximately 5-fold from 1970 to 2010, the non-urban population shrank by approximately 13%. This population growth pattern is also observed on a state wide scale (4.5-fold increase in the urban population). The massive increase in the local and regional urban population results in the need for more food – in this case, meat, which commonly originates from nearby producers. Thus, although the regional population is not the only market attended by agriculture production in the MARB, its growth is correlated to the expansion of pastureland ($R^2 = 0.97$, $p < 0.05$, Appendix S7). In regions where larger industries are scarce, such as the MARB, agriculture is the main economic activity. A few large farms are responsible for agricultural exports to the larger national markets. According to the Brazilian Beef Association (http://www.abiec.com.br/index.asp), the states of the MARB only recently approached ~12% beef production exports.

Most farms in the Cerrado still produce beef based on practices with low technological inputs (traditional management) and mainly produce for regional markets (Garcia and Ballester, 2016).

The rates of native vegetation conversion showed a temporal trend related to increases in cattle herds and the agricultural area (Appendix S7). The number of cattle presented significant rates of increase between 1985 and 2007 (~8% yr^{-1}), with a peak between 1996 and 2007 (~14% yr^{-1}). Such an increase in cattle herds over time corresponded to the temporal pattern of the conversion of natural areas. Agricultural census data also showed noteworthy increases in the growth rate of cultivated areas starting in the 1990s until 2013. Between 1990 and 2007, the cultivated area grew 4% (38 km^2) per year, while from 2007 to 2013, this value was 15% per year (100 km^2). It is worth noting that the period that had the higher increases in cultivated areas (2007–2013) does not correspond with the period that had the higher deforestation rates (Appendix S7) in the MARB (1985–2007).

Our results, associated with census data, indicate that deforestation seems to be more related to the expansion of pastures, while increases in crop areas do not have a clear relationship with deforestation inside the MARB. A similar trend was also observed in another section of the Amazon-Cerrado transition zone, where land use change was mainly driven by the expansion of pastures (Morton et al., 2006). Furthermore, between 2007 and 2013, we observed an increase in cattle herds and in crop areas that together were greater than the conversion of native cover. This may indicate an intensification of agricultural production by the substitution of native pasture with planted pasture, as well as double cropping systems. In this study, we did not evaluate whether the substitution of pasturelands by crop areas in the MARB implied deforestation elsewhere, as suggested by the leakage effect (Barona et al., 2010). Currently, studies have started to better characterize pastures in the Cerrado biome in terms of carbon stock and bovine support (biomass), which in the future could mean a better orientation of this expansion and an increase in the number of cattle per hectare, as well as the recovery and appropriate management of each soil/climate region (Arantes et al., 2016).

4.2. Landscape structure change

Landscape metrics showed a common fragmentation pattern of native vegetation that agreed with those reported other studies (Ferraz et al., 2005; Brannstrom et al., 2008; Cabacinha and Castro, 2009; Carvalho et al., 2009; Grecchi et al., 2013): a decrease in patch area, core area, and dominance of natural land covers, associated with an increase in their patch density and distance between them. In the upper Araguaia Basin, floristic diversity was related with fragment shape and size, while floristic richness and abundance were related to isolation or connectivity (Cabacinha and Castro, 2009). Core specialist species, such as shade-tolerant plants, are generally more affected by fragmentation (Metzger, 2000). In ecological terms, the natural cover was reduced and its fragmentation affected biodiversity through direct and indirect processes. Large patches of native vegetation have a lower proportion of edge area than small patches. Consequently, large patches better conserve core habitat specialist species and ecosystem functions (Lindenmayer and Fischer, 2006). Such components are generally the first to disappear in fragmented landscapes (Woodroffe, 1998). Edge increases are one of the initial effects of habitat fragmentation and are effectively quantified by the edge density metric (Hargis et al., 1998).

According to our results, forest is probably the most affected physiognomy in terms of edge effects. In addition to showing the maximum decrease in ED, it presents a higher canopy and tree density, which makes its biophysical conditions more different than those of other land cover, increasing the edge effects (Dodonov et al., 2013). Regardless of the different responses/effects of target species according to ED (McGarigal, 2002), the aim of this analysis was to quantify the amount of core habitats, which are important to maintaining the original ecological functions and specialist species. Thus, the core area (CA) gives us more precise information than the patch area on the real amount of habitat, with preserved ecological functions due to the exclusion of edge effects. Again, our results related to CA supported the conclusion that forest cover has been greatly affected by fragmentation compared to other physiognomies. It is emphasized by a decrease in connectivity among forest fragments calculated by landscape indices. The increase in distance between native patches affects ecological dynamics for some species, disturbing reproduction fluxes, with consequences for gene flow, leading to increased inbreeding and an increased chance of stochastic extinction (Banks et al., 2013).

The presence of PAs reduces the conversion of native cover into agricultural areas in the Amazon, Cerrado and other tropical biomes (Soares-Filho et al., 2006; Nagendra, 2008; Carranza et al., 2014). Avoiding deforestation is important, but it is not the only requirement for PAs. The preservation of ecological interactions affected by fragmentation is essential to biological diversity and the conservation of ecosystem services. The present study considered not only land use s but also changes in the landscape configuration inside different PA types (IL, strictly PAs and sustainable-use PAs).

IL and strictly PAs presented similar patterns of land cover changes, where an increase in natural areas over agricultural areas was found, while sustainable-use PAs presented an increase in agricultural areas. We observed that IL and strictly PAs tend to control fragmentation in the MARB in similar ways. Moreover, sustainable-use PAs had a negative influenced the fragmentation process. Some studies found a similar effectiveness between IL and strictly PAs in controlling deforestation (Nepstad et al., 2006) and that sustainable-use PAs are less effective in preventing land use conversion due to the less restrictive occupation rules applied to such areas (Carranza et al., 2014; Oliveira Paiva et al., 2015). Such tenure-related patterns were also observed in the Ecuadorian Amazon (Messina et al., 2006) and Mexican Dry Forest (Figueiroa and Sánchez-Cordero, 2008). We argue that in addition to flexible land use rules, sustainable-use PAs are created in response to an already established and intense conversion of land use. For example, the Bananal Environmental Protection Area (*APA do Bananal/Cantão*) was created in 1997. In 1996, approximately 20% of the area was already converted to agriculture, increasing to 47% in 2013. Still, the management plan established that 65% of this sustainable-use PA corresponded to economic development zones (Tocantins, 2015); thus, land use conversion will probably continue to grow in the region.

5. Conclusion

Over the last four decades (1975–2013), the Middle Araguaia River Basin has faced intense conversion and fragmentation of native vegetation and, consequently, the impoverishment of the quality of native cover. Until 2013, 37% of the native vegetation was converted into agricultural areas - or 45%, if PAs are not counted. The study area encompasses almost all of the protected areas of the Araguaia River Basin, including eight IL, two strictly PAs and three sustainable-use PAs. These different types of PAs were shown to have different roles in the fragmentation processes. Deforestation and fragmentation decreased inside IL and strictly PAs, maintaining the extent and quality of the native cover areas. The same trend was not observed inside sustainable-use PAs, which presented similar patterns of change to the landscape outside PAs. Yet, most of IL and strictly PAs are located within floodplain areas, which are predominately covered by grassland.

Most of the original area covered by forests and cerrado vegetation remains threatened, raising concern regarding the conservation of this physiognomy. This trend may also be true not only for the MARB but also for the entire Amazon-Cerrado transition zone, where agricultural expansion is faster than measures for planning and evaluating conservation. Forest can be considered to be the most threatened and least protected physiognomy in terms of the extent of cover and fragmentation. Still, conserved forest areas are those that can be flooded, are unsuitable for agriculture, and within PAs.

Nonetheless, we provide insights into how landscape fragmentation is driven according to different land tenure. Such results can be used when determining whether the establishment of PAs fulfills their implementation goals, to design management plans, to evaluate new implementations, as well as to design ecological corridors to connect special areas. Finally, the evaluation of the landscape composition and changes in configuration for large areas provides important information for regional planning regarding the identification of drivers controlling both deforestation and conservation, contributing to decision-making regarding the implementation of new protected areas by identifying threatened physiognomies and specific endangered areas that need attention in a given region.

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Appendix A. Supplementary data

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