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Landscape-fragmentation change due to recent agricultural expansion in the Brazilian Savanna, Western Bahia, Brazil

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Abstract The aim in this study was detect changes in landscape-fragmentation patterns resulting from the expansion of agriculture in the *Cerrado* region (Brazilian Savanna) during the period 1988–2011. The study area covers 7,559,783.69 ha and is restricted to the limits of the Urucuia Group (Upper Cretaceous), a geological unit formed by sedimentary rocks of continental deposits where there has been intense agricultural expansion due to favorable conditions for the use of mechanized farming. The temporal analysis considered land-use/land-cover data from Landsat TM image classification for the years 1988, 1992, 1996, 2000, 2004, 2008 and 2011. Fragmentation quantification was performed from the morphological spatial pattern analysis (MSPA) and traditional landscape metrics analysis. The calculation of MSPA attributes considered 10 edge widths, between 30 and 300 m. Traditional landscape metrics were obtained from Path Analyst and V-Late software. Change detection in MSPA classes was obtained through cross-tabulation. *Cerrado* deforestation in the study area increased from 795,502.61 ha in 1988 to 2804,679.75 ha in 2011. The spatial pattern of *Cerrado* deforestation and fragmentation has a spatial concentration in the western region of the study area that gradually progresses toward the east. Our results emphasize the fragmentation process with a reduction in the following fragmentation indicators over the past two decades: area, number of patches, core, and edge. In addition, the indicators increased in: complexity, size variation, and coreless fragments. Change detection enabled the description of spatial evolution of fragmentation indicators. The results can help define strategies for landscape planning and decision making for conservation priorities.

Keywords Fragmentation change detection ·
Morphological spatial pattern analysis · Landscape
metrics · Land-use/land-cover change

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Introduction

The *Cerrado* (savanna) biome located in Central Brazil covers an area of approximately 2 million km^2 and contains a very rich flora with high endemism (Klink and Machado 2005; Ratter et al. 1997). This biome is one of the major agricultural frontiers of Brazil (Brannstrom 2005). Human

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occupation of this biome intensified from the 1970s with the introduction of new agricultural technologies (Rada 2013), private agricultural colonization (Jepson 2006), public policies (Jepson et al. 2010), and expansion of rural credit (Castro and Teixeira 2012). By 2010, 48.54 % of the natural area of the *Cerrado* had been converted into land-use types according to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), a federal agency under the Ministry of Environment (MMA; MMA-IBAMA 2011). This land conversion to agriculture results in a habitat fragmentation that threatens the biodiversity and ecosystem functions (Carvalho et al. 2009; Grecchi et al. 2014). Therefore, the intensification of anthropogenic processes has made the Brazilian *Cerrado* a biodiversity hotspot for conservation priorities (Myers et al. 2000; Silva and Bates 2002).

Landscape fragmentation is a process that produces habitat loss, size reduction, and/or increasing isolation of habitats (Andrén 1994). The main causes of landscape fragmentation are agricultural growth, road construction, as well as implantation of urban areas and infrastructure projects (Uuemaa et al. 2009). Fragmentation quantification has been performed using landscape metrics (McGarigal and Marks 1995; Jaeger 2000), regression analysis (Su et al. 2012), moving window analysis (Fan and Myint 2014), fractal analysis (Sun et al. 2014), entropy (Zaccarelli et al. 2013), surface metrics (McGarigal et al. 2009), and morphological spatial pattern analysis (MSPA; Soille and Vogt 2009). However, few studies have been performed with a combination of landscape indicators. Some studies use two groups of metrics: traditional and those derived from a mathematical morphology framework (Höbinger et al. 2012; Salvati 2014; Salvati et al. 2015). This indicator combination enables a detailed examination of landscape transformation.

In a fragmentation study, characterization and quantification of the landscape structure must precede the study of the implications of their effects on ecological processes (Turner 1989, 1990; McGarigal et al. 2009). In this context, many studies have focused on the spatial and/or temporal analysis of fragmentation patterns without explicit association with specific fauna or flora (Tang et al. 2012; Kang and Choi 2014; Kang and Kim 2015). This is because landscape changes impact not only on one but on several species that depend of habitat quality factors (Fahrig 2003). Furthermore, spatial–temporal analysis of the landscape pattern assists in environmental planning and management, which increasingly seek to understand the cause-and-effect interrelationships between anthropogenic and natural agents (de Groot 2006; Saura et al. 2011).

Fragmentation change detection has been performed using morphological classes, since the landscape traditional metrics are not represented in pixels. Seebach et al. (2013) focused change analysis on the core class, while

Ostapowicz et al. (2006) and Cao et al. (2015) conducted studies considering all MSPA classes. In all fragmentation studies, the change detection method used is that of post-assessment, which is widely used in studies of change detection from remotely sensed data (Ardli and Wolff 2009; Soulard and Sleeter 2012; Mascorro et al. 2014). Post-classification change detection performs a comparison of two single-date classified images from manual or automatic classification and generates a change matrix, i.e., a cross-tabulation matrix between the temporal images (Howarth and Wickware 1981; Singh 1989).

The main requirement in post-classification change detection is the precise registration of the images to avoid mis-registration, which is one of the main sources of error (Carmel et al. 2001). Seebach et al. (2013) proposed morphological change detection (MCD), which performs post-classification for binary maps (core and background classes) with morphological post-processing to improve change detection accuracy, removing the unwanted spurious changes from mis-registration and classification errors. However, the proposed method is limited to binary images, considering only the core class. An alternative is the adoption of a visual classification that performs a retro-analysis (from newest to oldest), maintaining the same lines of vegetation polygons for unchanged areas. This prevents error propagation from registration as well as supervised and unsupervised classifications, such as those from changes in weather conditions, salt and pepper noise, phenological changes and soil moisture.

The aim in this paper is to detect changes in landscape fragmentation using MSPA and traditional landscape metrics, during the period 1988–2011. The study area is located in Bahia State (Brazil), in the *Cerrado* Biome, where mechanized agriculture is rapidly expanding. Traditional landscape metrics and MSPA classes were obtained from land-use and land-cover (LULC) dataset generated via classification of Landsat thematic mapper (TM) images for the years 1988, 1992, 1996, 2000, 2004, 2008, and 2011 (Oliveira et al. 2014). Traditional landscape metrics enable a fragmentation analysis at the general level, while the morphological analysis allows detailing and spatial evolution of the patches. Changes in MSPA classes were obtained from cross-tabulation showing the changed locations.

Materials and methods

Study area

The study area encompasses the Urucuia Group geological formation, which includes nine municipalities of Bahia State, Brazil: Formosa do Rio Preto, Riachão das Neves,

Barreiras, Luís Eduardo Magalhães, São Desidério, Baianópolis, Correntina, Jaborandi, and Cocos (Fig. 1). This area has 7,559,783.69 ha and extends from 10° 04′ 36″ S to 15° 14′ 38″ S latitude and from 44° 08′ 09″ W to 46° 37′ 48″ W longitude.

The Urucuia Group (Upper Cretaceous) is subdivided into Posse and Serra das Araras formations (Campos and Dardenne 1997a, b). The sedimentology and facies association suggests a desert environment with field dune deposits that changed to a fluvial-eolian system represented by sandy sheet deposits (Spigolon and Alvarenga 2002). The terrains of the Urucuia Group are flat and composed mainly of well-drained medium texture Oxisols, which favor the development of mechanized agriculture. This geological group contains the Urucuia aquifer that is responsible for flow regulation of the left-bank tributaries of the São Francisco River in the dry season (Gaspar et al. 2012). The groundwater has been used to supply farms, villages and irrigation projects. The study area has a cuesta landform associated with extensive and gently east-dipping surface. Therefore, the altitude decreases from west to east and the rivers have a parallel drainage pattern toward the São Francisco River (Fig. 2a). Fluvial incision into

sedimentary layers generates slope areas bordering the rivers (Fig. 2b).

The region has a tropical precipitation regime characterized by well-defined wet (October–April) and dry (May–September) seasons (Felfili and Felfili 2001). The annual average temperatures range between 18 and 22 °C. Mean annual rainfall decreases rapidly to the east, with irrigation crops replacing rainfed agriculture that relies on rainfall for water (Flores et al. 2012; Spagnolo et al. 2012; Fig. 2c).

In recent decades, this area represents a large agricultural frontier in the *Cerrado* biome, with intense conversion of natural vegetation to agricultural cropping (Brannstrom et al. 2008). The main crops are soybeans, cotton and corn (Oliveira et al. 2014). This is an appropriate study area for landscape-fragmentation change detection due to agriculture expansion.

Land-use and land-cover maps

Mapping using PRISM/ALOS images

This study used the LULC map at 1:2000 scale developed by the Laboratory of Spatial Information Systems (LSIE) at
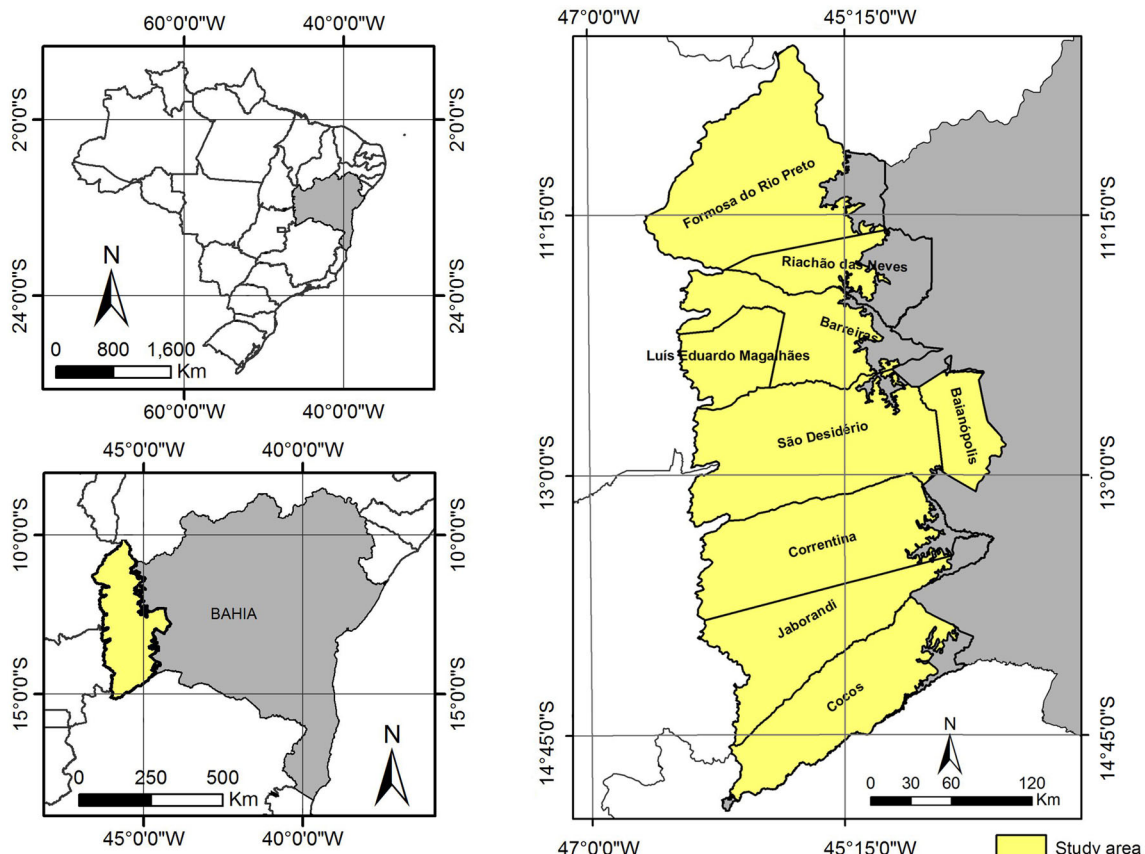

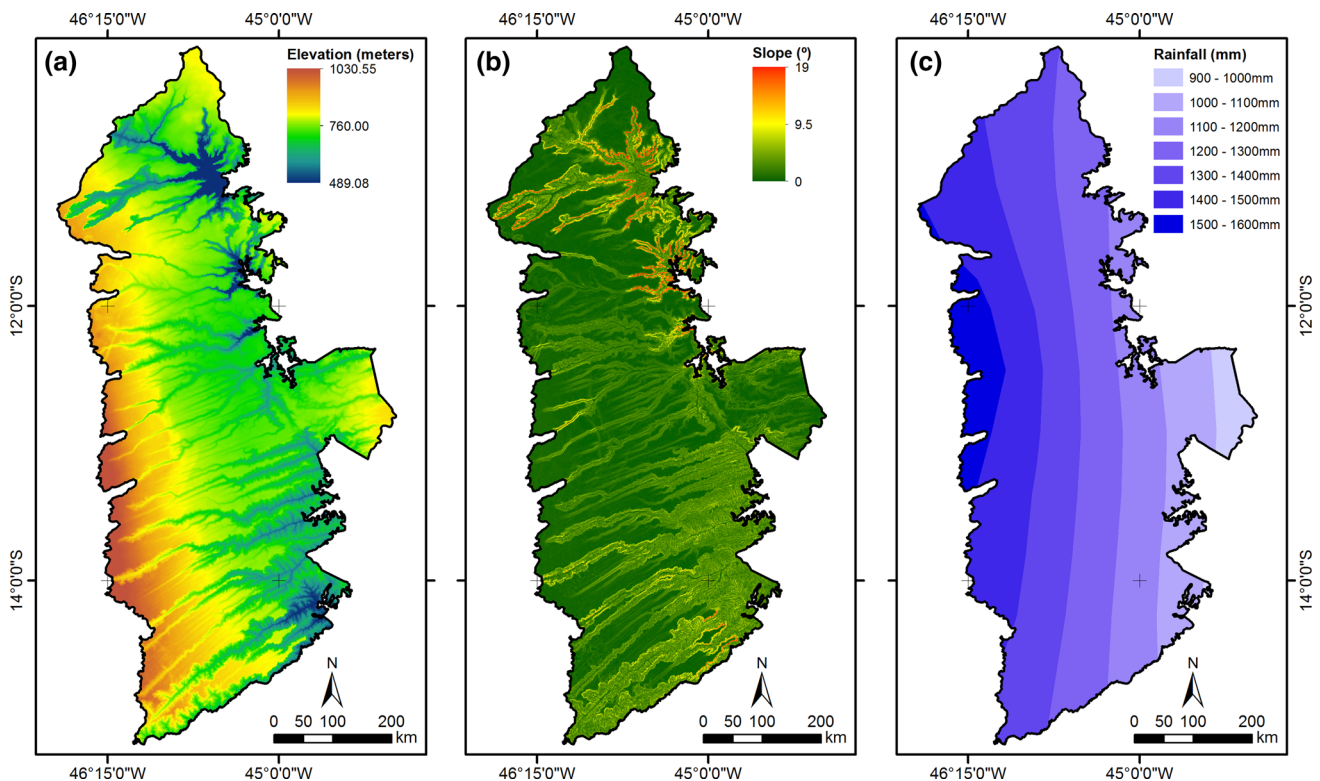**Fig. 1** Study area location

Fig. 2 Maps of terrain and rainfall attributes of study area: **a** elevation map generated from SRTM data, **b** slope, and **c** average rainfall (data from National Agency of Water and National Institute of Meteorology)

the University of Brasilia (UnB) in partnership with the Inter-American Institute of Commerce and Agriculture and the Ministry of National Integration. Images from Remote-Sensing Instrument for Stereo Mapping Panchromatic (PRISM) sensor onboard Advanced Land Observing Satellite (ALOS) were used for map elaboration. The panchromatic images had 2.5-m spatial resolution, 8 bits and a ground swath depending on the acquisition mode: 35 km in triplet mode and 70 km in nadir mode (Saunier et al. 2010). The product used was L1B2 (radiometrically and geometrically corrected), and the methodology was the visual interpretation using manual vectorization from ArcGIS 9.3 software. The image dates were predominantly from 2009, but with the possible lack of information for this year, 2008 or 2010 images were also used. In addition, fieldwork and other images from Landsat TM, CCD/CBERS 2 (Charged Couple Device/China-Brazil Earth Resources Satellite) and Google Earth helped in the interpretation. This LULC mapping identified 26 classes. However, these classes were simplified to six classes (water bodies, urban areas, agriculture, reforestation, altered vegetation and natural vegetation) to be consistent with the possible mapping performed for other dates with Landsat TM images. Most of the agglutinated classes had irrelevant areas.

Multitemporal mapping using Landsat images

Oliveira et al. (2014) conducted a classification of Landsat TM images for the years 1988, 1992, 1996, 2000, 2004, 2008, and 2011, considering a cloud cover of less than 10 % during the dry season (May–September). The Landsat 5 TM images were co-registered using ENVI software, considering a root-mean-squared error (RMSE) less than 0.2 pixels to achieve an accuracy of 90 % for change detection (Dai and Khorram 1998; Townshend et al. 1992). The Landsat TM images were classified by visual interpretation considering six predefined classes. This procedure ensured that the lines of polygons without land-use changes remain unchanged. Landscape-fragmentation change detection considered the natural vegetation class obtained for the study period.

The automatic mapping of LULC classes in agricultural areas is a complex procedure, because of the high variety of features (e.g., different types of soil, crops, and planting times). In addition, the spectral measurements may change according to the phenology of crop plants. In this context, the automated classification algorithms generate very different results for the same target (Rozenstein and Karnieli 2011), resulting in classification and change detection errors (Seebach et al. 2013). However, land-use and land-

cover classes are easily identified by visual interpretation, obtaining reliable results for small (Munsi et al. 2010; Ke et al. 2011) and large areas (Zuo et al. 2014). Additionally, the visual interpretation of remote sensing data for photointerpreters is widely used for the validation of supervised and unsupervised classifications (e.g., Stow et al. 2007; Sano et al. 2010).

Traditional landscape metrics analysis

Traditional landscape metrics at the class level were calculated from natural vegetation class for the study period using Patch Analyst 5.0 extensions (Rempel et al. 2012) and v-LATE 1.1 (Lang and Tiede 2003). In this paper, we use 15 traditional landscape metrics: class area (CA), total edge (TE), edge density (ED), mean patch edge (MPE), number of patches (NumP), mean patch size (MPS), patch size standard deviation (PSSD), patch size coefficient of variation (PSCoV), mean shape index (MSI), area-weighted mean shape index (AWMSI), mean patch fractal dimension (MPFD), area-weighted mean patch fractal dimension (AWMPFD), landscape division index (DIVISION), effective mesh size (MESH), and splitting index (SPLIT). The descriptions of the landscape metrics are given in the FRAGSTATS User's Guide (McGarigal and Marks 1995) and v-LATE User's Guide (Lang and Tiede 2003). These 15 landscape metrics can be grouped into five categories: area (CA), edge (TE, ED, and MPS), density, size, and variability (NumP, MPS, PSSD, and PSCoV), shape (MSI, AWMSI, MPFD, and AWMPFD), and aggregation (DIVISION, MESH, and SPLIT).

Morphological spatial pattern analysis

MSPA algorithm consists of a sequence of logic operations (union, intersection, complementation, and translation) considering geometric objects called "structuring elements" of previously defined size and shape (Vogt et al. 2007b). We apply a sequence of morphological operators known as erosion, dilation, and anchored homotopic skeletonization (Vogt et al. 2007a, 2009) in the 30-m resolution binary images (forest/non-forest). Automated classification was performed by Guidos software (http://forest.jrc.ec.europa.eu/download/software/guidos), resulting in seven mutually exclusive classes: core, islet, bridge, loop, edge, perforation, and branch (Soille and Vogt 2009).

The calculation of MSPA attributes was conducted for all study years, considering 10 edge widths, ranging from 30 (one pixel) to 300 m (10 pixels). The adoption of different edge dimensions was due to the distinct interference of different plant and animal species. In this interface between native vegetation and deforested areas, there are significant differences in composition, structure, or function, which are exposed to diverse abiotic (e.g., wind, light, and moisture) and biotic processes (e.g., animals, litter, seeds, pollen, pollutants) which vary with edge distance. Furthermore, the core area that consists of interior natural vegetation outside the edge zone is substantially changed by edge distance. Patch number and percentage of the total area were obtained for each class.

Fragmentation change detection

Traditional landscape metrics over the years studied enabled the identification of habitat fragmentation and landscape change at the general level. Cross-tabulations between MSPA-image pairs at successive dates and of the two extreme dates (1988 and 2011) were carried out using Abílio software. The result for each cross-tabulation consists of an image and a table. The cross-tabulation image has a number of classes matching the number of existing categorical combinations between two time periods. Therefore, cross-tabulation images indicate both where and when these disturbances took place. The cross-tabulation table, also known as the contingency table, provides an estimate of the total amount of changes. The columns and rows of the matrix show the morphological categories of two time periods for the same study area. The diagonal elements of table are invariant areas, while the others are changed areas.

Results

Multitemporal analysis of the LULC classes

LULC classes showed variation in the analyzed period (Fig. 3). Deforestation distribution pattern in the study area during the period 1988–2011 began along the western region and gradually moved eastward. The climatic conditions of western part with highest rainfall favored rainfed plantations (Fig. 3), which do not depend on additional costs for irrigation.

The natural vegetation area was reduced in 26.57 %, ranging from 89.41 % in 1988 to 62.84 % in 2011, i.e., an average deforestation rate of nearly 1.61 % or 87,355 ha year^{-1}. The agriculture and livestock area increased 27.13 %, ranging from 5.70 % in 1988 to 32.83 % in 2011. The altered vegetation showed irregular behavior during the study period, reaching an area of 5.42 % in 2008. The reforestation area decreased 1.51 %, ranging from 1.87 % in 1988 to 0.36 % in 2011. Proportionally urban areas and water bodies changed little over the years. *Cerrado* deforestation in the study area increased from 79,502.61 ha in 1988 to 2,804,679.75 ha in 2011. The
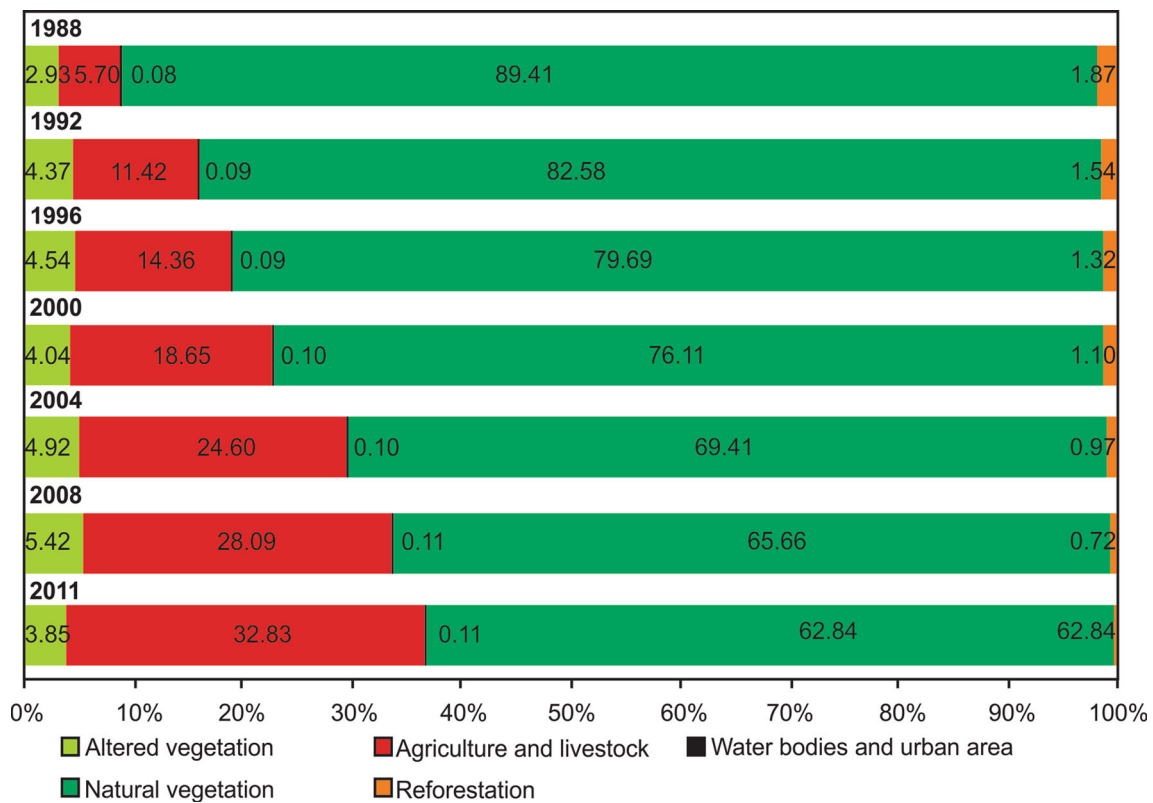
Fig. 3 Area percentage of land-use/land-cover classes in the study area during the period 1988–2011

pattern of *Cerrado* deforestation showed spatial concentration in the western part of the study area that gradually progressed toward the east. The annual deforestation rate over the Urucuia Group in Western Bahia is approximately 1.16 % per year.

The main growth vector of agriculture begins in the central west portion and progresses to the eastern region. Another growth vector is toward the north and south limits of the study area. Because of lower rainfall in the eastern portion (Fig. 2), plantations require greater investment in irrigation. The presence of permanent rivers and groundwater from Urucuia aquifer allowed for the growth of irrigated areas.

Landscape-fragmentation change detection by the traditional landscape metrics analysis

As shown in Fig. 4, there was a percentage reduction for CA (26.57 %), MPE (38.11 %), MPS (77.06 %), PSSD (61.28 %), and MESH (2.31 %), and an increase in landscape-metric values for TE (89.64 %), ED (169.77 %), NumP (206.41 %), PSCoV (68.79 %), AWMSI (95.13 %), AWMPFD (4.37 %), DIVISION (735.42 %), and SPLIT (7.92 %) in the period 1988–2011. The MSI and fragmentation metrics fluctuated over the studied years.

Landscape-fragmentation change detection by the morphological spatial pattern analysis (MSPA)

Supplementary Figure A1 shows the area percentage of the MSPA attributes considering ten edge widths over the studied years, while Supplementary Figure A2 shows patch number. Cross-tabulation showed changes detected in MSPA classes for the period 1988–2011 (Supplementary Table A1).

The core class was the most representative area for all scenarios of the studied years (Supplementary Figure A1). Over time, the core class showed a reduction in total area, while the islet, edge, bridge, and branch classes increased (Supplementary Figure A1). The loop class had area growth in the period 1988–2008 and a small reduction in the last period. In contrast, the perforation class had area growth in the initial period (1998–1992) and then a steady decline (Supplementary Figure A1).

Most classes (core, islet, perforation, bridge, loop, and branch) had a tendency to increase the patch number in the period 1998–2008, with a decrease in the last period, while the edge class showed a tendency for steady growth over time (Supplementary Figure A2). The increase in edge width resulted in the following characteristics:
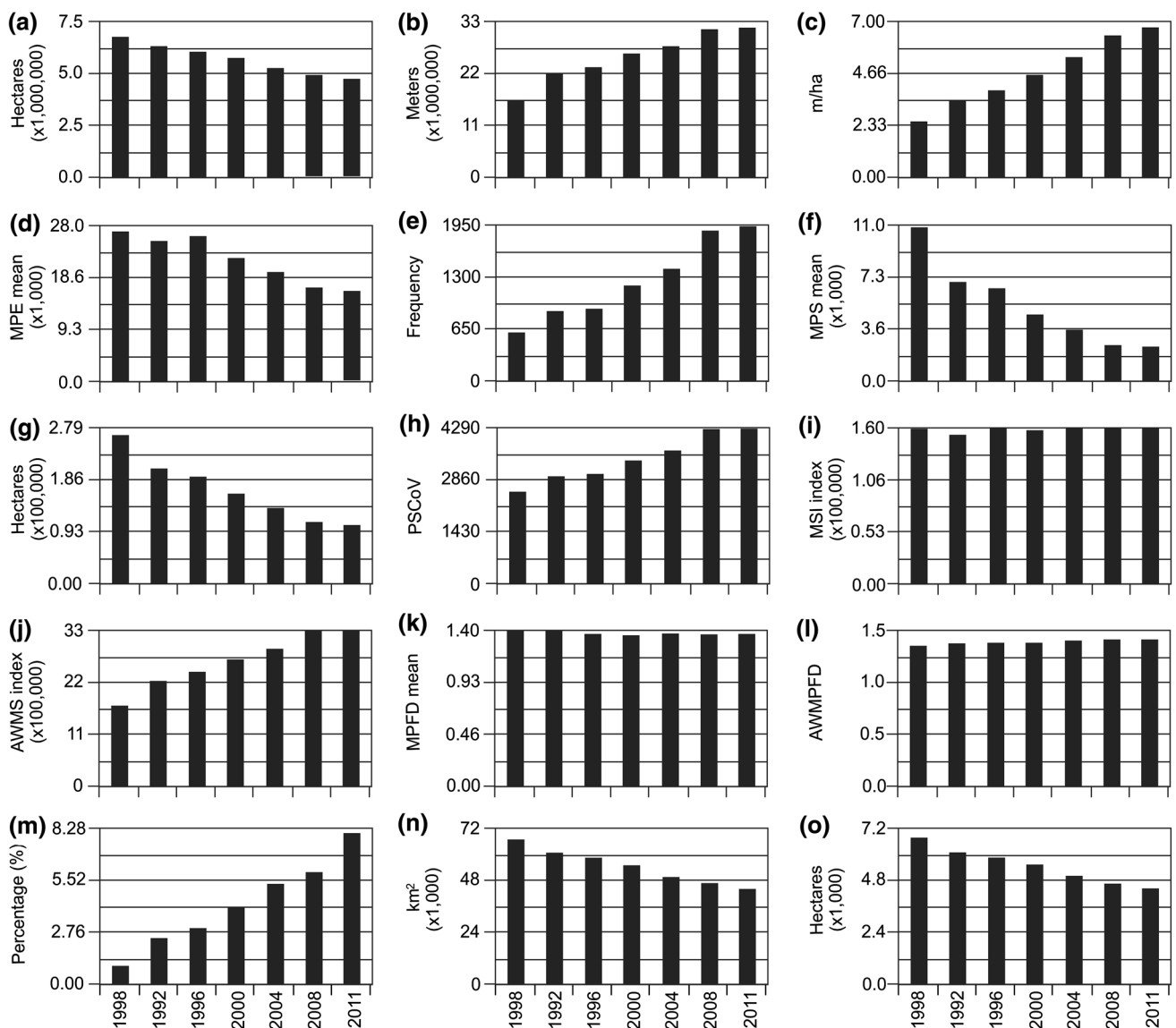
Fig. 4 Traditional landscape metrics of the study area during the period 1988–2011: **a** CA, **b** TE, **c** ED, **d** MPE, **e** NumP, **f** MPS, **g** PSSD, **h** PSCoV, **i** MSI, **j** AWMSI, **k** MPFD, **l** AWMPFD, **m** DIVISION, **n** MESH, **o** SPLIT

(a) reduction in both the total area and patch number for core class; (b) area growth for islet, edge, perforation, bridge, loop, and branch; (c) an increase in the islet patch number.

Supplementary Table A1 shows the change matrix for the MSPA classes in the period 1988–2011. The percentage change of bridge, edge, and islet classes were more than 250 %, while in the core this was over −30 %. The increase in edge width of 30 m to 150 and 300 m significantly expanded the changes in the MSPA classes (Supplementary Table A1), since the core reduced in area, the other classes increased (Fig. 5). The spatial pattern of *Cerrado* fragmentation has a spatial concentration in the western part of the study area (Fig. 5). All MSPA classes were preferentially converted to the background.

Supplementary Figure A3 shows an exemplification of changes in morphological classes.

Discussion

The visual interpretation technique used in this study to facilitate the change detection has the following advantages (Coppin et al. 2004; Narumalani et al. 2004; Menke et al. 2009): (a) easy updating over time, which favors monitoring; (b) minimizes the error propagation for image co-registration; (c) minimizes the mis-classification derived from atmospheric variations, salt and pepper noise (i.e., a type of impulse noise caused by error in image acquisition and/or recording, where individual pixels in digital image
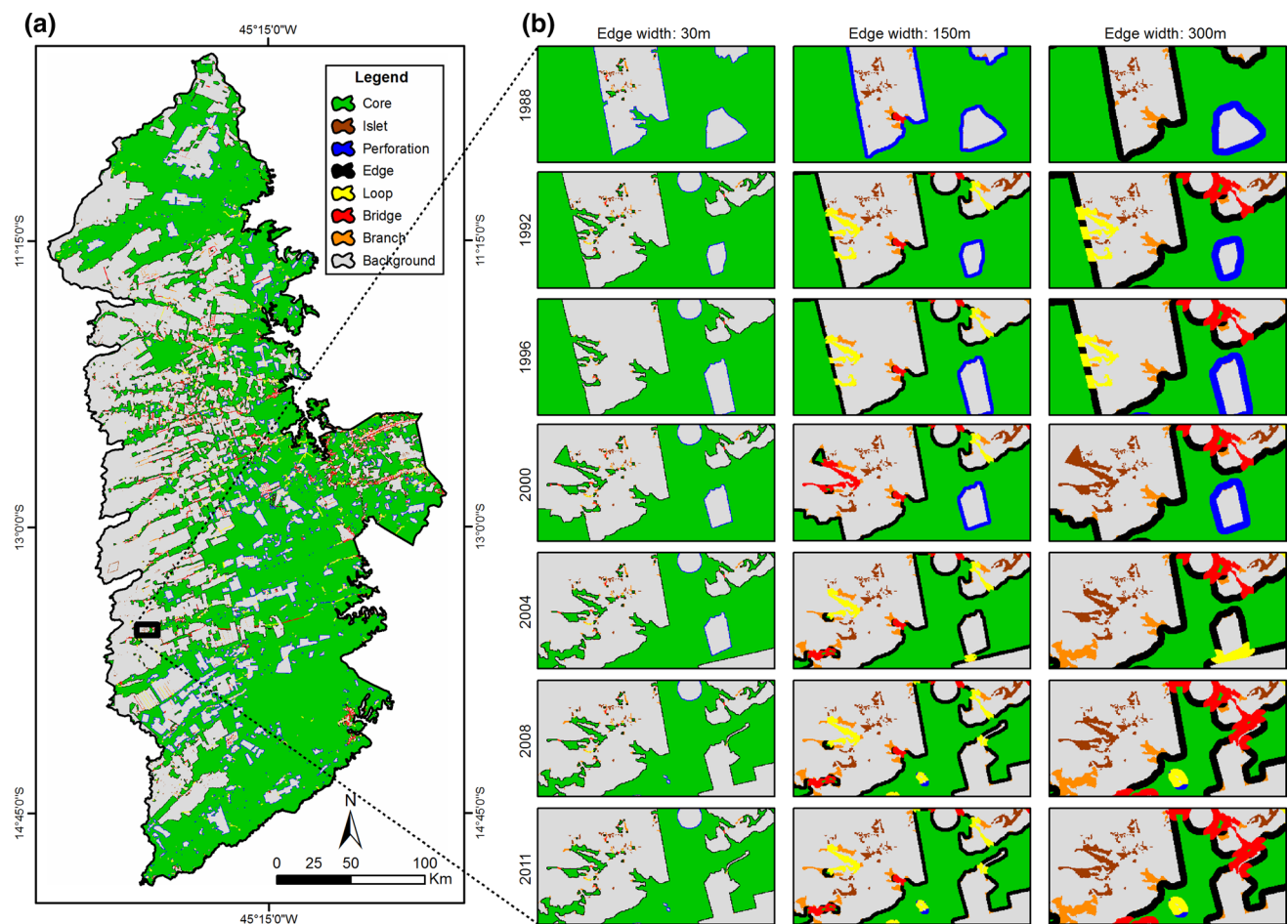
Fig. 5 Effect of edge width variation in MSPA classes: **a** MSPA classes for 2011 with edge width of 300 m; **b** detail of the MSPA class for all years and edge width of 30, 150 and 300 m

are randomly digitized into two extreme intensities, maximum and minimum; Toh and Isa 2010), phenological changes, and soil moisture; (d) allows integration and comparison of sensor images with different spatial, spectral, temporal, and radiometric resolutions. The main disadvantages include: (a) lack of automation; (b) the classification accuracy depends on user experience; (c) application over large areas may require a long time and involvement of many people.

The evolution of land use in western Bahia has occurred rapidly in recent decades. In 1992, the agricultural sector represented 11.42 % of the study area (863,327.30 ha) and was concentrated in the mid-west portion. Brazil's agricultural policy enacted in 1991, which extended credit lines and established harvest plans (Brasil 2001), stimulated the agricultural sector. In 2000 and 2001, the government of Bahia created programs to support the agribusiness, especially for cotton and coffee. Other political factors also contributed to this expansion, such as government incentives for the development of new techniques for soil fertility correction, tax incentives for agricultural

modernization, and government funding for irrigation programs (Flores et al. 2012; Spagnolo et al. 2012; Oliveira et al. 2014). The combination of these factors promoted an intense migration from all areas of southern Brazil to the Western Bahia region, promoting rapid agricultural frontier expansion (Brannstrom and Brandão 2012) and consequently landscape fragmentation. Therefore, there was a breakthrough especially for the eastern portions at a rate of 7.23 % (546,572.36 ha) from 1992 to 2000 and 14.19 % (1,072,733.31 ha) 2000–2011. The annual deforestation rate over the Urucuia Group in Western Bahia (approximately 1.16 % per year) is higher than the 0.6 % per year registered for the Brazilian *Cerrado* Biome as a whole in the period 2002–2010 (MMA-IBAMA 2011). This expansion is the result of favorable environmental conditions for mechanization, rainfall at regular intervals, and water availability for irrigation projects (Menke et al. 2009). Farms are usually large with over 1000 ha, where several properties exceed 5000 ha (Brannstrom 2009). However, natural vegetation areas remain in the eastern portion of the study area, where annual rainfall is lower.

The deforestation pattern of the Western Bahia region is different from the Amazon agricultural frontier, which has been extensively studied. In the Amazon, agriculture growth occurs through conversion of already deforested land, mostly under degraded pasture (Brown et al. 2005; Barona et al. 2010), or by direct conversion of forest to cropland (Carvalho et al. 2002; Fearnside 2005; Morton et al. 2006). In Western Bahia, the agricultural practice was predominantly livestock and originated essentially by the conversion of natural vegetation to cropland, contemplating large areas in a short period of time. According to Hessel et al. (2012), the municipality of Cocos presents an initial deforestation associated with coal producers followed by a subdivision of the land in tranches by orthogonal feeder roads. In this scenario, the spatial occupation of agriculture and livestock occurs initially interspersed in the landscape and progresses to continuous areas.

The deforestation rates in Western Bahia region are closely related to the occurance of highways, as described for the Amazon agricultural frontier (Fearnside and de Alencastro Graça 2006; Fearnside 2006, 2007; Barber et al. 2014). In the study area, the federal highways BR-020 and BR242 have great influence for agricultural development. The regions just west of the BR-020 highway, containing higher rainfall, were the first to be occupied and are now entirely dominated by agricultural landscape (Fig. 6).

The two landscape indicators (traditional landscape metrics analysis and morphological spatial pattern analysis) used allowed for an analysis of fragmentation change detection in both global and local (pixel-by-pixel) scales. Except for the MSI and MPFD metrics that showed fluctuations in the historical series, the traditional landscape metrics appointed two changing patterns: (a) continuous reduction in the value of CA, MPE, MPS, DSSP, and MESH; and (b) continuous increase in the values of TE, ED, NumP, PSCoV, AWMSI, AWMPFD, DIVISION, and SPLIT. These changing patterns are typical for areas with progressive fragmentation increase (e.g., Jaeger 2000; Su et al. 2014; Liu et al. 2014; Liu and Yang, 2015; Walz 2015). The main implications of the changes were: (a) decrease in sizes and area of patches; (b) increase in irregularity, complexity, size variation, and number of patches; (c) reduction in the size of the average edge; and (d) increase in total edge and edge density. MSPA results reveal the fragmentation growth by reduction of core area and by increase in patch number of core, islet, branch, and edge, as also described in the other fragmented areas (e.g., Kang and Choi 2014). The increase in edge width reduced the core fraction and increased the area of the other MSPA components. The core class gradually became concentrated in the eastern part of the study area due to agricultural expansion, which initially occurred sparsely in the landscape and over time progressed to continuous areas without
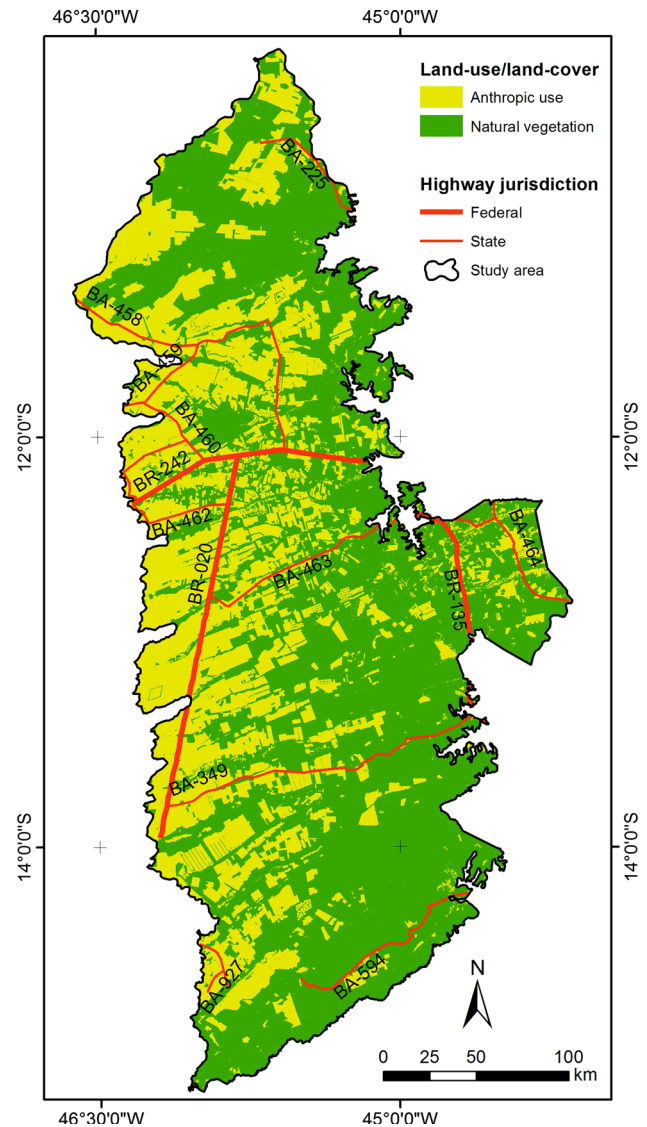

Fig. 6 Map of the main highways of the area of study, containing areas of natural vegetation and anthropic use in 2011

natural areas preserved in their interior. This occupation pattern occurs mainly in flat areas in the western part of the study area, where the remaining vegetation is concentrated along the rivers in areas protected by law.

Both procedures showed an increase in the vegetation fragmentation in the study area. The fragmentation of natural vegetation has severe implications for landscape dynamics. In the *Cerrado* Biome, the loss of vegetation cover can increase soil erosion up to 20 % (Merten and Minella 2013) and cause damage to endemic species (Ratter et al. 1997). Furthermore, fragmentation can also act as a barrier to the movement of wildlife (Mortelliti et al. 2014), interfere with pollination levels and seed production (Hadley and Betts 2012), reduce the connectivity of habitats (Liu et al. 2014), alter the natural ecosystem processes

(Hobbs 1993), reduce species diversity (Ma et al. 2013), increase mortality of species (Riley et al. 2003), and increase patch isolation (Fahrig 2003).

With the prospect of further expansion of mechanized agriculture in Western Bahia, guidelines are necessary to promote environmental conservation, especially through legislation for the protected area and improved agricultural practices (Silva and Bates 2002; Klink and Machado 2005; Grecchi et al. 2014). In Brazil, the National Forest Act (NFA; Brasil 1965, 2012a, b) is an important policy for ecosystem conservation, establishing: (a) Permanent Preservation Areas (PPA), ecologically sensitive areas designed to mandatory conservation; and (b) Legal Reserves (LR), minimum farm percentage of native vegetation that the landowner should preserve, specifically for the Cerrado this value is 20 % of the area. The NFA is the main strategy for environmental conservation in the Brazil, having a great influence over land use (Metzger et al. 2010; Sparovek et al. 2012). In Western Bahia on Urucuia Group, PPAs are important areas with remaining natural vegetation. Gurgel et al. (2013) analyzed the PPAs of the municipality of Riachão das Neves and found that areas with mechanized agriculture on the plateaus of Urucuia Group showed 5.5 % of inappropriate uses in 2008, which is low compared the depression areas on Bambuí Group with 26.5 %. However, only the PPAs are not sufficient to maintain biodiversity and ecosystem services. The new Brazilian Forest Code (Brazil 2012a, b) allowed for the compensation of legal reserves in the same biome, jeopardizing the maintenance of LRs in the study area due to the high economic value of land for mechanized agriculture. Future research should assess the impact of the agricultural expansion over riparian vegetation and protected areas, and propose ecological corridors at local and regional scales. The expansion of preserved areas can contribute to the maintenance of local biodiversity and recharge zone of the Urucuia aquifer (Silva et al. 2006; Gaspar et al. 2012).

Conclusions

The present study used two groups of fragmentation metrics (morphological spatial pattern analysis and traditional landscape metrics analysis), considering a multitemporal approach. The results contribute to the understanding of progressive agricultural expansion over the natural savanna in Central Brazil. Both types of metric demonstrate significant alterations in the composition, structure, and diversity of the landscape due to agriculture use over the last two decades. The effects of fragmentation over time are evidenced by the reduction in area, number of patches,

core, and edge, as well as the increase of complexity, size variation, and coreless fragments. Therefore, the conversion of natural vegetation into cropland areas is the most relevant landscape transformation in Western Bahia with negative consequences on the functioning ecosystem. The cross-tabulation between the temporal-map pairs from morphological spatial pattern analysis allows the detection of fragmentation change in the remaining vegetation. This approach quantifies the fragmentation changes both in the landscape and in the morphological classes (on the fraction of habitat). The spatiotemporal variations obtained by this approach can help define strategies for landscape planning and decision making on conservation priorities. Furthermore, this methodology permits a constant updating of the fragmentation dynamics.

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