SPATIO-TEMPORAL ANALYSIS OF LANDSCAPE PATTERNS IN THE CATOLÉ WATERSHED, NORTHERN MINAS GERAIS[1]

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ABSTRACT – The aim of this study was to quantify the spatio-temporal changes in land use/ cover (LULC), as well as analyze landscape patterns over a 20-year period (1995 – 2015) in the Catolé watershed, northern Minas Gerais State, using landscape metrics. The LULC maps were obtained using Landsat 5 and 8 data (Processing level 1) through supervised classification using the maximum likelihood classifier. Seven thematic classes were identified: dense vegetation, sparse vegetation, riparian vegetation, cropland, planted forest, bare soil, and water. From the LULC maps, classes related to the natural landscape (dense, sparse, and riparian vegetation) were grouped into forest patches, which was then ordered by size: very small (< 5 ha); small (5 – 10 ha); medium (10 – 100 ha); large (100 ha); and a general class (no distinction of patch size). Then, metrics of area, size and density, edge, shape, proximity and core area were calculated. The dense vegetation portion of the study area decreased considerably within a given time, while the portion of cropland and bare soil increased. Overall, in the Catolé river basin, the total area of natural vegetation decreased by 3,273 hectares (4.62%). Landscape metrics analysis exhibited a reduction in the number of very small patches, although the study area was still considered as fragmented. Moreover, a maximum edge distance of 50 m is suggested for conducting studies involving core area metrics in the Catolé watershed, as values above this distance would eliminate the very small patches.

Keywords: Land use/ cover; Landscape metrics; Forest patches.

ANÁLISE ESPAÇO-TEMPORAL DOS FRAGMENTOS FLORESTAIS NA BACIA DO RIO CATOLÉ, NORTE DE MINAS GERAIS

*RESUMO – O objetivo deste estudo foi quantificar as mudanças espaço-temporais no uso e cobertura da terra (*land use/ cover *– LULC), assim como, analisar o padrão da paisagem ao longo de 20 anos (1995 – 2015) na bacia do rio Catolé, utilizando métricas da paisagem. Os mapas foram obtidos utilizando imagens do Landsat 5 e 8 (nível de processamento 1) por meio de classificação supervisionada usando o classificador de máxima verossimilhança. Foram identificadas sete classes temáticas: vegetação densa, vegetação esparsa, mata ciliar, cultura agrícola, floresta plantada, solo exposto e água. Em seguida, as classes relacionadas à paisagem (vegetação densa, esparsa e mata ciliar) foram agrupadas em uma classe de fragmentos florestais, a qual foi ordenada por tamanho: muito pequeno (< 5 ha), pequeno (5 – 10 ha), médio (10 – 100 ha), grande (100 ha) e uma classe geral (sem distinção de tamanho). Em seguida, calcularam-se as métricas de área, tamanho e densidade, borda, forma, proximidade e área central. A vegetação densa na área de estudo diminuiu consideravelmente dentro do período avaliado, enquanto a área de culturas agrícolas e solo exposto aumentaram. No geral, na bacia do rio Catolé, a área total de vegetação natural reduziu 3.273 hectares (4,62%). As métricas da paisagem mostraram uma redução no número de fragmentos muito pequenos, embora a área ainda esteja fragmentada. Além disso, uma distância de borda máxima de 50 m é sugerida para a realização de estudos envolvendo métricas de área central na bacia do rio Catolé, pois valores acima desta distância eliminariam os fragmentos muito pequenos.*

Palavras-Chave: Uso e cobertura da terra; Métricas da paisagem; Fragmentos florestais.

1.INTRODUCTION

Progressive changes in natural environments have led to habitat loss and landscape fragmentation worldwide (Cardille and Foley, 2003; Vieira et al., 2003). Hence, conserving biological diversity has been recognized as a key issue in the scope of environmental protection. Human activities have modified the environment to the extent that most common landscape patterns exhibit mosaics of human settlements, agricultural land, and scattered fragments of natural ecosystems (Midha and Mathur, 2010). Owing to all these interferences, conservation areas are becoming increasingly surrounded by intensively modified environments, and, in the long-term, appear to be condemned to function as isolated natural ecosystems.

A reduction in natural vegetation cover has resulted in imbalances of the physical and biotic aspects of environments, which is a serious issue for the survival of numerous species in many ecosystems. Moreover, it jeopardizes the maintenance of the dynamic balance of landscapes and can also lead to a decrease in gene flow, reproductive isolation of species, and, consequently, a loss in genetic diversity (Neves et al., 2014; Dantas et al., 2017). Thus, increasing human interference is changing the structural and functional patterns of landscapes worldwide and has significantly impacted biodiversity (Sinha and Charma, 2006).

The São Francisco river basin is the main water source in the northern, semi-arid region of Minas Gerais State, and is important for the development of irrigated agriculture and human consumption. In this region, the Pandeiros river basin is the breeding ground for many fish species from the São Francisco river. Due to this, its diverse array of plant species, and as the basin is located in a transition zone from the *Cerrado* to the *Caatinga* biomes, the Pandeiros river basin was converted into an Environmental Protection Area (EPA) in accordance with State Law 11,901 on September 1st, 1995 (Minas Gerais, 1995). This EPA shelters several *Cerrado* phyto-physiognomies, such as the *Cerrado sensu stricto*, deciduous seasonal forest (*Mata Seca*), riparian forests, floodplain areas, and *Veredas*, a type of *Cerrado* vegetation (Bethonico, 2009; Nunes et al., 2009).

One of the main tributaries of the Pandeiros river is the Catolé river, the basin of which is suffering from erosive processes caused by deforestation for charcoal production, the expansion of agriculture in Veredas and riparian vegetation, and poor conservation of unpaved roads (Fonseca et al., 2011). To evaluate the fragmentation of forest remnants, and propose methods of managing their conservation, similar studies on landscape ecology have been conducted in recent years (Abdalla and Cruz, 2015; Silva et al., 2015; Saito et al., 2016).

Landscape ecology involves the study of landscape patterns, interactions among patches within a landscape mosaic, and how these patterns and interactions change over time (Mcgarigal and Marks, 1995). Through landscape ecology, landscape metrics has allowed the characterization of the complexity of landscapes and the determination of the conditions of forest fragments so that conservation measures can be developed (Silva and Souza, 2014). Landscape metrics are tools to characterize the geometric and spatial properties of a patch (a spatially homogeneous entity) or a mosaic of patches (Fortin, 1999). In addition, landscape ecology involves the application of these principles in the formulation and solution of real-world problems.

The use of geographic information systems (GIS), remote sensing (RS), and multitemporal products can provide important information on landscape fragmentation mechanisms (Coelho et al., 2014). Therefore, the aim of this study was to quantify the spatio-temporal changes in land use and land cover (LULC), as well as analyze landscape patterns over a 20-year period (1995 – 2015) in the Catolé watershed, northern Minas Gerais State, using landscape metrics.

2.MATERIALAND METHODS

2.1. Study Area

The Catolé watershed is located in northern Minas Gerais State, between 14° 58' 28" and 15° 25' 50" S and 44° 39' 33" and 44° 55' 24" W, and it covers an area of 70,692 hectares. It lies in the lower portion of the middle São Francisco river, within the boundaries of the Pandeiros EPA in the municipality of Bonito de Minas – MG (Figure 1). The climate of the region is semi-arid, with well-defined dry and rainy seasons. The mean annual temperature is approximately 21 to 24 ºC, and the region's elevation ranges from 485 to 515 m. The average rainfall is approximately 1,050 mm per year, with precipitation mostly occurring from October to March (Fonseca et al., 2011).

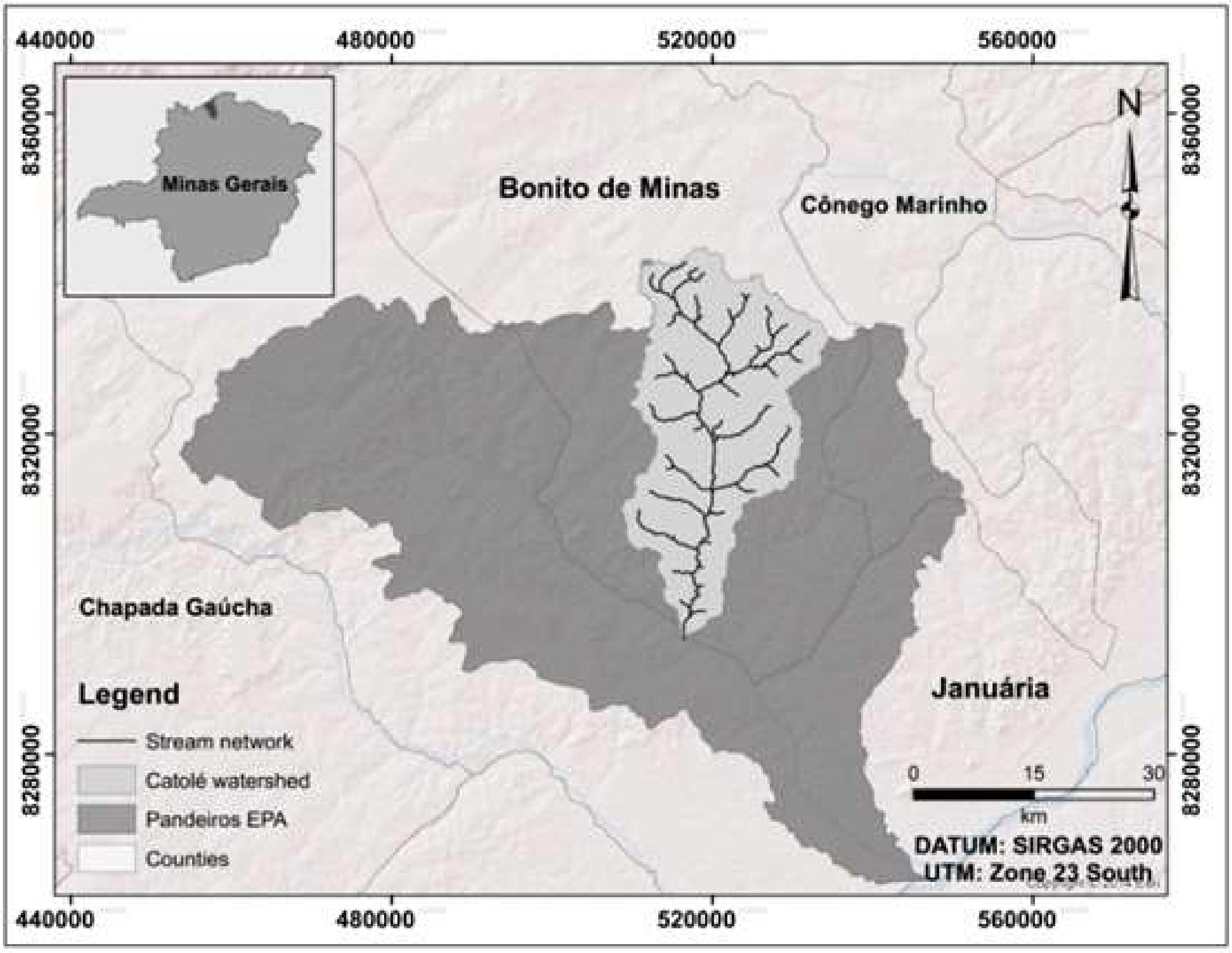

Figure 1– Location map of the Catolé watershed, Northern Minas Gerais.
Figura 1– *Mapa de localização da bacia do rio Catolé, Norte de Minas Gerais.*

2.2. Land Use/Cover Maps

Temporal remote sensing data were collected to extract the LULC information. The data were obtained using the Landsat 5 Thematic Mapper (TM; overpass: July 30, 1995) and Landsat 8 Operational Land Imager (OLI) sensors (overpass: June 19, 2015), which have a spatial resolution of 30 x 30 m (path: 219; rows: 70 and 71). The QGIS 2.18 software was used to preprocess the data, which included geometric and radiometric correction, mosaic, subset, and layer stacking.

Landsat 5 images were geometrically corrected using a second-degree polynomial model, which presented a mean square error (MSE) smaller than 1 pixel. Reference images for georeferencing the Landsat 5 data came from five RapidEye images at level 3A, which are orthorectified tile products with radiometric, geometric, and terrain corrections (Tile ID: 2331915, 2332015, 2332016, 2332115, and 2332116) (overpass from July 3, 2014 to August 31, 2015). All images were radiometrically corrected using the dark object subtraction (DOS) (Chavez, 1988). Supervised classification was conducted using the Maximum Likelihood classifier, where red, green, blue, and near-infrared bands were used for both Landsat 5 and 8 images. Seven thematic classes were identified: dense vegetation, sparse vegetation, riparian vegetation, cropland, planted forest, bare soil, and water.

The accuracy was assessed using the error matrix of the 1995 and 2015 supervised classification maps, which considered four accuracy measures: the overall accuracy, user's accuracy, producer's accuracy, and

Kappa coefficient. Twenty-five random samples were taken from each class to determine the accuracy of each classification. The 1995 LULC map samples were assessed using information from the inventory map of the flora and reforestation of Minas Gerais (Data from 2003 to 2007) and local forest fragment information from the georeferenced database (year 1998) in the local office of the State Forest Institute (IEF-MG). To assess the accuracy of the 2015 LULC map, samples were obtained through visual analysis of RapidEye images from 2014 and 2015. Moreover, the accuracy was assessed based on their omission (producer's accuracy) and commission (user's accuracy) errors, and the Kappa coefficient. The overall map accuracy was calculated by dividing the total number of correctly classified pixels (major diagonal of the error matrix) by the total number of pixels in the error matrix.

2.3. Forest Patches Mapping

From the LULC maps, classes related to the natural landscape, such as dense, sparse, and riparian vegetation, were grouped into a new class denoted as forest fragments and individualized for calculating landscape metrics. To better compare the degrees of conservation and patch sizes, all patches were separated in classes according to their size: very small (< 5 hectares); small (5 – 10 hectares); medium (10 – 100 hectares); large (100 hectare); and a general class (no distinction of patch size).

The spatial dynamics of the forest landscape refers to the temporal changes in the size, number, shape, adjacency, and proximity of patches in a landscape (Çakir et al., 2008). These landscape pattern metrics involve qualitative and quantitative measurements that express the characteristics of the landscape as a whole (Abdullah and Nakagoshi, 2006). Accordingly, some metrics or measurements were used as a proxy to quantify and spatially analyze changes in the structure, as demonstrated by McGarigal and Marks (1995): area, density and size, edge, shape, and proximity. The landscape metrics were computed using FRAGSTATS version 3.3 (Macgarigal et al., 2002). In addition, to calculate the core area metrics, edge distances of 50, 100, and 150 m were simulated to generate scenarios for analysis.

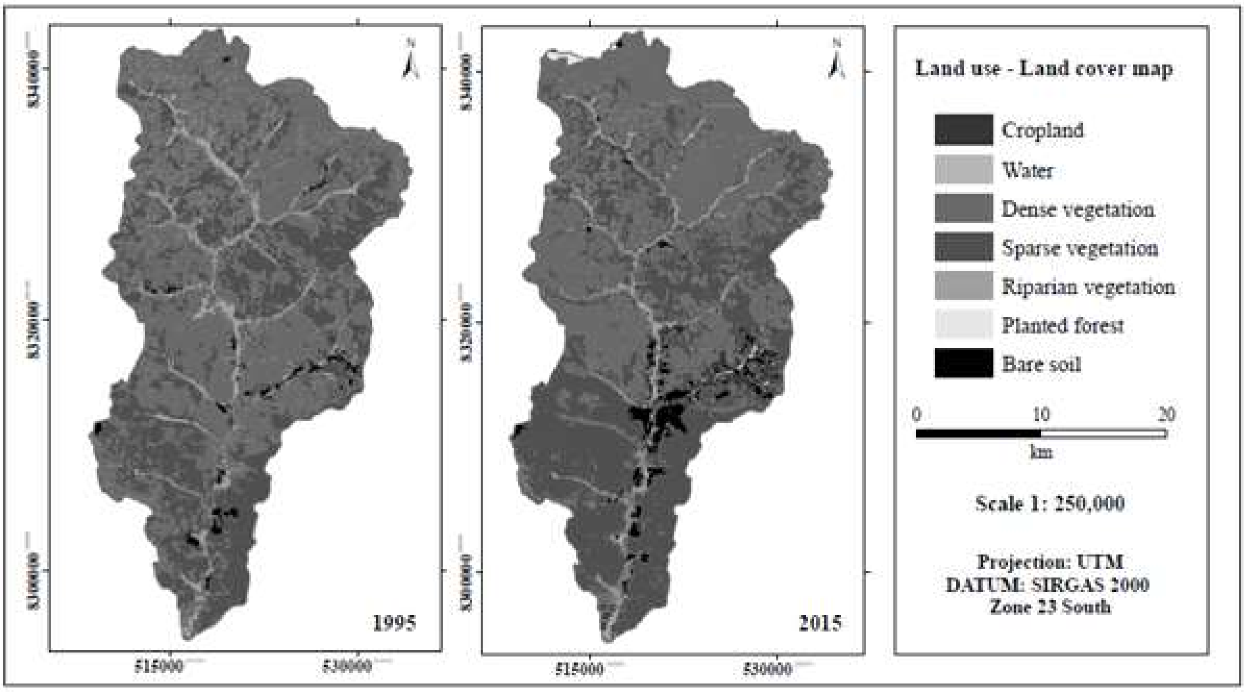

Figure 2 – Land use/ cover evolution in the Catolé watershed.
Figura 2 *– Evolução do uso e cobertura da terra na bacia do rio Catolé.*

3.RESULTS

The overall accuracy of classification was 95.61% for the 1995 LULC map from the Landsat 5 images and 98.46% for the 2015 map from the Landsat 8 data. The Kappa coefficients were 91.8% (1995) and 98.06% (2015), respectively. The user's accuracy of most classes in 1995 exceeded 97%, except for bare soil and cropland, which presented user's accuracies of 76.41% and 60.00%, respectively. The producer's accuracy for all classes in the same year was high, with the lowest values of 89.41% and 87.49% being observed for bare soil and sparse vegetation classes. In 2015, both the user's and producer's accuracies reached 94.65% for all classes. In general, all forest cover classes were classified accurately, while non-forest classes were not.

The results from the LULC maps (Figure 1) exhibited major changes in the dense vegetation class, which decreased by 18.52% (6,987 hectares) when comparing the 1995 and 2015 LULC maps (Table 1). Most of the area was converted into sparse vegetation (4,286 hectares, 14.78%), followed by cropland (an increase of 2,473%, 1,397 hectares), and bare soil, which increased by 125.64% (1,714 hectares). The coverage of riparian vegetation considerably reduced (23.00%; 572 hectares) as it was mostly converted into cropland alongside the Catolé river.

Overall, in the Catolé watershed, the total area of natural vegetation decreased by 3,273 hectares (4.62%) from 1995 to 2015. The detailed losses and gains among the seven land use/cover classes over the 20-year study period are presented in Table 1.

Forest patch analyses were conducted at the landscape level, with patches grouped into different size classes. In the Catolé watershed, considerable changes in the distribution of forest patches were observed over the study period (Table 2). In both years (1995 and 2015), forest area (CA) was mainly observed in larger patches (larger than 100 hectares), covering 73.08% and 79.64% of the area, respectively. The remaining forest area existed in smaller patches, with 7.67% and 6% as very small patches, 4.19% and 3.24% with areas ranging from 5 to 10 hectares (small patches), and 15.05% and 11.12% as medium patches in 1995 and 2015, respectively.

The number of patches (NP) can be used to quantify the spatial heterogeneity of the entire landscape. Even with a decrease in the number of patches in all classes, the landscape was still predominantly represented by very small patches, which covered 2,974 hectares (77.09%) and 2,056 hectares (76%) in 1995 and 2015, respectively. As fewer patches were larger than 100 hectares, the forest may become more fragile and fragmented. The mean patch size (MPS) increased in all classes, except the small patches class, in which the MPS decreased from 7.1 to 6.85 hectares. The NP and MPS should be used complementarily as high NP and low MPS values reinforce the interpretation of a fragmented landscape.

The patch size standard deviation (PSSD) and patch size coefficient of variance (PSCov) remained almost unaltered for all classes, excluding larger patches, where substantial increases from 1,716 to 2,541 hectares and 196.87% to 232.34% were observed, respectively. Similarly, there was an increase in the values for the general class.

Among the total edge metrics, all classes exhibited a reduction in the length, which was associated with the reduction in NP. In contrast, the edge density (ED), i.e., the amount of edge relative to the landscape area, which is also related to the degree of spatial heterogeneity,

Table 1 – Evolution of land use/ cover classes from 1995 to 2015 in the Catolé watershed.
Tabela 1 – *Evolução do uso e cobertura da terra de 1995 a 2015 na bacia do rio Catolé.*

Class	1995		2015		1995 - 2015	
	Area (ha)	Area (%)	Area (ha)	Area (%)	(%)	(ha)
Dense vegetation	37,736.65	53.38	30,749.49	43.50	-18.52	6,987.16
Sparse vegetation	28,992.37	41.01	33,278.76	47.08	+14.78	4,286.39
Riparian vegetation	2,479.62	3.51	1,907,19	2.70	-23.08	572.43
Cropland	56.51	0.08	1,453.86	2.06	+2,472.75	1,397.35
Planted forest	-*	-	180.00	0.25	+180.00	180.00
Bare soil	1,364.46	1.93	3,078.72	4.35	+125.64	1,714.26
Water	63.23	0.09	44.82	0.06	-29.11	18.41
Total	70,692.84	100	70,692.84	100	-	-

* Class absent in 1995; Positive values show an increase while negative values show a decrease.

Table 2 – Landscape metrics of forest patches in the Catolé watershed, MG.
Tabela 2 – *Métricas da paisagem de fragmentos florestais na bacia do rio Catolé, MG.*

			1995				
Group	Index	Units	Patch size				
			< 5 ha	5 – 10 ha	10 – 100 ha	> 100 ha	General
Area	CA	ha	5,309.17	2,902.76	10,418.35	50,578.68	69,208.96
	MPS	ha	1.79	7.10	24.98	872.05	17.94
Density	NUMP	-	2,974	409	417	58	3,858
and	PSSD	ha	1.05	1.40	18.32	1,716.79	235.65
Size	PSCov	%	58.62	19.68	73.31	196.87	1,313.64
Edge	TE	m	2,178,887	789,254.91	1,900,142.8	3,961,132	8,829,427
	ED	m/ha	410.40	271.90	182.38	78.31	127.58
	MSI	-	1.57	2.05	2.57	6.09	1.79
Shape	AWMSI	-	1.65	2.05	2.87	11.42	8.99
Proximity	MNN	m	177.92	315.9	205.62	101.34	203.20
			2015				
Group	Index	Units	Patch size				
			< 5 ha	5 – 10 ha	10 – 100 ha	> 100 ha	General
Area	CA	ha	3,953.52	2,136.42	7,334.01	52,511.49	65,935.44
	MPS	ha	1.92	6.85	25.38	1,093.99	24,37
Density	NUMP	-	2,056	312	289	48	2705
and	PSSD	ha	1.08	1.41	18.47	2,541.73	367,96
Size	PSCov	%	56.07	20.67	72.80	232.34	1.509,57
	TE	m	1,586,640	598,680	1,401,360	2,974,500	6,561,180
Edge	ED	m/ha	401.32	280.22	191.07	56.64	99.51
	MSI	-	1.59	2.07	2.71	5.45	1.83
Shape	AWMSI	-	1.66	2.09	3.04	9.71	8.23
Proximity	MNN	m	201.63	318.61	249.05	100.00	70.68

CA - Class area; NUMP – Number of patches; MPS – Mean patch size; PSSD – Patch size standard deviation; PSCov – Patch size coefficient of variance; MSI – Mean shape index; AWMSI – Area weighted mean shape index; TE – Total edge. ED – Edge density; MNN – Mean nearest neighbor.

exhibited different trends depending between LULC classes. The ED increased in the small and medium patch size classes, while it decreased in the very small, large, and general classes (without size distinction).

Similar to TE and ED, the mean shape index (MSI) is also related to the degree of spatial heterogeneity in the landscape. However, this serves as a measure of the shapes of patches. The former denotes the average shape or average perimeter-area ratio for all patches in the landscape. The lowest index value (MSI = 1) is achieved when patches are circular (vector) or square (raster), and increases as they become more irregular in shape.

Comparing the MSI and TE indices reveals a decrease in the TE for all classes, while the MSI decreases for some classes and increases for others; in general, the patches became more irregular as the MSI increased from 1.79 to 1.83. This indicates that MSI is more sensitive to changes in the number of patches than changes in their perimeters. The results of the area-weighted mean shape index (AWMSI) were similar to those of the MSI, however, the patches became more regular in the general class as the AWMSI decreased from 8.99 to 8.23.

The mean nearest neighbor (MNN) defines the average edge-to-edge distance between a patch and its nearest neighbor in the landscape. The results exhibited an increase in the isolation degree of patches smaller than 100 hectares as all classes within this area increased the distance from edge-to-edge. However, the patches in the general class became more connected, as its distance decreased from 203.20 to 70.68 m.

The core area metrics obtained through simulations of 50, 100, and 150 m edge distances (Table 3) showed that the number of core areas (NCA) in all classes (excluding very small patches) exceeded the NP at an edge distance of 50 m. However, as the edge distance increases, the NCA value decreases, indicating how the edge effect would affect the entire patch area. The total core area (TCA) values were proportional to the

Table 3 – Core area metrics of forest patches in the Catolé watershed, MG.
Tabela 3 – *Métricas de área central para os fragmentos florestais na bacia do rio Catolé, MG.*

Patchsize	Index	Units	Edge distance (m)					
			50		100		150	
			1995	2015	1995	2015	1995	2015
Very small (< 5 ha)	NCA	-	776	523	0	0	0	0
	TCA	ha	94.4	79.33	0	0	0	0
	TCAI	%	1.78	2	0	0	0	0
Small (5 – 10 ha)	NCA	-	565	406	57	19	0	0
	TCA	ha	357.48	219.25	6.81	1.41	0	0
	TCAI	%	12.31	10.26	0.23	0.06	0	0
Medium (10 – 100 ha)	NCA	-	1,050	807	452	255	162	79
	TCA	ha	3,394.17	2,182.77	908.34	587.85	208.72	168.69
	TCAI	%	32.58	29.76	8.71	8.01	2	2.30
Large (> 100 ha)	NCA	-	930	549	628	430	536	337
	TCA	ha	33,917.98	39,896.17	23,351.67	31,420.22	16,294.66	25,257.31
	TCAI	%	67.05	75.98	46.17	59.83	32.22	48.09

NCA – Number of core areas; TCA – Total core area; TCAI – Total area core index.

patch size. The total core area index (TCAI) allows a better understanding of the edge effect over the different patch sizes. TCAI values decreased significantly with the increase in edge distance, reaching 0% at an edge distance of 150 m for patches smaller than 10 hectares. That is, at this point, all patches smaller than 10 hectares experienced the edge effect, which would directly affect its conservation degree.

4.DISCUSSIONS

According to Landis and Koch (1977), the Kappa index results obtained for the 1995 and 2015 classification maps were highly accurate when compared to the ground truth samples. This indicates that, even when using images with a mean spatial resolution of 30 m (such as those from Landsat 5 and 8), it was possible to accurately map the LULC in the study area. In general, forest cover classes are still predominant in the Catolé watershed. However, in 2015, there was a considerable increase in cropland and bare soil areas, and a decrease in riparian vegetation, indicating the occurrence of anthropization processes that are more intense in central areas close to the riverbed.

There are historical reports of agricultural activity in the rural communities located within the EPA's boundaries. During a study on the Pandeiros and Catolé rivers, Bethonico (2009) observed a steady growth in subsistence agriculture among those communities. Most of these areas were used to cultivate beans, rice, cassava, maize, and sugarcane. In addition, some farmers practice extensive livestock agriculture, which was included in the sparse vegetation class.

A large area of the Catolé watershed is covered by Neosol Quartzarenic soil, which is characterized by its sandy texture and is more susceptible to degradation when no soil conservation practices are established. There are several reports of illegal deforestation and charcoal production in the study area, and the use of fire for soil cleaning. These actions accelerate soil erosion by up to 20%, and are considered as the most degrading practices in natural forests (Cabacinha and Castro, 2010; Merten and Minella, 2013).

Owing to the increase in cropland and bare soil areas alongside the riverbed, there is a need to recover degraded areas and preserve riparian vegetation. Moreover, most of the changes were observed in the central and southern areas of the basin, where the terrain is mildly sloped, which favors agricultural exploration in the region.

During 1995-2015, the landscape was mostly represented by very small forest patches, which indicates high fragmentation and a low degree of conservation. As stated by Metzger and Sodhi (2009), such conditions can lead to a reduction in species richness as the patch becomes unsuitable for maintaining the survival of wild populations. There is an inverse relationship between the number of patches and its area, that is, there was a greater number of very small patches. However, when looking at the total area, it presents the smallest percentage of the landscape area. On the other hand, patches larger than 100 hectares present fewer units, though it has the highest amount of area.

Silva et al. (2015) observed similar conditions; 84.15% of forest patches in the River Plate basin of Ibiraçu and Aracruz, ES, were smaller than five hectares, however, large and medium patches accounted for 54.75% and 30.93% of the study area, respectively. Larger patches are important for maintaining ecological processes and ensuring biodiversity. However, small patches play different roles, such as increasing connectivity between different habitats (Liu et al., 2014), acting as ecological trampolines (Mortelliti et al., 2014), and reducing the isolation degree between patches (Fahrig, 2003).

High variability in patch size is common in landscape ecology studies, as described by several authors in recent years. After analyzing forest patches in the Itapemirin river basin (ES), Pirovani et al. (2014) observed high PSSD (164 hectares and 37 hectares) and PSCov metric (122.79% and 433.85%) values for large size patches (> 50 hectares) and the general class (all patches). Santos et al. (2016) found that the Black river basin, western Bahia State, was mainly occupied by small patches, and the MPS index ranged from 14.3 to 59.9 hectares in different regions within the basin. However, the PSSD values (148 hectares and 2,308 hectares) varied greatly among patch sizes, which indicated the existence of larger patches than average.

Large patches presented the highest TE values and lowest ED metric values in both years (1995 and 2015). These results indicate a high degree of conservation in this class, as the edge effect is one of the main causes of declining biodiversity in vegetation remnants, which corresponds to changes due to contact between the forest patch and the deforested area (Borges et al., 2004; Nascimento and Laurence, 2006). Furthermore, the border region is mostly subject to pressure associated with anthropic activities that occur in the deforested area, which directly interfere with ecosystem dynamics.

Just as the TE and ED indices are important for landscape metrics analysis, patch shape metrics are necessary to evaluate landscape structure and disturbance in forest remnants. A standard format should be adopted when comparing the shapes of forest patches. Lang and Blaschke (2009) suggested that the closer the value is to one, the better the shape. If the patch is more circular, the edge effect on the ecosystem is reduced. Thus, shape values closer to one indicated that the core area may be more protected, whereas values greater than one indicate a more elongated tendency, assuming that the fragment is more vulnerable to edge effects.

Analysis of the MSI results revealed that, in both years, the shape of very small patches was the most regular shape (1.57 and 1.59) among all classes. Higher values were obtained for the AWMSI index than those for the MSI, which indicates that the shape of the largest patches is more irregular than that of average patches. This is due to the calculation of the AWMSI index, which considers the patch size. Thus, although smaller patches are more regular in shape, they are still more susceptible to edge effects.

Patch isolation was measured by the MNN index, which, according to Bender et al. (2003), refers to the inaccessibility of living beings for migrating between patches. Small patches presented the highest degree of isolation, with distances of 315.39 and 318.61 m for 1995 and 2015, respectively. Small patches are more isolated than other size classes, however, their ecological importance should be considered as small patches are important for connecting larger patches.

To reduce the degree of patch isolation in the Catolé watershed, degraded areas should be restored to create ecological corridors between the most isolated patches as isolation directly affects plants dispersion and wildlife movement. In addition, it is more difficult to connect habitats due to the reduction in species richness and composition (Collinge, 1996; Costa et al., 2015).

Core area metrics were calculated by simulating different edge distances to evaluate which distance exerts the greatest influence on the core area results. The highest NCA values for smaller fragments were due to their irregular forms, which increases the difficulty of connecting core areas in the same forest patch. Silva et al. (2015) found that there is a decrease in NCA values with an increase in the edge distance, as edge effects act on the patch and its irregularities. That is, the edge effect transforms complex geometric figures into circular surfaces, and the results of this metric are obtained through several simulations.

In both years (1995 and 2015), the very small and small patches exhibited null values for core area indices; the very small patches exhibited null values for these metrics at 100 m, and small patches exhibited null values above an edge distance of 100 m. These results demonstrate that, under this condition, all patches within these classes are dominated by the edge effect would be susceptible to the matrix influence (Juvanhol et al. 2011). The TCA index, which represents the sum of core areas (excluding the edges), decreased as the edge distance increased in 1995 and 2015.

The results of TCAI were the most suitable to represent the edge effect on different patch sizes. In 1995, the TCAI result for very small patches was 1.78% of their area, therefore, 98.22% of the class was susceptible to edge effects in the first 50-m distance. Vidolin et al. (2011) stated that core area metrics are measures of habitat quality as they indicate the remaining effective area of a patch after discounting the edge effect.

Several studies have discussed different edge distances, however, there is no consensus on the size of the edge to be considered. Abdalla and Cruz (2015) analyzed fragmentation in the São João river EPA, and used an edge distance of 100 m. Fernandes et al. (2017) simulated distances of 30, 60, and 90 m in the Piauitinga river basin, southern Sergipe State, and found that the increase in distance directly affects the core area, especially for small patches. The same authors recommended the creation of ecological corridors for better conservation and a maximum distance of 30 m for edge effects analysis.

These results are consistent with the values found here, because, for the 100 and 150 m edge distances, null values were observed for core area metrics. This demonstrates the dominance of the edge effect on small-sized patches. Thus, the maximum distance for evaluating edge effects on the Catolé watershed landscape should be 50 m.

5.CONCLUSIONS

Landsat TM and OLI images were appropriate for generating LULC maps. The accuracy assessment results showed that both maps were accurately produced by applying the Maximum Likelihood classifier. The change detection results exhibited substantial changes in the LULC from 1995 to 2015. The dense vegetation portion of the study area decreased considerably within a given time, while the portion of cropland and bare soil increased. Overall, in the Catolé river basin, the total area of natural vegetation decreased by 3,273 hectares (4.62%).

Landscape metrics analysis exhibited a reduction in the number of very small patches, although the study area was still considered as fragmented. The more irregular the patch shape, the larger the total edge of the patch. Although larger patches have the most irregular shapes, their core area metrics were still better than those of smaller patches, even under the effect of larger edge distances. A maximum edge distance of 50 m is suggested for conducting studies involving core area metrics in the Catolé river basin, as values above this distance would eliminate the very small patches. In summary, these results can aid in defining strategies for land planning and design, and decision making for conservation priorities.

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