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Original Article

Dynamics of vegetation structure in a fragmented landscape in Minas Gerais, Brazil

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Abstract

Considering that area and edge effects are the most important factors that lead to landscape changes from the fragmentation of terrestrial communities, the present study aimed to analyze changes in the structure of vegetation classes of a fragmented landscape. The methodology employed was based on a model of patch dynamics for the years between 1979 and 2015. The analysis was performed with quantitative (area, shape and edge effect) and qualitative (low declivity of the terrain, fire resistance and tolerance to variation in light) variables of the classes of vegetation. Processes of retraction and expansion of the vegetation classes were identified, as well as the alteration of the structure of the fragments, which resulted in the intensification of the edge effect.

Keywords: changes, fragmentation, classes, edge effects.

Dinâmica da estrutura da vegetação em uma paisagem fragmentada em Minas Gerais, Brasil

Resumo

Considerando que os efeitos de área e os efeitos de borda são os mais importantes fatores que levam às alterações na paisagem através da fragmentação de comunidades terrestre, o presente estudo teve por objetivo analisar as mudanças em área e estrutura das classes de vegetação de uma paisagem fragmentada. Para tanto, a metodologia foi baseada no modelo de dinâmica de manchas entre os anos de 1979 e 2015 e a análise por meio de variáveis quantitativas (área, formato e efeito de borda) e qualitativas (baixa declividade do terreno, resistência ao fogo e tolerância à variação de luz) das classes de vegetação. O presente estudo identificou processos de retração e expansão das classes de vegetação e a alteração na estrutura dos fragmentos resultando na intensificação do efeito de borda.

Palavras-chaves: mudanças, fragmentação, classes, efeito de borda.

1. Introduction

Although Brazil is rich in forest ecosystems, and the state of Minas Gerais (MG) possesses a concentration of varied formations due to its geological, topographic and climatic physical condition (Lopes et al., 2002), the natural cover of much of the country has been reduced to remnants of different sizes. The current accelerated pace of change has been the greatest challenge for the conservation of Brazilian ecosystems due to the processes of landscape fragmentation, which are responsible for changes in the diversity and composition of the communities involved (Metzger et al., 1998). Unfortunately fragmentation of large Brazilian biomes is apparently an irreversible process (Nadai and Henry, 2009)

Area and edge effects are the most important factors that lead to changes in fragmented communities (Nascimento and Laurance, 2006). While area effects are ecological changes that are proportional to the fragmented area (Shaffer, 1981), edge effects are caused by physical and biotic changes near forest edges and are therefore proportional to the distance to the nearest edge (Murcia, 1995). Changes caused by edge effects are due to the pressure exerted by the external environment on the fragments, with their intensity varying according to the nature of the activities in the area around the fragment (Abdo et al., 2015).

Terrestrial landscapes can be classified according to the degree of human intervention as a natural or cultural landscape (Dolfuss, 1978). A natural landscape is one that has not been recently subjected to the actions of humans, whereas a cultural landscape is defined as a landscape that has undergone man-made changes over a long period of time, creating a particular set of patterns, species and processes (Farina, 1998). The evaluation of a cultural landscape becomes an important tool for diagnosing contemporary problems of anthropization by allowing future influences to be estimated and the changes necessary for maintaining a natural balance determined (Calegari et al., 2010).

In the face of changing landscapes, Troll introduced Landscape Ecology in 1939 as an important tool for the study of environmental dynamics (Santos and Pena, 2011), by studying questions of land use through aerial photographs and interpretation of landscapes (Nucci, 2007). The availability of remote sensing data allows the development of such a study, however, the modeling of environmental processes at the landscape level still remains a major challenge, given the difficulties in describing something that is constantly evolving (Soares-Filho et al., 2002).

According to Metzger et al. (2007), models used in Landscape Ecology are characterized by considering the "pattern-process" relationships and the heterogeneity of space. Models of patch dynamics have been used to analyze the most varied consequences of landscape changes, but mainly the changes derived from the process of deforestation (Gustafson, 1999).

According to Soares-Filho et al. (2007), the construction of a dynamic model consists of mapping mutable patterns of land use and cover of the region of interest. Thus, survey methods are necessary to identify changes in the landscape and for this purpose, field surveys, previously existing maps, aerial photographs, census data and remote orbital sensing can be used as sources of data (Solorzáno et al., 2009). In this context, techniques of spatial analysis are used to quantify and qualify the spatial effects of the variables that affect changes (Soares-Filho et al., 2007).

The variables that affect changes can be differentiated as proximal and causal (Soares-Filho at al., 2004). According to these authors, proximal variables quantify the regional influences in the spatial configuration of the patterns of change while causal variables explain the underlying or motivating forces of the changes.

The study area is in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, and is inserted in an area of transition between two Brazilian biomes, the Atlantic Forest and the Cerrado. The constant degradation of its natural ecosystem is a result of local forest fragmentation due to the misuse of land for agriculture and, especially, pasture. Fragmentation is a serious threat for the Atlantic Forest since today it is estimated that only 7% remains manly in the form of small fragments (Piratelli et al., 2008). For the Cerrado biome, a global biodiversity hotspot, expansion of agriculture and pasture have been the main causes for the loss of biodiversity by fragmentation since the 1970s (Manica et al., 2010)

Considering the biological importance of the region, and that there have been no scientific studies in the area useful for informing local public policies with regard to sustainable management of the natural resources there, the present work aims to analyze the structure of the fragmentation landscape. The questions that led to this study are: (1) How has vegetation structure changed between the years 1979 and 2015? And (2) which variables have interfered with vegetation structure? The hypothesis tested is that the use of land for pasture has altered vegetation structure by reducing the area of the vegetation classes and intensifying the edge effect.

2. Materials and Methods

2.1. Study area

The studied landscape covers an area of 2.721 hectares and is inserted in a region of transition between Cerrado and Atlantic Forest biomes. According to the Köppen and Geiger (1928) climate classification, the climate of the region is tropical altitude, which is represented by elevations above 500 m, mild temperatures between 18 °C and 26 °C and annual thermal amplitude of between 7 °C and 9 °C.

Although the analyzed area is in a transition zone between two Brazilian biomes (Cerrado and Atlantic Forest), it has ceased to be simply a set of natural plant communities and has become dominated by a cultural landscape due to misuse of the soil by pasture and agriculture. The area of Cerrado is a rupestrian environment; that is, it occurs at high elevations and possesses rocky outcrops (Rupestrian Complexes). Its vegetation is quite diverse, with two distinguishable strata in the area: a woody stratum comprising trees and busheds, and an herbaceous stratum comprising herbs and busheds (Vasconcelos, 2014). The Atlantic forest domain consists of Seasonal Semideciduous Forest, and possesses shallow soil with low fertility and high water stress, and experiences extreme variations in temperature and exposure to wind (Scarano, 2002).

2.2. Landscape dynamics model

To analyze environmental dynamics, and the main agents responsible for them, the model of patch dynamics (Pickett and Thompson, 1978) was used (Metzger at al., 2007).

Field survey and remote sensing were the source of data for the development and calibration of the model represented by Figure 1. The application of remote sensing involved the interpretation and classification of aerial photographs and satellite images and the subsequent analysis of the resulting maps.

To quantify changes in vegetation structure, proximal variables were used, while causal variables, represented by the explanatory variables, were used to explain the changes in vegetation structure. The result of this process consisted of a quantitative and qualitative framework of changes in vegetation structure between 1979 and 2015.

2.3. Field survey

According to the field survey performed during the month of July 2015, the area is centered on the UTM coordinates 64º80'36"(latitude) 79º08'32"(longitude),

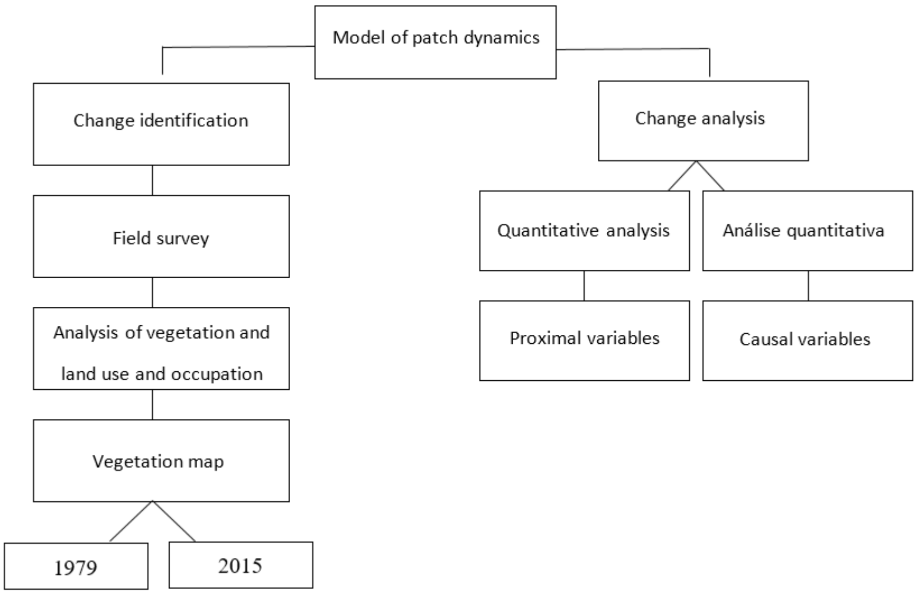

Figure 1. Patch dynamics model applied in the study area.

and the vegetation classified as arboreal (Atlantic Forest), bush and herbaceous (Cerrado).

The information obtained by means of field records determined the presence of pasture (mainly for beef cattle ranching), burned areas and the presence of exotic grasses in the study fragment. These alterations were responsible for the fragmentation of the landscape and the removal of much of the native vegetation.

2.4. Mapping of vegetation

2.4.1. Classification of the 1979 aerial photo mosaic

For the analysis of the vegetation of the fragment for the year 1979, a mosaic of aerial photographs of the landscape was composed. The mosaic (Figure 2) is a set of aerial photographs recorded and linked by adjustments and overlays (Cunha et al., 2006). Eight aerial photographs from flights from 12 July to 27 October 1979 were used.

After constructing the mosaic, the vegetation of the mosaic was visually classified. The classification was based on the analysis of the parameters of tonality (color intensity), saturation, texture and shape (Panizza and Fonseca, 2011). Tonality was classified by shades of gray according to the key for interpretation of vegetation in panchromatic images (black and white) proposed by Messias (2016).

The classification resulted in three classes of vegetation: tree vegetation (Figure 3a), represented by the darker-tone gray and greater saturation; bush vegetation (Figure 3b), represented by medium-tone gray and lower saturation; and herbaceous vegetation (Figure 3c), represented by light-tone gray and low saturation. All classes displayed little difference in granulation and shape, and were considered of medium granulation and irregular shape.

Figure 2. Mosaic of aerial photographs for the year 1979 of the study area.

2.4.2. Classification of the 2015 Landsat image

The landscape vegetation analysis for the year 2015 was performed by means of supervised classification of the Landsat 8 satellite image of 18 July, 2015, of the municipality of Conceição do Mato Dentro (Figure 4). According to Piroli et al. (2002), supervised classification recognizes the predominant features in a color composition according to

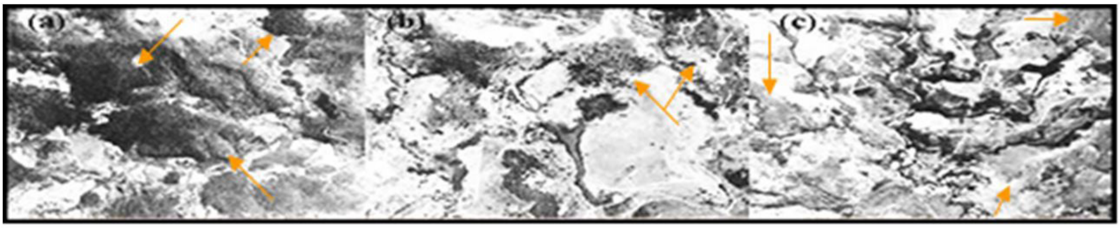

Figure 3. Representation of vegetation classes in mosaic cutouts: Tree vegetation (a), bush vegetation (b) and herbaceous vegetation (c).

data collected in the field. From field visits, three classes of vegetation were determined for the landscape: arboreal, bush and herbaceous. The tool *classification* of the software Envi 4.5 was used to perform the supervised classification.

Finally, the accuracy of the data obtained from the supervised classification of the landscape was checked. The points collected in the field were inserted and analyzed using the *global accuracy* and *Kappa* accuracy indexes described by Bolfe et al. (2004), which, according to the author, should be greater than 85%. These values were obtained in the software Envi 4.5, from a confusion matrix generated in the *post classification* option for the comparison between regions of interest of the classified image and the classification observed during fieldwork. The result of this classification generated an overall accuracy of 93.8215% and a Kappa value of 85.64%, which means that the classification was satisfactory.

2.5. Quantitative analysis (proximal variables)

Proximal variables were calculated for the area and edge effects by vegetation class. We used the software Fragstats 4.2 to calculate the area metrics of "total area" and "landscape percentage" and the edge metrics "shape", "total edge" (TE) and "total central area" (TCA). The shapes of the classes ranged between the values of 1 and 2 with values closer to 1 having a more regular shape (Volotão, 1998). The metrics TE and TCA represented the sum of all the edges (meters) and sum of all the central areas (hectares), respectively (Cabacinha et al., 2010). The vegetation classes with greater TE, lower TCA and irregular shape had greater edge effect. A distance of 30 meters was used for the edge.

2.6. Qualitative analysis (causal variables)

The causal variables were chosen to explain changes in the area and intensity of the edge effect per vegetation class. The opening of areas for grazing implied the deforestation of arboreal vegetation (Atlantic Forest) in areas of moderate declivity, and frequent fire use and the introduction of exotic grasses belonging to the genus *Brachiaria* in areas of Cerrado. In this way, the variable *low declivity of the terrain* was chosen to explain the process of retraction of the area of the arboreal class, the variable *resistance to fire* to explain the process of expansion of the area of the bushed class and the variable *tolerance to variation in light* to explain the expansion process of the area of the herbaceous class.

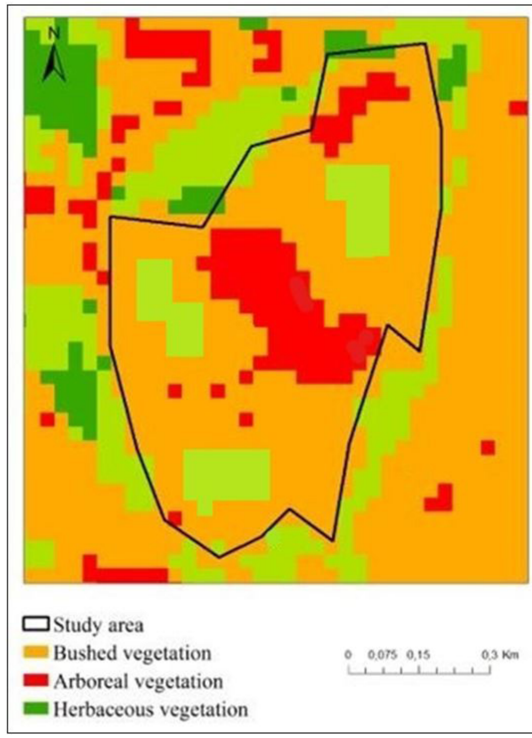

Figure 4. Supervised classification of the study area.

Based on the direct relationship between edge effect intensity and the protection of the core of the class from external factors (Riguete et al., 2013), the explanatory variables used to illustrate the intensity of edge effect were *greater protection of fragment core*, to explain lower edge effect intensity, and *lower protection of fragment core*, to explain higher edge effect intensity.

3. Results

3.1. Dynamics of vegetation structure

3.1.1. Quantitative analysis

According to the quantitative analysis of vegetation structure between the years 1979 and 2005 (Table 1), the arboreal class experienced a retraction in area (negative sign) and its edge effect intensified due to the transformation of its regular shape (value closer to 1) to an irregular one (value farther from 1), thus increasing total edge and decreasing its core area. Both bush and herbaceous classes experienced an expansion in area (positive sign) and their edge effects increased from 1975 to 2015 due to their transformation from regular shapes (values closer to 1) to irregular shapes (value farther from 1), thus increasing total edge and decreasing their core areas.

3.1.2. Qualitative analysis

Qualitative changes in vegetation structure are described in Table 2 below. The variables *low declivity of the terrain* and *lower protection of fragment core* explained changes in structure of the arboreal class. The variables *resistance to fire* and *lower protection of fragment core* explained the changes in the structure of the bush class, while the variables *tolerance to variation in light* and *lower protection of fragment core* explained the changes in the structure of the herbaceous class.

4. Discussion

The process of retraction of 1,171 hectares of arboreal vegetation (Table 1) was explained by the variable *low declivity of the terrain* (Table 2). Declivity is one of the main parameters considered in the classification of land use aptitude in Brazil and is directly related to the practice of raising cattle (Ramalho-Filho and Beek, 1995). This parameter is consistent with that observed in the study area since the area is considered relatively flat and pastures were, in fact, not found in areas at higher elevations.

In Brazil, pasture areas were characterized and classified according to the declivity of the terrain, based on the generation of a digital Elevation Model (DEM) derived from SRTM (Shuttle Radar Topography Mission) of the project *Brasil em Relevo* (Brazil in Relief) carried out by Embrapa in 2005 (Miranda, 2005). According to the distribution of pasture areas by declivity class in Brazil, 75% are in areas of flat relief (declivity between 0 and 2%) and smooth undulating (declivity between 2 and 8%). With respect to the distribution of pastures by biomes, the pattern of declivity found for pastures in the Atlantic |Forest is also between flat and undulating.

Rupestrian fields (campos rupestres) are a type of phytophysiognomy of the Cerrado biome and the predominant component of the herbaceous-bushed stratum of the region (Gomes et al., 2015). Until recently, raising cattle in the Cerrado region was extensive, and based on native vegetation of low productivity (Durigan et al., 1998). However, African grasses, perfectly adapted to the environmental conditions of the Brazilian Cerrado, provided an increase in productivity and, therefore, have become the main invaders of pasture areas (Klink, 1994).

The process of expansion of 1.168 hectares of herbaceous vegetation (Table 1) was explained by the variable *tolerance to variation in light* (Table 2) by virtue of the introduction of the exotic herbaceous *Brachiaria decumbens* (Stapf. Prain.) in pasture areas. Solar radiation is essential for the native herbaceous stratum in Cerrado areas since it is necessary for positive carbon balance and growth (Oliveira et al., 2007). However, the daily and seasonal fluctuations that occur in the study area due to the reduction of native vegetation tend to cause extensive variation in the intensity of luminosity and, for this reason, the species that possess ecophysiological mechanisms more suitable for these changes are at a competitive advantage (Larcher, 2000).

The morphological and structural changes of the species *Brachiaria decumbens* (Stapf. Prain.) are typical of plants subjected to an environment with low luminosity, making them able to adapt to the conditions imposed by the environment (Gobbi et al., 2009). The morphological responses of *Brachiaria decumbens* aim to avoid shade and to increase light uptake by the assimilating organs by means of leaf blade elongation that allows the plant to tolerate different levels of shade (Lambers et al., 1998). In this manner, the variable *tolerance to variation in light*

Table 1. Table of changes in vegetation structure between the years 1979 and 2015.

Class	Area (ha) 1979	Area (ha) 2015	% of landscape 1979	% of landscape 2015	Process 1979 - 2015	Hectares	Shape 1979	Shape 2015	TE 1979	TE 2015	TCA (ha) 1979	TCA (ha) 2015
Arboreal	1769	598	65	22	Retraction	-1.171	1.022	1.078	246.730	465.791	119.225	780
Bush	925	928	34	34.10	Expansion	+3	1.025	1.076	167.028	300.153	62.342	444
Herbaceous	27	1195	1	43.9	Expansion	+1.168	1.021	1.079	77.972	599.806	1.821	146
Total	2.721	2.721	100	100	1.171		-	-	491.730	1.365.750	183.388	1.370

Table 2. Qualitative analysis of vegetation structure.

Vegetation class 1979 - 2015	Change in area	Explanatory variable	Edge effect	Explanatory variable
Arboreal	Retraction for pasture	*Low declivity of the terrain*	Greater	*Lower protection of fragment core*
Bush	Expansion by frequent use of fire	*Resistance to fire*	Greater	*Lower protection of fragment core*
Herbaceous	Expansion from exotic grasses	*Tolerance to variation in light*	Greater	*Lower protection of fragment core*

favored the expansion of the area of the exotic herbaceous class due to the ability of *Brachiaria decumbens* to develop this mechanism of acclimatization. This mechanism allows the species to grow in this environment of high light variation and, therefore, be a species of potential use in pasture areas (Fernandes and Barbosa, 2013).

The expansion of only three hectares of bushed vegetation (Table 1), reflected stability of this vegetation class, which was explained by the variable *resistance to fire* (Table 2). Burning pastures is a common practice in areas of rupestrian fields (campos rupestres) due to the resistance of its bush vegetation (Jacques, 2013). This greater resistance to fire by the bush vegetation in fields, relative to other vegetation types, is due to their morphological (structures such as specialized lignotubers), physiological (induced germination, flowering, fruit dehiscence, seed dispersion or breaking of dormancy) and demographic (recruitment or adult mortality) adaptations to fire resistance (Figueira et al., 2016).

In the quantitative analysis of the edge effect, an increase in the variable *total edge*, a reduction in the variable *total central area* and an increase in irregularity of the fragment according to the variable *shape* (Table 1), were responsible for the increased edge effect in all vegetation classes from 1979 to 2015 (Table 2). Because all of the vegetation classes possessed greater total edges, they also had shorter distances between the interior (core) and the edge, and therefore a smaller central area (Nascimento and Laurance, 2006). The central area of a class is the best indication of its quality and, thus, even if the class of vegetation is large enough to contain some species, if it does not have a sufficient central area to support these species its structure will be affected (Cabacinha et al., 2010).

The reduction of core area is directly related to the shape of a fragment since more irregular fragments are subjected to more matrix intervention and less protection of the interior environment, leaving the core more exposed to edge effects (Metzger, 2001). Thus, the explanatory variable *lower protection of fragment core* explained the greater intensity of the edge effect in the vegetation classes in 2015, while the explanatory variable *greater protection of the fragment core* explained the lower intensity of the edge effect in the vegetation classes in 1979.

In areas frequently deteriorated by the effects of pasture and fire, like the one in the present study, edge effects alter vegetation structure (Laurance et al., 2002), since individuals at the edge are prone to more intense adversities than individuals of the interior, such as higher air and soil temperatures, lower air humidity, more intense and frequent winds and luminosity throughout the year, greater evapotranspiration and greater exposure to fire (Lima-Ribeiro, 2008).

The area and edge metrics analyzed in this study for vegetation structure dynamics also determined the structural dynamics of the landscape between the years 1984 and 2013, as reported by the structural analysis of the landscape in an area of Cerrado in northeastern Minas Gerais (Paracatu MG, Brazil) by Oliveira et al., 2007. Those authors found similar results to that of the present study, identifying a reduction of area and an intensification of the edge effect as the cause of the dynamics in the structure of the natural landscape.

5. Conclusion

Analysis of the dynamics of vegetation structure showed that it was strongly impacted. Because it is an area of transition between two Brazilian biomes rich in biodiversity, but in a state of degradation, management actions regarding land use and occupation, and the recovery of vegetation cover, are recommended to help reduce the impacts of pasture, and thus the edge effect, and restore the original vegetation structure.

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References

ABDO, M.T.V.N., VALERI, S.V., FERRAUDO, A.S. 2015. Avaliação do efeito de borda da reserva biológica de Pindorama, SP. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*. v.10, n.4, p. 01-07. http://dx.doi.org/10.18378/rvads.v10i4.3398.

BOLFE, E.L., PEREIRA, R.S., MADRUGA, P.R.A., FONSECA, E.L. 2004. Avaliação da classificação digital de povoamentos florestais em imagens de satélite através de índices de acurácia. *Árvore*, v.28, n.1, p.85-90. http://dx.doi.org/10.1590/S0100-67622004000100011.

CABACINHA, C.D., CASTRO, S.S. and GONÇALVES, D.A., 2010. Análise da estrutura da paisagem da alta bacia do rio Araguaia na savana brasileira. *Floresta*, vol. 40, no. 4, pp. 675-690. http://dx.doi.org/10.5380/rf.v40i4.20318.

CALEGARI, L.; MARTINS, S.V.; GLERIANI, J.M.; ELIAS, S.; BUSATO, L.C. 2010. Análise da dinâmica de fragmentos florestais no município de Carandaí, MG, para fins de restauração florestal. *Árvore*, v. 34, n.5, p.871-880. http://dx.doi.org/10.1590/S0100-67622010000500012.

CUNHA, A.M., LANI, J.L., AMARAL, E.F., REZENDE, S.B. and RIBEIRO, L.S., 2006. Mosaico digital de aerofotos não-convencionais na avaliação de recursos naturais: Estudo de caso. *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 10, no. 1, pp. 182-187. http://dx.doi.org/10.1590/S1415-43662006000100027.

DOLFUSS, O., 1978. *O espaço geográfico*. São Paulo: Difel, 128 p.

DURIGAN, G., CONTIERI, W.A., FRANCO, G.A.D.C. and GARRIDO, M.A.O., 1998. Indução do processo de regeneração da vegetação de Cerrado em área de pastagem, Assis, SP. *Acta*

Botanica Brasílica, vol. 12, no. 3, pp. 421-429. http://dx.doi.org/10.1590/S0102-33061998000400011.

FARINA, A., 1998. *Principles and methods in Landscape Ecology*. New York: Springer. 228 p. http://dx.doi.org/10.1007/978-94-015-8984-0.

FERNANDES, G.W. and BARBOSA, N.P.U., 2013. Bombas-relógio que ameaçam a natureza. *Scientific American Brasil*, vol. 135, no. 1, pp. 60-61.

FIGUEIRA, J.E.C., RIBEIRO, K.T., RIBEIRO, M.C., JACOBI, C.M., FRANC¸, A. H., NEVES, A.C.O., CONCEIÇÃO, A.A., MOURÃO, F.A., SOUZA, J.M., MIRANDA, C.A.K. 2016. Fire in rupestrian grasslands: plant response and management. In: G.W. FERNANDES, ed. *Ecology and Conservation of Mountain-Top Grasslands in Brazil*. New York: Springer, pp. 415-448.

GOBBI, K.F., GARCIA R., A.F. GARCEZ, N., 2009. Morphological, structural and productivity of signal grass and forage peanut submitted to shading. *Journal of Animal Science*, vol. 38, no. 9, pp. 1645-1654. http://dx.doi.org/10.1590/S1516-35982009000900002.

GOMES, V.M., NEGREIROS, D., CARVALHO, V. and FERNANDES, G.W. 2015. Crescimento e desempenho de espécies nativas de campo rupestre em áreas degradadas quartzíticas. *Neotropical Biology and Conservation*, v. 10, n.3, pp. 159-168. http:// dx.doi: 10.4013/nbc.2015.103.06

GUSTAFSON, E.J. 1999. *Harvest: a timber harvest allocation model for simulating management alternatives*. New York: Springer, 124 p.

JACQUES, A.V.A., 2013. A queima das pastagens naturais - efeitos sobre o solo e a vegetação. *Ciência Rural*, vol. 33, no. 1, pp. 177-181. http://dx.doi.org/10.1590/S0103-84782003000100030.

KLINK, C.A., 1994. Effects of clipping on size and tillering of native and African grasses of the Brazilian savannas (the Cerrado). *Oikos*, vol. 70, no. 3, pp. 365-376. http://dx.doi.org/10.2307/3545774.

KÖPPEN, W., GEIGER, R. 1928. *Klimate der Erde*. Gotha: Verlag. Wall-map 150 cm x 200 cm.

LAMBERS, H., STUART, C. and PONS, T. 1998. *Plant physiological ecology*. Springer, New York, 223 p. http://dx.doi.org/10.1007/978-1-4757-2855-2.

LARCHER, W. 2000. *Ecofisiologia Vegetal*. São Carlos: Rima Artes e Textos, 2000. 531p.

LAURANCE, W.F., LOVEJOY, T.E., VASCONCELOS, H.L., BRUNA, E.M., DIDHAM, R.K., STOUFFER, P.C., GASCON, C., BIERREGAARD, R.O., LAURANCE, S.G. and SAMPAIO, E., 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conservation Biology*, vol. 16, no. 3, pp. 605-618. http://dx.doi.org/10.1046/j.1523-1739.2002.01025.x.

LIMA-RIBEIRO, M.S.L., 2008. Efeitos de borda sobre a vegetação e estruturação populacional em fragmentos de Cerradão no Sudoeste Goiano, Brasil. *Acta Botanica Brasílica*, vol. 22, no. 2, pp. 535-545. http://dx.doi.org/10.1590/S0102-33062008000200020.

LOPES, W. P.; PAULA, A.; SEVILHA, A. C.; SILVA, A. F. 2002. Composição da flora arbórea de um trecho de Floresta Estacional no Jardim Botânico da Universidade Federal de Viçosa (Face Sudoeste), Viçosa, Minas Gerais. *Árvore*, v.26, n.3, p.339-347. http://dx.doi.org/10.1590/S0100-67622002000300009.

MANICA, L.T., TELLES, M. and DIAS, M.M., 2010. Bird richness and composition in a Cerrado fragment in the State of São Paulo. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 70, no. 2, pp. 243-254. http://dx.doi.org/10.1590/S1519-69842010005000001. PMid:20552144.

MESSIAS, C.G., 2016. Análise de uso do solo utilizando diferentes técnicas e imagens de média e alta resolução espacial. *Revija za Geografijo*, vol. 2, no. 1, pp. 1-9.

METZGER, J.P., 2001. O que é Ecologia de Paisagens? *Biota Neotropica, Campinas*, vol. 1, no. 1-2, pp. 1-9. http://dx.doi.org/10.1590/S1676-06032001000100006.

METZGER, J.P., FONSECA, M.A., OLIVEIRA-FILHO, F.J.B. and MARTENSEN, A.C., 2007. O uso de modelos em Ecologia de Paisagens. *Megadiversidade*, vol. 3, no. 1-2, pp. 64-73.

METZGER, J.P., GOLDENBERG, R. and BERNACCI, L.C., 1998. Diversidade e estrutura de fragmentos de mata de várzea e de mata mesófila semidecídua submontana do rio Jacaré-Pepira (SP). *Revista Brasileira de Botanica. Brazilian Journal of Botany*, vol. 21, no. 3, pp. 321-330. http://dx.doi.org/10.1590/S0100-84041998000300012.

MIRANDA, E.E. *Brasil em Relevo*. Campinas: Embrapa Monitoramento por Satélite, 2005.

MURCIA, C., 1995. Edge effects in fragmented forests: implications for conservation. *Trends in Ecology & Evolution*, vol. 10, no. 2, pp. 58-62. http://dx.doi.org/10.1016/S0169-5347(00)88977-6. PMid:21236953.

NADAI, R. and HENRY, R., 2009. Temporary fragmentation of a marginal lake and its effects on zooplankton community structure and organization. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 69, no. 3, pp. 819-835. http://dx.doi.org/10.1590/S1519-69842009000400009. PMid:19802441.

NASCIMENTO, H.E. and LAURANCE, W.F., 2006. Efeitos de área e de borda sobre a estrutura florestal em fragmentos de floresta de terra-firme após 13-17 anos de isolamento. *Acta Amazonica*, vol. 36, no. 2, pp. 183-192. http://dx.doi.org/10.1590/S0044-59672006000200008.

NUCCI, J.K., 2007. Origin and development of ecology and Landscape Ecology. *Geografar*, vol. 2, no. 1, pp. 77-99.

OLIVEIRA, T.K., MACEDO, R.L.G., SANTOS, I.P.A., HIGASHIKAWA, E.M. and VENTURIN, N., 2007. Produtividade de *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf cv. Marandu sob diferentes arranjos estruturais de sistema agrossilvipastoril com eucalipto. *Ciência e Agrotecnologia*, vol. 31, no. 3, pp. 749-757. http://dx.doi.org/10.1590/S1413-70542007000300022.

PANIZZA, A.C. and FONSECA, F.P., 2011. Técnicas de interpretação visual de imagens. *Geousp*, vol. 30, pp. 30-43. http://dx.doi.org/10.11606/issn.2179-0892.geousp.2011.74230.

PICKETT, S.T. and THOMPSON, J.N., 1978. Patch dynamics and design of nature reserves. *Biological Conservation*, vol. 13, no. 1, pp. 27-37. http://dx.doi.org/10.1016/0006-3207(78)90016-2.

PIRATELLI, A., SOUSA, S.D.B., CORRÊA, J.S.B., ANDRADE, V.A.B., RIBEIRO, R.Y.B., AVELAR, L.H.B. and OLIVEIRA, E.F.B., 2008. Searching for bioindicators of forest fragmentation: passerine birds in the Atlantic forest of southeastern Brazil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 68, no. 2, pp. 259-268. http://dx.doi.org/10.1590/S1519-69842008000200006. PMid:18660953.

PIROLI, E.L., BECKER, E.L.S., BOLFE, E.L. and PEREIRA, R.S., 2002. Análise do uso da terra na microbacia do arroio do meio – Santa Maria – RS, por sistema de informações geográficas e imagem de satélite. *Ciência Rural*, vol. 32, no. 3, pp. 407-413. http://dx.doi.org/10.1590/S0103-84782002000300007.

RAMALHO-FILHO, A. and BEEK, K.J. 1995. *Sistema de avaliação da aptidão agrícola das terras*. Rio de Janeiro: EMBRAPA-CNPS. 65 p.

RIGUETE, J.R., NETO, E.E.J.D. and TEIXEIRA, B.B.P., 2013. Avaliação do efeito de borda em fragmento florestal tomando o diâmetro de árvores como indicador. Natureza on line. *Santa Tereza*, vol. 11, no. 4, pp. 193-195.

SANTOS, J.T.S.S. and PENA, H.W.A., 2011. Geoprocessamento aplicado a ecologia de paisagem: uma análise da dinâmica espacial da Ilha do Papagaio – PA, Amazônia Brasil. *Oídles*, vol. 5, no. 11, pp. 63-90.

SCARANO, F.R., 2002. Structure, function and floristic relationships of plant communities in stressful habitats marginal to the Brazilian Atlantic rain forest. *Annals of Botany*, vol. 90, no. 4, pp. 517-524. http://dx.doi.org/10.1093/aob/mcf189. PMid:12324276.

SHAFFER, M.L., 1981. Minimum population sizes for species conservation. *Bioscience*, vol. 31, no. 2, pp. 131-134. http://dx.doi.org/10.2307/1308256.

SOARES-FILHO, B., ALENCAR, A., NEPSTAD, D., CERQUEIRA, G., VERA DIAZ, M.C., RIVERO, S., SOLORZANO, L. and VOLL, E., 2004. Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: The Santarém- Cuiabá corridor. *Global Change Biology*, vol. 10, no. 5, pp. 745-764. http://dx.doi.org/10.1111/j.1529-8817.2003.00769.x.

SOARES-FILHO, B.S., CERQUEIRA, G.C., ARAÚJO, W.L. and VOLL, E., 2007. Modelagem de dinâmica de paisagem:concepção e potencial de aplicação de modelos de simulação baseados em autômato celular. *Megadiversidade*, vol. 3, no. 1-2, pp. 74-86.

SOARES-FILHO, B.S., COUTINHO CERQUEIRA, G. and LOPES PENNACHIN, C., 2002. Dinamica-a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. *Ecological Modelling, Towson*, vol. 154, no. 3, pp. 217-235. http://dx.doi.org/10.1016/S0304-3800(02)00059-5.

SOLÓRZANO, A., OLIVEIRA, R.R. and GUEDES-BRUNI, R.R., 2009. Geografia, história e ecologia: criando pontes para a interpretação da paisagem. *Ambiente & Sociedade*, vol. 12, no. 1, pp. 49-66. http://dx.doi.org/10.1590/S1414-753X2009000100005.

VASCONCELOS, V.V., 2014. Campos de altitude, campos rupestres e aplicação da lei da Mata Atlântica: estudo prospectivo para o estado de minas gerais. *Boletim Geografico*, vol. 32, no. 2, pp. 110-133. http://dx.doi.org/10.4025/bolgeogr.v32i2.18624.

VOLOTÃO, C.F.S., 1998. *Trabalho de análise espacial - métricas do Fragstats*. São José dos Campos: Curso de Pós-graduação em Sensoriamento Remoto, Instituto Nacional de Pesquisas Espaciais, 45 p. Dissertação de Metsrado em Análise Espacial.