REVISTA CAMINHOS DE GEOGRAFIA
http://www.seer.ufu.br/index.php/caminhosdegeografia/

ISSN 1678-6343
DOI: https://doi.org/10.14393/RCG259769228

HOW THE BRAZILIAN CERRADO IS CHANGING OVERTIME IN NORTHERN MINAS GERAIS? SPATIAL ANALYSIS AND PREDICTION

Vicente Paulo Santana Neto
Federal University of Viçosa – UFV, Department of Forest Engineering, Viçosa, MG, Brasil
vipsneto@gmail.com

Reginaldo Arthur Gloria Marcelino
Federal University of Viçosa – UFV, Department of Forest Engineering, Viçosa, MG, Brasil
regisarthursc@hotmail.com

Emanuelly Canabrava Magalhães
Federal University of Viçosa – UFV, Department of Forest Engineering, Viçosa, MG, Brasil
emanuellymagalhaes1@gmail.com

Polyanne Aparecida Coelho
Federal University of Lavras – UFLA, Department of Forest Science, Lavras, MG, Brasil
pcoelho.ufla@gmail.com

Aretha Franklin Guimarães
Biodiversity Coordenation, National Institute for Amazonian Research, Manaus, AM, Brazil
areguimaraes@gmail.com

Fausto Weimar Acerbi Júnior
Federal University of Lavras – UFLA, Department of Forest Science, Lavras, MG, Brasil
fausto@ufla.br

Alexandre Simões Lorenzon
Federal University of Viçosa – UFV, Department of Forest Engineering, Viçosa, MG, Brasil
alexandre.lorenzon@ufv.br

ABSTRACT

Deforestation is a complex problem worldwide caused mostly by the increase in farming activities. Despite the Brazilian Cerrado being the most biodiverse savanna in the world, this biome is threatened by high deforestation rates. The present study aimed to evaluate deforestation in in São Francisco municipality – Minas Gerais state in Brazil's southwestern region, analyzing changes in land cover between 2012 and 2020 focusing on forest, savanna, and grassland physiognomies, and predicting changes in the land cover for the year 2030. It was evaluated metrics of density and size, edge, shape, core area, and proximity. The forest and savanna fragments suffered a reduction in area (0.92% and 12.60%, respectively) and core area, and also increased its proximity. On the other hand, the grassland physiognomy increased its total area (12.72%), nuclear area, and distance from the other fragments. In general, the forest fragment and savanna fragments tended to be elongated and irregular. For 2030, a scenario is predicted with increasing grassland and decreasing forest and savanna. Those changes in the landscape can threaten the region's biodiversity, so public policy attention is needed to the conservation of the fragmented areas.

Keywords: Deforestation. Landscape Metrics. GIS. Landscape Ecology. MapBiomas.

COMO O CERRADO BRASILEIRO ESTÁ MUDANDO AO LONGO DO TEMPO NO NORTE DE MINAS? ANÁLISE ESPACIAL E PREDIÇÃO

RESUMO

O desmatamento é um problema complexo em todo o mundo causado principalmente pelo aumento das atividades agrícolas. Apesar do Cerrado Brasileiro ser a savana com maior biodiversidade do mundo, esse bioma tem sido ameaçado devido às altas taxas de desmatamento. O presente trabalho teve como objetivo avaliar o desmatamento em uma região de Cerrado no no município de São Francisco (Minas Gerais), analisando mudanças na cobertura da terra entre 2012 e 2020 para as fisionomias florestais, savânicas e campestres e prevendo mudanças na cobertura da terra para o ano de 2030. Foram avaliadas métricas de densidade e tamanho, borda, forma, área central e proximidade. Os fragmentos de floresta e savana sofreram redução de área (0,92% e 12.60%, respectivamente) e área nuclear, além de aumento de sua proximidade. Por outro lado, a fisionomia campestre aumentou sua área total (12,72%), área nuclear e distância dos demais fragmentos. Em geral, os fragmentos de florestais e savanicos tenderam a ser alongados e irregulares. Para 2030, é previsto um cenário de aumento de pastagens e diminuição de florestas e savanas. Essas mudanças na paisagem podem ameaçar a biodiversidade da região, por isso é necessária atenção das políticas públicas para a conservação das áreas fragmentadas.

Palavras-chave: Desmatamento. Métricas de paisagem. SIG. Ecologia da Paisagem. MapBiomas.

INTRODUCTION

Rapid population growth has led to an increased demand for natural resources, leading to the degradation and fragmentation of natural areas, mainly due to the expansion of agricultural borders and urban projects (SCARANO & CEOTTO, 2015; SERTEL et al., 2018; SAHA et al., 2020; YANAI et al., 2020). Anthropic activities in natural areas have a direct influence on habitat fragmentation (HANSEN et al., 2020; SOUZA et al., 2020). The main consequences of habitat fragmentation are the decrease in species richness, changes in the floristic and forest structural composition, interspecific interactions, social relations, movement of individuals, nutrient flow, and genetic composition of populations (FAHRIG, 2003; CLAUDINO; GOMES; CAMPOS, 2015; CARVALHO et al., 2016; LIRA et al., 2016; SCHÜßLER et al., 2020). In addition, forest fragmentation is also responsible for the loss of plant biomass, carbon stock, seed bank, and reduction of flora, fauna and an overall decreased genetic diversity (ACHARD et al., 2014; PÜTZ et al., 2014; SOUSA et al., 2017).

The Cerrado biome in Brazil is a vegetation complex composed of a wide range of physiognomies, including forest, savanna, and grasslands (RIBEIRO & WALTER, 1998). Due to its irreplaceable biodiversity and the threat faced by native vegetation loss, the Cerrado is considered a “*hotspot*” for the conservation of global biodiversity (KLINK & MACHADO, 2005). The Brazilian savanna is considered the richest in the world regarding the number of species, with approximately 11,046 species of phanerogams (40% endemic from the biome) (ANDRADE et al., 2022) and a remarkable diversity of endemic animal species. Also, the Cerrado covers an area of 2,036,448 km², about 23.9% of the Brazilian territory, and the high diversity of species found in the biome can be linked to the habitat heterogeneity, where soil geochemistry has a fundamental role in plant’s life (ANDRADE et. al., 2022). From 2012 to 2020, the biome accumulated an area of native vegetation loss covering approximately 79,660.1 km², mostly converting natural areas to farming areas (INPE, 2021).

In this context, landscape ecology indexes have been widely used in the landscape (MCGARIGAL & MARKS, 1995). These indexes make it possible to quantify the fragmentation impact on the environment, evaluating and monitoring anthropogenic effects and their consequences on ecosystems on a temporal and spatial scale (WANG; HAMANN; CUMMING, 2012). Several studies addressed this problem by using landscape indexes as geospatial analysis tools, using those metrics to access changes in the environment (CASTILLO et al., 2015; PIROVANI; SILVA; SANTOS, 2015; SAITO et al., 2016; FERREIRA et al., 2018). In addition to evaluating Land use/Land cover (LULC) changes over a certain period, an alternative is to use prediction tools to map future change scenarios for exploration, conservation, preservation, and/or environmental sustainability (LI et al., 2020). One tool that stands out in predicting changes in the landscape is the Land Change Modeler (LCM), which allows for the design and evaluation of modifications in the landscape structure, as well as planning of LULC when considering a before and after image (EASTMAN & TOLEDANO, 2018; LCM, 2021). This tool has been widely utilized and deployed to predict changes both in natural areas (ABURAS et al., 2018; AIRES et al. 2018; ANSARI & GOLABI, 2019; LI et al., 2020; KHOSHNOOD MOTLAGH et al., 2021), and urban areas (JAIN; JAIN, ALI, 2017; KIM; NEWMAN; GÜNERALP, 2020).

Understanding how variations in landscape affect vegetation over time and predicting future changes in land uses is crucial for implementing effective Biome conservation policies. Therefore, the aim of our study was to examine the spatial changes in a Cerrado area in São Francisco County, Minas Gerais

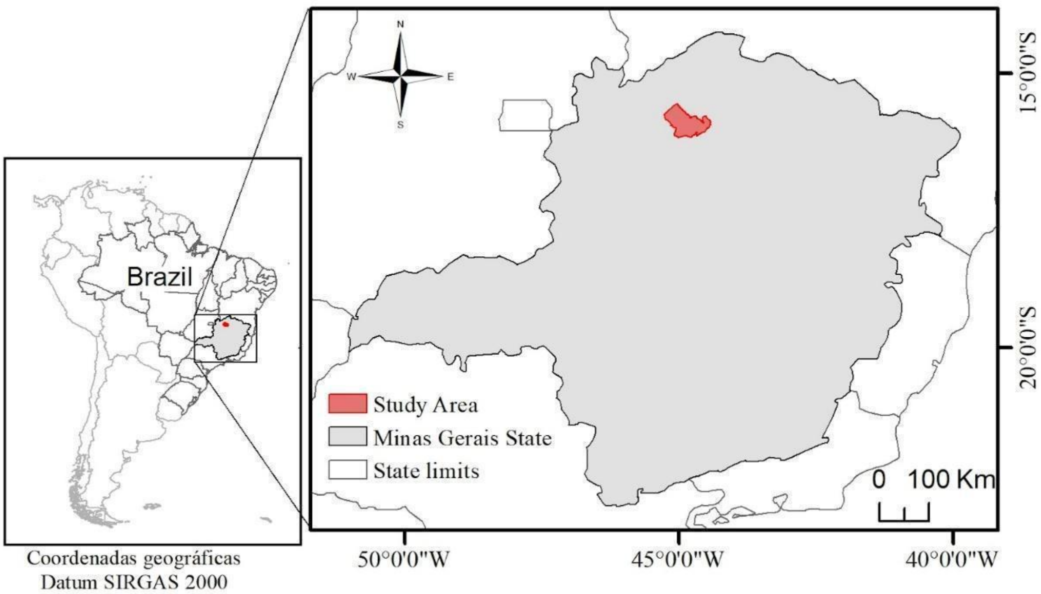
State, from 2012 to 2020 and predict LULC for the year of 2030. Our hypothesis was that all physiognomies (i.e., forest, savanna and grassland) in São Francisco County, would present an increased area of small fragments and a decrease in the area of larger fragments.

MATERIALS AND METHODS

Study area

The study was conducted in the São Francisco County, in northern Minas Gerais State (Figure 1), Southeast Brazil. This county is located in the microregion of Januária, São Francisco River basin. The county has approximately 3,308.1 km² of area and an 56,625 estimated population (IBGE, 2021). According to the Embrapa slope classification, the county has a mostly Flat, Smooth-wavy, and Wavy relief (EMBRAPA, 2006). Also, it has four types of soils, namely: Red Argisol, Haplic Cambisol, Fluvial Neosol, Quartzarian Neosol (EMBRAPA, 2001). The climate is classified as Aw, characterized by a tropical climate (rainy season from September to March and a dry winter with low temperatures from April to August) (MARTINS et al., 2018). The region is known for an intense agropastoral activities, and between 2012 and 2020 the area occupied by farming activities increased from 121,216.30 ha to 145,596.53 ha, an increment of more than 20% (MAPBIOMAS, 2021).

Figure 1 - Map from South America, with Brazil highlighted on the left. In the right, Minas Gerais state and the County of São Francisco (in red), Southeast Brazil in red, 2023.



Source - Prepared by the authors.

Land cover dataset

Land cover data was obtained from the MapBiomas Project (MAPBIOMAS, 2021) at a 30 meters resolution. Details of Land Use/Land Cover (LULC) classification methodology can be verified in Mapbiomas (2020). The temporal analysis was conducted from 2012 to 2020, an eight years interval. This period was chosen due to the changes made in the Brazilian Forest Code, as outlined in Law No. 12,651, of May 25, 2012, commonly referred to as the New Forest Code (BRASIL, 2012), modifying land use and conservation policies in the Country.

The preprocessing stage was carried out in the Geographic Information System (GIS) environment, specifically using ArcMap 10.8 (ESRI, 2011). Initially, the images were clipped to the study area boundary, and then they were converted into a vector format. We utilized three main phytophysiognomies to distinguish the vegetation in the county and perform the landscape analysis: forest, savanna and grasslands. These selected physiognomies were categorized into four different size classes based on Fernandes & Fernandes (2017) methodology: very small (<5 ha) (VS), small (5-10 ha) (S), medium (10-100 ha) (M), and large (> 100 ha) (L), and then converted to a raster format.

Landscape metrics were calculated using *Fragstats 4.2* (MCGARIGAL & MARKS, 2015). To avoid redundant landscape metrics, we chose the ones that were most effectively in illustrating the structural aspects of the environment. The metrics were associated to their ecological function (INKOOM et al., 2018; KELLY; TUXEN; STRALBERG, 2011) and were classified into six groups (area, density and size, edge, shape, core area and proximity) as detailed in Table 1. We utilized a total of eight metrics, since isolated metrics may be considered insufficient to understand the phenomenon (DALLOZ et al., 2017). Unlike other metrics, the MNN was calculated without distinguishing size classes to find proximity values of fragments of the same physiognomy. In this work, the distance from the edge was considered to be 60 meters from the outer boundary of the fragment, following the recommendation of DODONOV; HARPER and SILVA-SANTOS (2013). This distance was found to detect variations in microclimate, regardless of the phytophysiognomy and matrix analyzed (DODONOV; HARPER; SILVA-SANTOS, 2013).

Table 1 - Landscape metrics used on the landscape structure quantification.

Group	Acronym (units)	Metric	Description
Area	CA (ha)	Class Area	Area sum of all fragments of the LULC class.
Density and Size	NumP	Number of patches	Total number of fragments by LULC class.
	MPS (ha)	Mean patch size	Mean fragment size by LULC class type.
Edge	ED (m/ha)	Edge density	Relationship between the total edge size and the total landscape area.
Shape	MSI	Mean shape index	Expresses how close the fragment is to a regular square. The closer to 1, the more regular the fragment.
Core area	TCA (ha)	Total core area	Sum of the core area of all fragments of a given LULC class, considering a 60 m edge.
	TCAI (%)	Total core area index	Relationship between the core area and the total area of the corresponding class (CA) in percentage.
Proximity	MNN (m) *	Mean nearest neighbor distance	Mean of the sum of all the shortest euclidean distances between one fragment and another of the same physiognomy.

* Calculated for the entire physiognomy. Source: Adapted from McGarigal (2015).

Land Cover 2030 prediction

We analyzed landscape changes and trends using LULC images from the Mapbiomas (MAPBIOMAS, 2021) for the years 2012 to 2019, and for model validation and prediction, we used the Mapbiomas 2020 classification image. The images were selected and grouped for analysis in the Land Change Modeler (LCM) tool. For the prediction of the LCM sub model, we considered forest, savanna, and grassland classes under the other changes influence in the landscape. The LCM modeling included the following steps: change analysis, transition potentials, change prediction for validation, and prediction as stipulated by LCM modeling (LCM, 2021). In addition, LCM modeling allowed us to include the Digital Elevation Model (DEM) as an input to enhance the modeling and area characterization. We chose to set the years of 2012 to 2019 to see if the variations observed in this period will hold for future analyses and prediction of changes in São Francisco County in the year of 2030.The year of 2030 stands out due to the 2030 Agenda, created in 2015, which established mandatory requirements to achieve World Sustainability in 17 Sustainable Development Goals (SDGs), regarding soil and vegetation management (SDG BRAZIL, 2022).

The LCM compared the observed changes in each land cover class (forest, savanna, grassland) and their contributions, as well as the relationships between them. To determine the validation accuracy, we used the Kappa statistic (LANDIS & KOCH, 1977) to measure the agreement/disagreement between the model and observed data, and the Root Mean Square (RMS) statistic error for training and model testing. After validating the 2030 image, we calculated landscape metrics to compare the scenarios across the evaluated time periods.

RESULTS

First Period (2012 - 2020)

Landscape Metrics

Forest and savanna lost 0.92% and 12.60% of total area, respectively, while the grassland increased by 12.82% in study area. In addition, a predominance of fragments in the VS class was observed in all physiognomies, as well as an increase in MPS, MSI, TCA, and TCAI metrics as the size classes increase. The very small fragments presented higher edge values in relation to the other classes, except the savanna physiognomy, where the small fragments class stood out in the aforementioned metric. Savanna also presented a larger area and greater number of fragments in the landscape for years, representing approximately 52.88% of the total area in 2012 and 43.76% in 2020 (Tables 2, 3 and 4).

Table 2 - Landscape metrics for the forest size classes for the years 2012 and 2020. CA: class area; NumP: number of patches; MPS: mean patch size; ED: edge density; MSI: mean shape index; TCA: total core area; TCAI: total core area index; MNN: mean nearest neighbor.

		Size classes			
Metric	**Year**	**Very small**	**Small**	**Medium**	**Large**
CA (ha)	2012	2,320.92	728.55	2,026.44	873.18
	2020	2,591.01	641.88	1,919.52	742.05
NumP	2012	2,229	103	83	6
	2020	2,295	93	81	5
MPS (ha)	2012	1.0412	7.0733	24.4149	145.53
	2020	1.129	6.9019	23.6978	148.41

ED (m/ha)	2012	5.3149	0.9405	1.9446	0.5032
	2020	5.855	0.8222	1.7933	0.4638
MSI	2012	1.4007	2.0867	2.8536	4.9601
	2020	1.4121	1.9977	2.8067	4.705
TCA (ha)	2012	25.2	68.31	488.61	380.97
	2020	34.65	63.36	459.72	343.44
		Size classes			
Metric	**Year**	**Very small**	**Small**	**Medium**	**Large**
TCAI (%)	2012	1.0858	9.3762	24.1117	43.6302
	2020	1.3373	9.871	23.9497	46.2826
MNN (m)*	2012	228.8715			
	2020	228.3124			

*Calculated for the entire physiognomy. Source Prepared by the authors.

Table 3 - Landscape metrics for the savanna size classes for the years 2012 and 2020. CA: class area; NumP: number of patches; MPS: mean patch size; ED: edge density; MSI: mean shape index; TCA: total core area; TCAI: total core area index; MNN: mean nearest neighbor.

Metric	**Year**	**Size classes**			
		Very small	**Small**	**Medium**	**Large**
CA (ha)	2012	6,249.42	2,371.7	8,590.32	174,942.09
	2020	7,725.96	3,076.9	12,374.4	144,759.60
NumP	2012	7549	342	328	41
	2020	11966	437	459	62
MPS (ha)	2012	0.9854	6.9347	26.19	4,266.88
	2020	1.0234	7.041	26.9594	2,334.83
ED (m/ha)	2012	2.1994	0.3496	1.0413	9.7437
	2020	2.8343	0.458	1.4481	9.8724
MSI	2012	1.3182	1.8866	2.5935	6.87
	2020	1.327	1.9101	2.6357	6.3346
TCA (ha)	2012	110.52	326.16	2746.26	131,809.59
	2020	144.81	405	3963.69	108,825.30
TCAI (%)	2012	1.7685	13.752	31.9692	75.3447
	2020	1.8743	13.163	32.0314	75.1766
MNN (m)*	2012	99.5723			
	2020	104.9667			

*Calculated for the entire physiognomy. Source – Prepared by the authors.

Vicente Paulo Santana Neto
Reginaldo Arthur Gloria Marcelino
Emanuelly Canabrava Magalhães
Polyanne Aparecida Coelho
Aretha Franklin Guimarães
Fausto Weimar Acerbi Júnior
Alexandre Simões Lorenzon

Table 4 - Landscape metrics for the grassland size classes for the years 2012 and 2020. CA: class area; NumP: number of patches; MPS: mean patch size; ED: edge density; MSI: mean shape index; TCA: total core area; TCAI: total core area index; MNN: mean nearest neighbor.

Metric	Year	Size classes			
		Very small	Small	Medium	Large
CA (ha)	2012	1,058.67	236.61	704.07	2,061.72
	2020	1,264.14	215.55	953.91	2,148.12
NumP	2012	934	35	23	5
	2020	1266	33	28	4
MPS (ha)	2012	1.1335	6.7603	30.6117	412.344
	2020	0.9985	6.5318	34.0682	537.03
Metric	**Years**	**Size classes**			
		Very small	**Small**	**Medium**	**Large**
ED (m/ha)	2012	2.189	0.326	0.7351	1.3762
	2020	2.7164	0.3577	1.0176	1.5851
MSI	2012	1.4026	2.1885	3.3008	7.0905
	2020	1.3745	2.178	3.3591	7.5623
TCA (ha)	2012	12.51	17.91	185.04	926.37
	2020	12.24	16.47	252.9	1,006.83
TCAI (%)	2012	1.1817	7.5694	26.2815	44.9319
	2020	0.9682	7.6409	26.5119	46.8703
MNN (m)*	2012	332.1319			
	2020	341.1656			

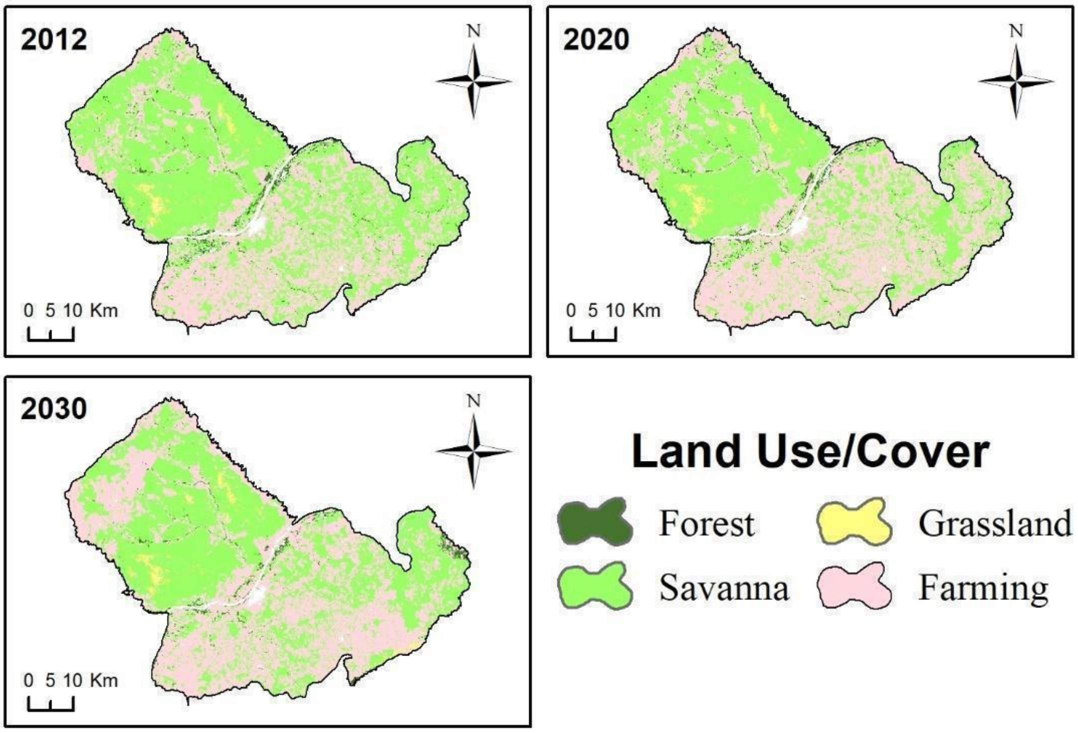
*Calculated for the entire physiognomy. Source - Prepared by the authors.

Most of the forest is distributed in very small fragments class, whilst savanna and grassland predominated in the small fragments class. In addition, the savanna scored higher values for class area (CA), total core area (TCA), and total core area index (TCAI) for all size classes and underwent significant changes in the analyzed period, with emphasis on the large fragments class responsible for 100% of AC losses in the physiognomy. In contrast to the savanna, the forest and grassland had fewer changes over the study period. However, there was a tendency towards fragmentation in the forest, while the grassland presented an opposite pattern (Tables 2, 3 and 4). Regarding the fragment's isolation, the mean nearest neighbor (MNN) metric showed minor changes in the analyzed period, and the grassland presented the highest value, followed by forest and savanna for both years.

Landscape dynamics and future prediction by LCM

The model with the best fit achieved an accuracy of 96.13% and a Kappa index of 0.9494, being most of the area designated for farming activities, followed by savanna, grassland, and forest, showing an increase in the county's eastern region. Farming activities was responsible for a significant portion of the landscape changes, with an increase of approximately 24.86% between 2012 and 2030 (as shown in Figure 2). In the period between 2020 and 2030, The area covered by forest and savanna decreased by 27.4% and 2.17%, respectively, while grassland increased by 5.53% (as indicated in Table 5).

Figure 2 - Land use/Land cover for the selected physiognomies of 2012 (top left), 2020 (top right), and predicted for 2030 (bottom of the figure in the left), for the county of São Francisco, Southeast Brazil. The different colors in the bottom right of the figure represent Land use/Land cover (dark green: forest; light green: Savanna; yellow: grassland; pink: farming).



Source - Prepared by the authors.

Table 5 - Landscape metrics for all physiognomies size classes for 2030. CA: class area; NumP: number of patches; MPS: mean patch size; ED: edge density; MSI: mean shape index; TCA: total core area; TCAI: total core area index; MNN: mean nearest neighbor.

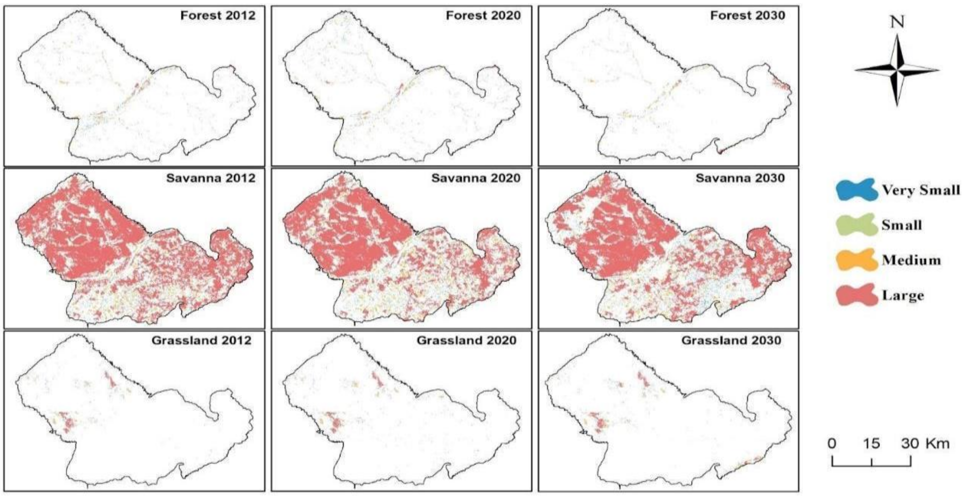
Physiognomies	Metric	Size classes			
		Very small	Small	Medium	Large
Forest	CA (ha)	1,306.62	493.83	1,365.39	1,113.66
	NumP	1329	69	53	5
	MPS (ha)	0.9832	7.157	25.7621	222.732
	ED (m/ha)	2.6759	0.5946	1.2227	0.5828
	MSI	1.3761	2.007	2.8204	5.616
	TCA (ha)	14.4	54.81	355.95	489.33
	TCAI (%)	1.1021	11.099	26.0695	43.9389
	MNN (m)*	252.8431			
Savanna	CA (ha)	8,335.62	2,405.97	8,413.2	145,145.07
	NumP	12748	341	311	46
	MPS (ha)	0.6539	7.0556	27.0521	3,155.33

Physiognomies	Metric	Size classes			
		Very small	Small	Medium	Large
	ED (m/ha)	2.6676	0.4304	0.8088	6.7775
	MSI	1.257	1.9161	2.5095	6.5552
Savanna	TCA (ha)	111.33	323.46	2992.86	113,545.98
	TCAI (%)	1.3356	13.4441	35.5734	78.2293
	MNN (m)*	95.0136			
Grassland	CA (ha)	950.58	258.39	1047.15	2,578.86
	NumP	926	38	32	6
	MPS (ha)	1.0265	6.7997	32.7234	429.81
	ED (m/ha)	2.2652	0.3778	1.0807	1.9135
	MSI	1.3727	2.0752	3.17	7.1963
	TCA (ha)	13.32	30.78	316.98	1,187.64
	TCAI (%)	1.4012	11.9122	30.2707	46.0529
	MNN (m)*	347.1046			

*Calculated for the entire physiognomy. Source – Prepared by the authors.

The forest physiognomy presented a similar pattern to previous years, with a predominance of very small fragments. However, the number of these fragments in the landscape has decreased, as evidenced by the analysis of CA and NumP metrics, as well as an increase in area in the large fragments when evaluating CA and TCA. The savanna follows the same pattern for the CA, TCAI, and TCA metrics in the large fragment class. There is a reduction in the core area in the smaller size classes, indicating that the large class was responsible for the entire physiognomy expansion, with an increase of 4,720.68 ha. In the grassland, the number of very small fragments decreased while the number of the other classes increased, indicating the grouping of the physiognomy. According to the proximity index, an increase was predicted in the forest and grassland and a reduction in the savanna (Figure 3).

Figure 3 - Physiognomies classified by size for the years 2012, and 2020 and predicted for 2030, for the county of São Francisco, Southeast Brazil. In the scale we can see very small fragments (blue), small (green), medium (yellow) and large (pink).



Source - Prepared by the authors.

DISCUSSION

Our study aimed to investigate the effects of fragmentation in a Cerrado area located in Minas Gerais State and to provide insights on the potential impacts of further agricultural expansion in this region. The study's hypothesis was accepted, as we observed an increase in the area covered by small and very small fragments across all fragment classes, along with a decrease in the area of larger fragments. In the following sections, we discuss the specific changes observed for each physiognomy and their potential implications for São Francisco County in the future.

The landscape responses varied depending on the impact suffered by different classes and physiognomies. In the forest physiognomy, we observed an increase in the area covered by very small and small fragments, and a decrease in medium and large fragments, indicating an increasing fragmentation in the region. These results suggest that larger fragments may be converted into smaller ones, which can have negative consequences for the ecosystem, since larger fragments are essential to maintain the biodiversity and ecological processes on a large scale (FORMAN & GODRON, 1986).

Fragment size is important, since it correlates positively with species richness (EVJU & SVERDRUP-THYGESON, 2016; LIRA et al., 2016; MOHANDASS et al., 2017). However, not only the area, but also the characteristics and quality of the habitat contribute to greater wealth (LEE & CARROLL, 2018). Isolated small fragments are more susceptible to external factors, but a set of them they can cover a greater variety of habitats than a single large fragment, as they may not contain all habitats in a given region (SAUNDERS; HOBBS; MARGULES, 1991; FAHRIG, 2020). In addition, smaller fragments are an important reservoir of phylogenetic diversity, serving as important sources for reforestation and restoration projects, and also functioning as "springboards" between fragments (MATOS et al., 2017; FERREIRA et al., 2018). In this sense, it is important to highlight that the number of fragments of a given class constitutes a measure of the fragmentation degree in a landscape, where larger numbers imply greater fragmentation, and smaller numbers indicate the union or extinction of fragments (CALEGARI et al. 2010, SOUZA et al., 2014).

The forest physiognomy showed an increase in edge density in the very small class, while the savanna and grassland showed an increase in edge density in all size classes. In general, as the fragment number of a particular class increases, there is also an increase in the border density and landscape fragmentation (CALEGARI et al., 2010), resulting in edge effect. This pattern has several implications, such as isolation, decreased connectivity, and acting as an impenetrable barrier for some species (LIU et al., 2019). These consequences may include an increase in the air temperature and greater thermal variability throughout the day, promoting changes in the environmental balance, disruption of ecological relationships between populations, and changes in species composition (PIROVANI; SILVA; SANTOS, 2014; TUFF; TUFF; DAVIES, 2016). A predominance of forest fragments with more elongated shapes was observed (Figure 3), which can be explained by the predominance of forests on the edges of rivers and/or drainage areas (OLIVEIRA et al., 1997), where agropastoral efforts are difficult to establish. In addition, Zimbres, Peres & Machado (2017) found that forests with elongated shapes have a lower functional richness than forests of other shapes, which reinforces the importance of larger and regular fragments.

The savanna physiognomy showed small differences when assessing relative metrics (mean shape index, edge effect, total core area index), compared to its huge loss on the total core area, indicating that despite its high native vegetation loss, the patches did not show a significant change of behavior. The larger grassland fragments presented a high mean shape index and low total core area index, as well as a strong edge effect on the patches. Therefore, the core area of a forest fragment can be considered a better indicator of fragment quality than their total area, since it is directly affected by its shape and borders (MCGARIGAL & MARKS, 1995). Furthermore, the larger savanna fragments, despite their reduction in MSI, presented a loss in their core area indexes, while the grasslands showed the opposite pattern, which can indicate the loss and emergence of fragments respectively.

Changes in the metrics for the core area reflect the fragmentation and native vegetation loss, or even an increase in natural vegetation when the changes are positive. However, the core area metrics depend on several other metrics to be interpreted correctly. For example, the increase in edges leads to the loss of nuclear area in the fragments, reducing the habitat quality, which highlights that fragment shape is fundamental to ensure and preserve the biodiversity in a given area (REIS & NISHYAMA, 2017).

Moreover, with the increase in the edge density, the fragment may become completely dominated by edge effect, losing its entire nuclear area (JUVANHOL et al., 2011). This phenomenon explains the low total core area index values for the smaller classes (very small and small), and, consequently, the small changes in them.

The forest physiognomy presented a decrease in the mean nearest neighbor, in opposition to the savanna and the grassland physiognomies. Higher values of mean nearest neighbor indicate a greater degree of isolation, which directly influences the connectivity between fragments. This is especially concerning in grassland areas because it is easier for humans to occupy those areas than it is to clear a forest fragment. Understanding the physical characteristics of the fragments, aided by the mean nearest neighbor, is essential because the biodiversity can be reduced in isolated fragments when subjected to the effects of fragment size and/or habitat loss (MORAES; DE MELLO; TOPPA, 2015). Furthermore, the landscape structure around the patches can help to control species diversity and patch area, given the presence of strong connectivity between them (Metzger, 2000), a decreasing pattern in the São Francisco County. Knowledge about isolation, combined with the fragments area, is an excellent method to analyze plant species richness in fragmented habitats (LINDGREN & COUSINS, 2017).

The forecast for land use in 2030 indicates an increase in grassland areas, with a decrease in forest and savanna areas. This shift may indicate the transformation of deforested areas in two directions. First, one of the initial stages of environmental recovery in the Brazilian Cerrado is through the return of the graminoid stratum, which may return the original vegetation if the environmental conditions are suitable (SAITO et al., 2016). Additionally, the increase in grassland physiognomy may also indicate an increase in pasture areas, as there is a predominance of the graminoid stratum in both, which makes it easy to confound. Spectral differences between grassland physiognomies and pasture are among the most difficult to distinguish, especially during dry seasons, together with the relative calibration of orbital sensors related to the characterization and classification of the same object to the detriment of the set of detectors (TEIXEIRA et al., 2018). However, the pattern observed in the physiognomies studied in the region indicates the expansion of agricultural activities in the study area. IBGE (2017) indicates an increase in farming areas in São Francisco County over the period of 11 years, since in 2006 there was 150,500 ha of farming areas and 180,163 ha in 2017, which represents a gain of 29,636 ha in farming area.

If there are no changes in the management of soil and vegetation in São Francisco, the forest physiognomy will suffer a high suppression of patches, due to the reduction of class area and number of fragments in the three smallest size classes. The increase of the area in the large class is mainly related to the appearance and clustering of a fragment in the eastern region of the municipality, caused by the residues of the LCM modeling. This might indicate an overtrained parameter inserted in the model, which is a principal operation of an Artificial Neural Network, such as Kroeger et al. (2019) and Rebello et al. (2022) studies. However, these findings do not invalidate our results once the statistical range of error proposed by the LCM tool fits the spatial validation of Landis & Koch (1977).

Regarding the savanna physiognomy, the results indicate an increase in fragmentation, as evidenced by the higher in the number of fragments in the very small class and the reduction in the larger classes. It is also important to highlight that there’s a reduction in area in the small and very small classes. Each Cerrado physiognomy harbors specific species that depend on that habit to occur in the landscape. Decreasing the Cerrado areas in São Francisco may cause a loss of the regional biodiversity and local extinctions.

The work considered MapBiomas classifications as the main database for the study of the landscape ecology, which makes the work easily replicable for any other areas in Brazil. In addition, more accurate classifications, with field analysis, forest inventories, species identification, and native knowledge of the area could be implemented for further studies on the subject. Our study calls for attention of researchers to the question: Do the currently known landscape ecology indices provide sufficient knowledge of an area, what are their limitations, and how can remotely conducted field studies be improved?

FINAL CONSIDERATIONS

Forest and savanna areas are decreasing over time and this trend may continue in the future if land management practices remain unchanged. The expansion of grassland areas indicates an increase in farming activities, which is the major factor for the increased native vegetation loss and fragmentation in the region.

In this sense, we suggest that some policy actions be taken to prevent long-term effects of the ongoing fragmentation in the county such as 1) protection of forest areas with the creation of parks and conservation units; 2) increase the connectivity of the fragments by creating corridors and stepping stones and 3) creating effective fiscalization policies to prevent further illegal exploitation of the natural areas. Create corridors and stepping stones will help to connect the smaller fragments, which would increase landscape permeability and the mobility of fauna through the fragments. Also, developing specific legislation, promote surveillance to prevent further conversion of natural areas in pasture and/or habitations for humans and protection of the remaining forest fragments will benefit fauna and flora and prevent further local extinctions. Additionally, we suggest that the remaining native Cerrado fragments in the county can be used as a key element in reforestation plans, serving as a springboard, and ecological corridors and increasing the connectivity of the fragments.

Finally, understanding how fragmentation processes will affect the native vegetation is crucial to prevent further biodiversity losses and the mitigation and remediation of this situation. We suggest that futures studies concerning biodiversity loss in São Francisco County and habitat fragmentation focus on using in land metrics to access if the predictions made in our model are accurate and if the fragmentation patterns found in our study will keep similar in the future.

REFERENCES

ABURAS, M. M.; ABDULLAH, S. H.; RAMLI, M. F.; ASH'AARI, Z. H.; AHAMAD, M. S. S. (2018, June). Simulating and monitoring future land-use trends using CA-Markov and LCM models. In: IOP conference series: Earth and environmental science, 169, 2018, p. 012050. IOP Publishing. https://doi.org/10.1088/1755-1315/169/1/012050

ACHARD. F.; BEUCHLE, R.; MAYAUX, P.; STIBIG, H.J.; BODART, C.; BRINK, A. et al. Determination of tropical deforestation rates and carbon-related losses from 1990 to 2010. **Global Change Biology**, v. 20, n.8, p. 2540-2554, 2014. **https://doi.org/10.1111/gcb.12605.** https://doi.org/10.1111/gcb.12605

AIRES, U. R. V.; SANTOS, B. S. M.; COELHO, C. D.; DA SILVA, D. D.; CALIJURI, M. L. Changes in land use and land cover as a result of the failure of a mining tailings dam in Mariana, MG, Brazil. **Land Use Policy**, v. 70, p. 63-70, 2018. **https://doi.org/10.1016/j.landusepol.2017.10.026.** https://doi.org/10.1016/j.landusepol.2017.10.026

ANDRADE, L.R.M.; AQUINO, F.G.; ECHEVARRIA, G.; OLIVEIRA, J.S.; PEREIRA, C.D.; MALAQUIAS, J.V.; SOUZA, K.S.; MONTARGES-PELLETIER, E.; FALEIRO, F.G.; JUNIOR, F.B.R.; MIRANDA, Z.G.; SANO, E.E.; AMARAL, L.I.V. **Edaphic factors as genetic selection agents and adaptation drivers of native plant species in harsh environments of the Brazilian savanna**. Plant and Soil, p. 1-23, 2022. https://doi.org/10.1007/s11104-022-05520-3

ANSARI, A.; GOLABI, M. H. Prediction of spatial land use changes based on LCM in a GIS environment for Desert Wetlands–A case study: Meighan Wetland, Iran. **International soil and water conservation research**, v. 7, n. 1, 64-70, 2019. **https://doi.org/10.1016/j.iswcr.2018.10.001.** https://doi.org/10.1016/j.iswcr.2018.10.001

BRASIL. **Lei 12651/2012. Código Florestal Brasileiro [on line]** Available at: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm. Accessed on 22.03.2022.

CALEGARI, L.; MARTINS, S. V.; GLERIANI, J. M.; SILVA, E.; BUSATO, L. C. Analysis of the dynamics of forest fragments in the county of Carandaí, MG, for forest restoration purposes. **Árvore**, v. 34, n. 5, p. 871-880, 2010.

CARVALHO, F. A.; BRAGA, J. M. A.; NASCIMENTO, M. T. Tree structure and diversity of fragments of low Atlantic forest: comparison of disturbed and undisturbed remnants. **Forest Research Journal**, v. 27, n. 3, p. 605-609, 2016. https://doi.org/10.1007/s11676-015-0165-2

CASTILLO, E. M.; GARCÍA-MARTIN, A.; LONGARES ALADRÉN, L. A., DE LUIS, M. Evaluation of forest cover change using remote sensing techniques and landscape metrics in the Natural Park of Moncayo (Spain). **Applied Geography**, v. 62, p. 247-255, 2015. https://doi.org/10.1016/j.apgeog.2015.05.002

CLAUDINO, E.S.; GOMES, M. A. F; CAMPOS, P. R. A. Extinction debt and the role of static and dynamic fragmentation in biodiversity. **Ecological Complexity**, v. 21, p. 150-155, 2015. **https://doi.org/10.1016/j.ecocom.2014.11.011**

DALLOZ, M. F.; CROUZEILLES, R., ALMEIDA-GOMES, M.; PAPI, B.; PREVEDELLO, J. A. Incorporating landscape ecology metrics in the environmental impact assessment in the Brazilian Atlantic Forest. **Perspectives on ecology and conservation**, v. 15, n. 3, p. 216-220, 2017. **https://doi.org/10.1016/j.pecon.2017.07.002.** https://doi.org/10.1016/j.pecon.2017.07.002

DODONOV, P.; HARPER, K. A.; SILVA-MATOS, D. M. The role of contrast of edges and forest structure in the influence of the border: vegetation and microclimate on the edges of the Brazilian cerrado. **Plant Ecology**, v. 214, n. 11, p. 1345-1359, 2013. **https://doi.org/10.1007/s11258-013-0256-0.** https://doi.org/10.1007/s11258-013-0256-0

EASTMAN, J. R.; TOLEDANO, J. **A short presentation of the Land Change Modeler (LCM)**. Geomatic approaches for modeling land change scenarios. Springer, Cham., 2018. https://doi.org/10.1007/978-3-319-60801-3_36

EMBRAPA. National Center for Soil Research. **Brazilian system of soil classification. 2. ed.** – Rio de Janeiro: EMBRAPA-SPI, 306 p, 2006. Available at: < https://www.agrolink.com.br/downloads/sistema-brasileiro-de-classificacao-dos-solos2006.pdf>. Accessed on 05.06.2023.

EMBRAPA. Brazil soil map. Rio de Janeiro: IBGE, 2001 - Scale 1:5.000.000. Available at: < http://www.dpi.inpe.br/Ambdata/mapa_solos.php>. Accessed on 05.06.2023.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute. License ID 2533209054.

EVJU, M.; SVERDRUP-THYGESON, A. Spatial configuration matters: a hypothesis test of the amount of habitat for plants in Calcucucuous pastures. **Landscape Ecology**, v. 31, n. 9, p. 1891-1902, 2016.

FAHRIG, L. Effects of Habitat Fragmentation on Biodiversity. **Annual Review of Ecology, Evolution, and Systematics**, v. 34, p. 487–515, 2003. http://doi.org/10.1146/annurev.ecolsys.34.011802.132419

FAHRIG, L. Why do several small patches hold more species than few large patches? **Global Ecology and Biogeography**, v. 29, n. 4, p. 615–628, 2020. https://doi.org/10.1111/geb.13059

FERNANDES, M.M.; FERNANDES M. R. M. Spatial Analysis of forest fragmentation of the Ubá-RJ River. **Forest Science**, v. 27, n. 4, p. 1429-1439, 2017. https://doi.org/10.5902/1980509830330

FERREIRA, I.J.M.; FERREIRA, J.H.D.; BUENO, P.A.A.; VIEIRA, L.M.; OLIVEIRA BUENO, R.D.; DO COUTO, E.V. Landscape metrics of spatial dimension of atlantic forest remnants in the State of Paraná, Brazil. **Acta Scientiarum - Technology**, v. 40, p. 1-8, 2018. https://doi.org/10.4025/actascitechnol.v40i1.36503

FORMAN, R.T.T.; GODRON, M. **Landscape ecology**.1 sted. Nova Iorque: J. Wiley, 1986.

HANSEN, M.C.; WANG, L.; SONG, X.P.; TYUKAVINA, A.; TURUBANOVA, S.; POTAPOV, P.V. et al. The fate of the fragments of tropical forests. **Scientific advances**, v. 6, n. 11, p. 1–10, 2020. https://doi.org/10.1126/sciadv.aax8574

INKOOM, J.N.; FRANK, S.; GREVE, K.; WALZ, U.; FÜRST, C. Adequacy of different landscape metrics for the assessments of irregular landscapes in West Africa. **Ecological Indicators**, v. 85, p. 117-127, 2018.

IBGE - Brazilian Institute of Geography and Statistics. **Agricultural Census 2017** - Definitive results. Rio de Janeiro: IBGE, 2017.

IBGE - Brazilian Institute of Geography and Statistics. Rio de Janeiro: IBGE, 2021. Available at: https://cidades.ibge.gov.br/brasil/mg/sao-francisco/panorama. Accessed on 01.10.2021.

INPE - National Institute of Space Research. General Coordination of Earth Observation. Prodes. Increased deforestation in the Brazilian Cerrado. Available at: http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/cerrado/increments. Accessed on 30.09.2021.

JAIN, R. K.; JAIN, K.; ALI, S. R. Modeling urban land cover growth dynamics based on land change modeler (LCM) using remote sensing: a case study of Gurgaon, India. **Advances in Computational Sciences and Technology**, v. 10, n. 10, p. 2947-2961, 2017.

JUVANHOL, R. S.; FIEDLER, N. C.; SANTOS, A. R.; PIROVANI, D.B.; LOUZADA F.L.R.D.O.; DIAS, H.M. et al. Spatial analysis of forest fragments: case of the State Parks of Forno Grande and Pedra Azul, state of Espírito Santo. **Forest and Environment**, v. 18, n. 4, p. 353-364, 2011. **http://dx.doi.org/10.4322/floram.2011.055**

KELLY, M.; TUXEN, K.A.; STRALBERG, D. Mapping changes to the vegetation pattern in a restoring wetland: Find standard metrics that are consistent in spatial scale and time. **Ecological Indicators**, v. 11, n. 2, p. 263-273, 2011. https://doi.org/10.1016/j.ecolind.2010.05.003

KHOSHNOOD, M.; S., SADODDIN, A.; HAGHNEGAHDAR, A.; RAZAVI, S.; SALMANMAHINY, A.; GHORBANI, K. Analysis and prediction of land cover changes using the land change modeler (LCM) in a semiarid river basin, Iran. Land **Degradation & Development**, v. 32, n. 10, p. 3092-3105, 2021. https://doi.org/10.1002/ldr.3969

KIM, Y.; NEWMAN, G.; GÜNERALP, B. A review of driving factors, scenarios, and topics in urban land change models. **Land**, v. 9, n. 8, 2020. https://doi.org/10.3390/land9080246

KLINK, C. A. & MACHADO, R. Conservation of the Brazilian Cerrado. **Conservation Biology**, v. 19, p. 707 -713, 2005. https://doi.org/10.1111/j.1523-1739.2005.00702.x

KROEGER, T.; KLEMZ, C.; BOUCHER, T.; FISHER, J. R.; ACOSTA, E.; CAVASSANI, A. T.; ... & DACOL, K. Returns on investment in watershed conservation: Application of a best practices analytical framework to the Rio Camboriú Water Producer program, Santa Catarina, Brazil. **Science of the Total Environment**, v. 657, p. 1368-1381, 2019. https://doi.org/10.1016/j.scitotenv.2018.12.116

LANDIS, J.R.; KOCH, G.G. The measurement of observer agreement for categorical data, v. 31, p. 159 – 174, 1977. https://doi.org/10.2307/2529310

LCM. 2021. TerrSet Geospatial Monitoring and Modeling System. Land Change Modeler - LCM - Modelagem de Detecção de Mudanças. Available at: http://www.terrset.com.br/index.php/idrisi/lcm. accessed on 07.10.2021.

LEE, M.B.; CARROLL, J.P. Effects of patch size and basal area on taxonomic and functional avian diversity in pine forests: Implication for the influence of habitat quality on the species-area relationship. **Ecology and Evolution**, v. 8, n. 14, p. 6909-6920, 2018. https://doi.org/10.1002/ece3.4208

LI, K.; FENG, M.; BISWAS, A.; SU, H.; NIU, Y.; CAO, J. Driving factors and future prediction of land use and cover change based on satellite remote sensing data by the LCM model: a case study from Gansu province, China. **Sensors**, v. 20, n. 10, 2757, 2020. **https://doi.org/10.3390/s20102757**

LINDGREN, J.P.; COUSINS, S.A.O. The theory of biogeography of the islands overcomes the hypothesis of the amount of habitat in the prediction of the richness of plant species in small remnants of pastures. **Landscape Ecology**, v. 32, n. 9, p. 1895-1906, 2017. https://doi.org/10.1007/s10980-017-0544-5

LIRA, A.F.; ARAÚJO, V.L.D.; SOUZA, A.M.D.; REGO, F.N.; ALBUQUERQUE, C. M. The effect of habitat fragmentation on the scorpion set of a Brazilian Atlantic Forest. **Insect Conservation Journal**, v. 20, n. 3, p. 457-466, 2016. **https://doi.org/10.1007/s10841-016-9878-6.** https://doi.org/10.1007/s10841-016-9878-6

LIU, J., COOMES, D. A., GIBSON, L., HU, G., LIU, J., LUO, Y., ... & YU, M. Forest fragmentation in China and its effect on biodiversity. **Biological Reviews**, v. 94, n. 5, p. 1636-1657, 2019. https://doi.org/10.1111/brv.12519

MAPBIOMAS. Theoretical Algorithm Base Document (ATBD) - Collection 5 - Version 1.0. 2020. 48 p. Available at: https://mapbiomas-br-site.s3.amazonaws.com/ATBD_Collection_5_v1.pdf. Accessed on 03.09.2021

MAPBIOMAS. MapBiomas Project - Collection 6 of the Annual Series of Land Cover and Land Use Maps in Brazil. 2021. Available at: http://mapbiomas.org. Accessed on 30.09.2021.

MARQUES, A. S.; BERNARDES, B. M.; BORSAGLI, A. The Quilombola Bom Jardim da Prata Community in São Francisco/Minas Gerais, as well as the socioenvironmental conflicts associated with the So Francisco River and mediation efforts. **Cerrados**, v. 19, n. 2, p. 81-108, 2021. https://doi.org/10.46551/rc24482692202120

MARTINS, F.B.; GONZAGA, G.; SANTOS, D.F.; REBOITA, M.S. Köppen and Thornthwaite climate classification for Minas Gerais: Current scenario and future projections. **Brazilian Journal of Climatology**, v. 1, p.128–156, 2018. https://doi.org/10.5380/abclima.v1i0.60896

MATOS, F.A.R.; MAGNAGO, L.F.S.; GASTAUER, M.; CARREIRAS, J.M.; SIMONELLI, M.; MEIRA-NETO, J.A.A. et al. Effects of landscape configuration and composition on the phylogenetic diversity of trees in a highly fragmented tropical forest. **Journal of Ecology**, v. 105, n. 1, p. 265-276, 2017**. https://doi.org/10.1111/1365-2745.12661**

MCGARIGAL, K.; MARKS, B.J. FRAGSTATS**:** program of analysis of spacing patterns for quantification of the landscape structure**.** Portland: Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1995. 122p.

MCGARIGAL, K.; SAMUEL, C.; ENE, E. FRAGSTATS v4.2: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Amherst: University of Massachusetts, 2015. Available at: http://www.umass.edu/landeco/research/fragstats/fragstats.html. Accessed on 30.09.2021

METZGER, J. P. Functional wealth of trees and landscape structure in a fragmented Brazilian tropical landscape. **Ecological applications**, v. 10, n. 4, p. 1147-1161, 2000. https://doi.org/10.1890/1051-0761(2000)010[1147:TFGRAL]2.0.CO;2

MOHANDASS, D.; CAMPBELL, M.J.; HUGHES, A.C.; MAMMIDES, C.; DAVIDAR, P. The effect of altitude, spot size and disturbance on the richness and density of liana species in montane forest patches. **Acta Oecologicala,** v. 83, p. 1-14, 2017. **https://doi.org/10.1016/j.actao.2017.06.004**

MORAES, M.C.P.; DE MELLO, K.; TOPPA, R.H. Landscape analysis of a buffer zone for planning and management of protected area. **Árvore**, v. 39, n. 1, p. 1-8, 2015.

ODS Brasil. **Transforming Our World - The 2030 Agenda for Sustainable Development.** 2022. Available at: https://odsbrasil.gov.br/home/agenda. Accessed on 22.03.2022.

OLIVEIRA, L.D.; SILVA, E.; BRITES, R.S.; SOUZA, A. D. Diagnosis of native forest fragments, at landscape level, Eunápolis - BA. **Árvore**, v. 21, n. 4, p. 501-510, 1997.

PIROVANI, D.B.; SILVA, A.G.D.; SANTOS, A.R.D.; CECÍLIO, R.A.; GLERIANI, J.M.; MARTINS, S.V. Spatial analysis of forest fragments in the Itapemirim River Basin, ES. **Árvore**, v. 38, n. 2, p. 271-281, 2014. https://doi.org/10.1590/S0100-67622014000200007

PIROVANI, D.B.; SILVA, A.G.D.; SANTOS, A.R.D. Landscape analysis and land use changes around RPPN Cafundó, ES. **Cerne**, v. 21, n. 1, p. 27-35, 2015. https://doi.org/10.1590/01047760201521011182

PÜTZ, S.; GROENEVELD, J.; HENLE, K.; KNOGGE, C.; MARTENSEN, A.C.; METZ, M. A. Long-term carbon loss in fragmented neotropical forests. **Nature Communication,** v. 5, n. 1, p. 1-8, 2014. https://doi.org/10.1038/ncomms6037

REBELLO, C. M.; MARROCOS, P. H.; COSTA, E. A.; SANTANA, V. V.; RODRIGUES, A. E.; RIBEIRO, A. M.; NOGUEIRA, I. B. Machine Learning-Based Dynamic Modeling for Process Engineering Applications: A Guideline for Simulation and Prediction from Perceptron to Deep Learning. **Processes**, v. 10, n. 2, 250, 2022. https://doi.org/10.3390/pr10020250

REIS, L.N.G.; NISHIYAMA, L.A. Spatial structure of the fragments of native vegetation of the Araguari River Basin in Minas Gerais. **Geosul**, v. 32, n. 65, p. 30-48, 2017. https://doi.org/10.5007/2177-5230.2017v32n65p30

RIBEIRO, J. F. & WALTER, B. M. T. **Fitofisionomias do Bioma Cerrado**. In. Sano, S.M. & Almeida, S.P. (ed.). Cerrado: ambiente e flora. Planaltina, DF: EMBRAPA - CPAC, 556p., 1998.

SAHA, S.; SAHA, M.; MUKHERJEE, K.; ARABAMERI, A.; NGO, P.T.T.; PAUL, G.C. Predict the probability of deforestation using binary logistic regression, random forest, rotational forest sets and REPTree: A case study in the Gumani River Basin, India. **Total Environmental Science**, v. 730, p. 1-20, 2020. https://doi.org/10.1016/j.scitotenv.2020.139197

SAITO, N.S.; MOREIRA, M.A.; SANTOS, A.R.D.; EUGENIO, F.C.; FIGUEIREDO, Á.C. Geotechnology and landscape ecology in forest fragmentation monitoring. **Forest and Environment**, v. 23, n. 2, p. 201-210, 2016. https://doi.org/10.1590/2179-8087.119814

SAUNDERS, D.A.; HOBBS, R.J.; MARGULES, C.R. Biological consequences of ecosystem fragmentation: a review. **Conservation Biology**, v. 5, p. 18-32, 1991.

SCARANO, F.R.; CEOTTO, P. Brazilian Atlantic forest: impact, vulnerability and adaptation to climate change. **Biodiversity and Conservation**, v. 24, n. 9, p. 2319–2331, 2015. https://doi.org/10.1007/s10531-015-0972-y

SCHÜßLER, D.; MANTILLA-CONTRERAS, J.; STADTMANN, R.; RATSIMBAZAFY, J.H.; RADESPIEL, U. Identification of crucial stepping stones habitats for biodiversity conservation in northeastern Madagascar using remote sensing and comparative predictive modeling. **Biodiversity and Conservation**, v. 29, n. 7, p. 2161–2184, 2020. https://doi.org/10.1007/s10531-020-01965-z

SERTEL, E.; TOPALOĞLU, R.H.; ŞALLI, B.; ALGAN, I.Y.; AKSU, G.A. Comparison of landscape metrics for three different maps of land cover/land use. **International Journal of Geo-Information**, v. 7, n. 10, p. 1 – 21, 2018. **https://doi.org/10.3390/ijgi7100408**

SOUSA, T.R.; COSTA, F.R.C., BENTOS, T.V.; LEAL FILHO, N.; MESQUITA, R.C.G.; RIBEIRO, I.O. The effect of forest fragmentation on the seed bank of the central Amazon soil. **Ecology and forest management**, n. 393, p. 105-112, 2017. **https://doi.org/10.1016/j.foreco.2017.03.020**

SOUZA, C.G.; ZANELLA, L.; BORÉM, R.A.T.; CARVALHO, L.M.T.D.; ALVES, H.M.R; VOLPATO, M.M.L. Analysis of forest fragmentation of the environmental protection area Coqueiral, Coqueiral-MG. **Forest Science**, v. 24, n. 3, p. 631-644, 2014.

SOUZA, C.A.M.; DAZA, S.L.C.; LIMA FILHO, J.A.; CAMPOS, P.R.A.; OLIVEIRA, V.M. Effect of dynamic fragmentation of biodiversity in a heterogeneous environment. **Physical Letters, Section A: General Physics, Atomic and Solid State**, v. 384, n. 22, p. 1-7, 2020. https://doi.org/10.1016/j.physleta.2020.126542

TEIXEIRA, M.B.; CAMARGO, P.L.T.D.; JUNIOR, P.P.M. Use of Remote Sensor Images for Critical Analysis of Cerrado Degradation in the Upper Middle São Francisco-Minas Gerais. **Anuario do Instituto de Geociencias**, v. 41, n. 1, p. 245-254, 2018. https://doi.org/10.11137/2018_1_245_254

TUFF, K.T.; TUFF, T.; DAVIES, K. F. A framework for integrating thermal biology into cluster research. **Letters of ecology**, v. 19, n. 4, p. 361-374, 2016. https://doi.org/10.1111/ele.12579

WANG, X.; HAMANN, A.; CUMMING, S.G. Measuring boreal forest fragmentation after fire: Which configuration metrics are best? **Ecological indicators**, v. 13, n. 1, p. 189-195, 2012. https://doi.org/10.1016/j.ecolind.2011.06.002

YANAI, A.M.; GRAÇA, P.M.L.A.; ESCADA, M.I.S.; ZICCARDI, L.G.; FEARNSIDE, P. The dynamics of deforestation in Brazilian Amazonian settlements: Effects of land concentration. **Environmental Management Journal**, v. 268, p. 1-12, 2020. https://doi.org/10.1016/j.jenvman.2020.110555

ZIMBRES, B.; PERES, C.A.; MACHADO, R. B. Responses of terrestrial mammals to habitat structure and the quality of remaining riparian forests in an Amazonian livestock landscape. **Biological Conservation**, v. 206, 2017. https://doi.org/10.1016/j.biocon.2016.11.033

Recebido em: 03/05/2023
Aceito para publicação em: 22/06/2023