

Fragmentation of native vegetation in a watershed

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Abstract

This study aimed to evaluate patterns of the fragmentation of native vegetation of the Upper São Bartolomeu River Watershed (USBRW) in the Federal District, Brazil, with an extension of 21,178.77 ha. The landscape metrics for the USBRW were drawn up after extracting the fragments of native vegetation, in shapefile format, from the vector map of land use and occupation, obtained in matrix format by unsupervised classification in the ArcMap 10.5 program. Images were acquired from the LANDSAT-1 and LANDSAT-8 satellites with pass dates of June 26, 1975, and September 3, 2020, referring to orbit/point 237/071 and 221/071, respectively. The USBRW native vegetation fragments were grouped for the years 1975 and 2020 using vector maps in area size classes. The landscape metrics were area (total core area, average fragment area, core area index and edge density), shape (mean perimeter-area ratio and mean shape indicator), and proximity (distance from nearest neighbor fragment given in meters and proximity index). According to the landscape metrics of the USBRW, it was found that continuous human activities for land use and occupation have led to the fragmentation of land into increasingly smaller portions. As a result, there has been a reduction in the size of fragments of native vegetation, making them less protected and more susceptible to the edge effect, with a lower degree of connectivity between them since they are further apart.

Keywords: Geosystems. Landscape metrics. Interactive units.

Introduction

Landscape is considered a heterogeneous mosaic formed by interactive units, and this heterogeneity is associated to at least one factor, according to an observer, and under a certain scale of observation (METZGER, 2001). The author adds that the set of interactive units in a landscape is defined by ecosystems, vegetation cover, or land use and occupation, and that the choice of the representative form of these units is arbitrary and up to the observer.

The study of landscapes from an ecological approach contemplates territorial use and planning from the perspective of the interaction between society and nature, implying the spatiality and heterogeneity of the space where humans operate. Therefore, landscape ecology considers the Earth's surface to be heterogeneous, formed by natural processes and shaped as a result of social, economic, political, and cultural processes (COSTA, 2020), and foresees in the

heterogeneous spatiality, geomorphological and land-cover aspects, both natural and cultural, in the heterogeneous spatiality (AZEVEDO *et al.*, 2021). Thus, when landscape ecology studies focus on ecology, they seek to understand the consequences of the spatial pattern in the landscape mosaic, whereby heterogeneity is expressed (FORMAN and GORDON, 1986; TURNER, 1989; WIENS *et al.*, 1993).

The boundaries of the interactive units of the landscape are defined by three factors: abiotic environmental factors, natural disturbances, and human activities. These, in their interrelation, create differentiated patterns (interactive sets) in the geographical space (METZGER, 2001).

According to Casimiro (2009), the structure of the landscape includes the matrix, patches or fragments, and corridors. The disruption of fragments of native vegetation in landscapes increases the potential fragility of ecosystems by isolating plants and animal species and reducing

their habitats, accentuating the edge effect in the contact areas between the matrix disturbed by humans and the remaining native vegetation (ANDRADE *et al.*, 2020; ETTO *et al.*, 2013; HENTZ *et al.*, 2015).

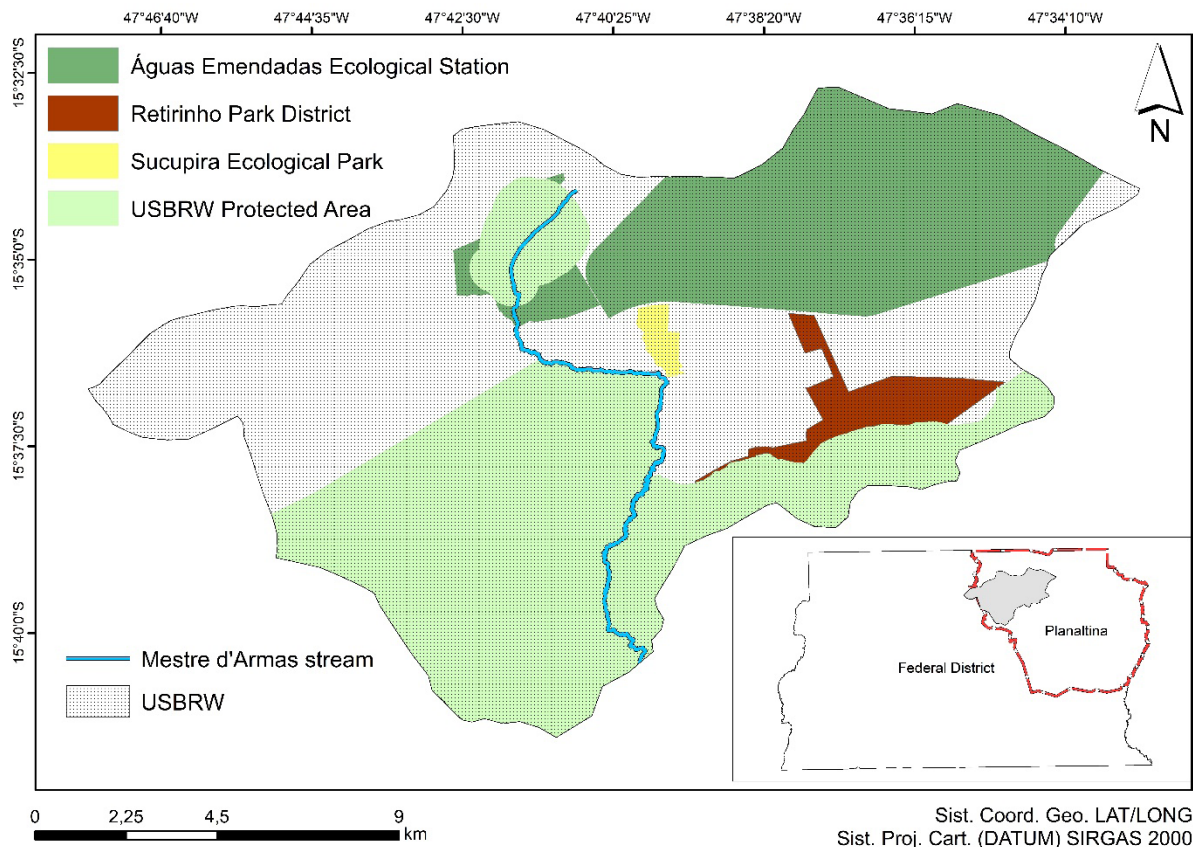
The scales of observations in landscapes that allow for different degrees of differentiation in space and time can be local (smaller areas in which the results of the internal self-development of geosystems are considered), regional (large territorial extensions distinguished by morphological, edaphic, and functional characteristics), and planetary (ODUM and BARRET, 2008; RODRIGUEZ, SILVA and CAVALCANTI, 2007).

The metric study of landscapes on a regional scale, by quantifying and spatializing the results, produces information on the fragmentation

pattern of landscape elements in watersheds, municipalities, and conservation units, for example, and can be quickly and relatively cheap to conduct using Geographic Information Systems and geoprocessing and remote sensing techniques (AMORIM, SOUSA, and PIROLI, 2021; CALEGARI *et al.*, 2010; SILVA and SOUZA, 2014).

Upper São Bartolomeu River Watershed (USBW) is important from an environmental point of view in the Administrative Region of Planaltina, Federal District, because it contains the Mestre d'Armas stream, with an approximate length of 22 km, as well as part of the Águas Emendadas Ecological Station, the parks of Retirinho (district) and Sucupira (ecological) and portions of the USBW Protected Area (Figure 1).

Figure 1. Upper São Bartolomeu River Watershed, located almost entirely in the Administrative Region of Planaltina, Federal District, Brazil.



Source: prepared by the authors

The fragmentation of native vegetation in the USBRW is due to the continuous human land use and occupation, which began close to the banks of the Mestre d'Armas stream. Figures 2 and 3 depict this human occupation. From 1958 to 1975, human occupation began to be significantly noted in the central portion of the Mestre d'Armas stream around its left bank. These occupied areas in Planaltina are currently divided into the Setor Tradicional (initial nucleus of the city according to Oliveira, 2014) and Setor Leste. For 10 years, from 1985 onwards, other territorial occupations were observed at a lower intensity, along with a development of those already mentioned, with streets and blocks being the most notable. In 1995, the occupation of the central-northern portion of the Mestre d'Armas stream was already remarkable, on both sides of its banks, in the localities now called: Mestre d'Armas I, II, III, IV, and V Condominiums, Setor Habitacional Mestre d'Armas, Setor de Mansões Mestre d'Armas, Sarandi Condominium, Nova Esperança Condominium, Park Mônaco Condominium, and Setor Norte. In 1995, the occupation of areas now belonging to Hollywood, Mestre d'Armas, Nosso Lar, and Samauma condominiums, areas located in the southern portion of the stream to the right, were also populated. To the left, the same occurs for areas that are now known as Vila Nossa Senhora de Fátima. Therefore, from the beginning of the occupation of the areas around the Mestre d'Armas stream until 2021, there has been a continuous, expansive—driven mainly by real estate speculation—and disordered parceling of this territory (SHIRATORI, 2011).

Given these considerations, this study was conducted aiming to evaluate the dynamics and fragmentation patterns of native vegetation associated with the evolution of urban occupation in the USBRW, Federal District, Brazil.

Material and methods

This work was conducted at the USBRW, located between the geographical coordinates of longitudes 47°41'58.148" and 47°39'45.374" West and latitudes 15° 34'08.298" and 15° 40'44.479" South, in the Federal District, Brazil (Figure 1), with an extension of 21,178.77 ha. Therefore, the analysis of the landscape dynamics of the native vegetation fragments was conducted on a local scale, considering the USBRW as a geosystem, with a structural approach to the pattern and spatial organization of the landscape.

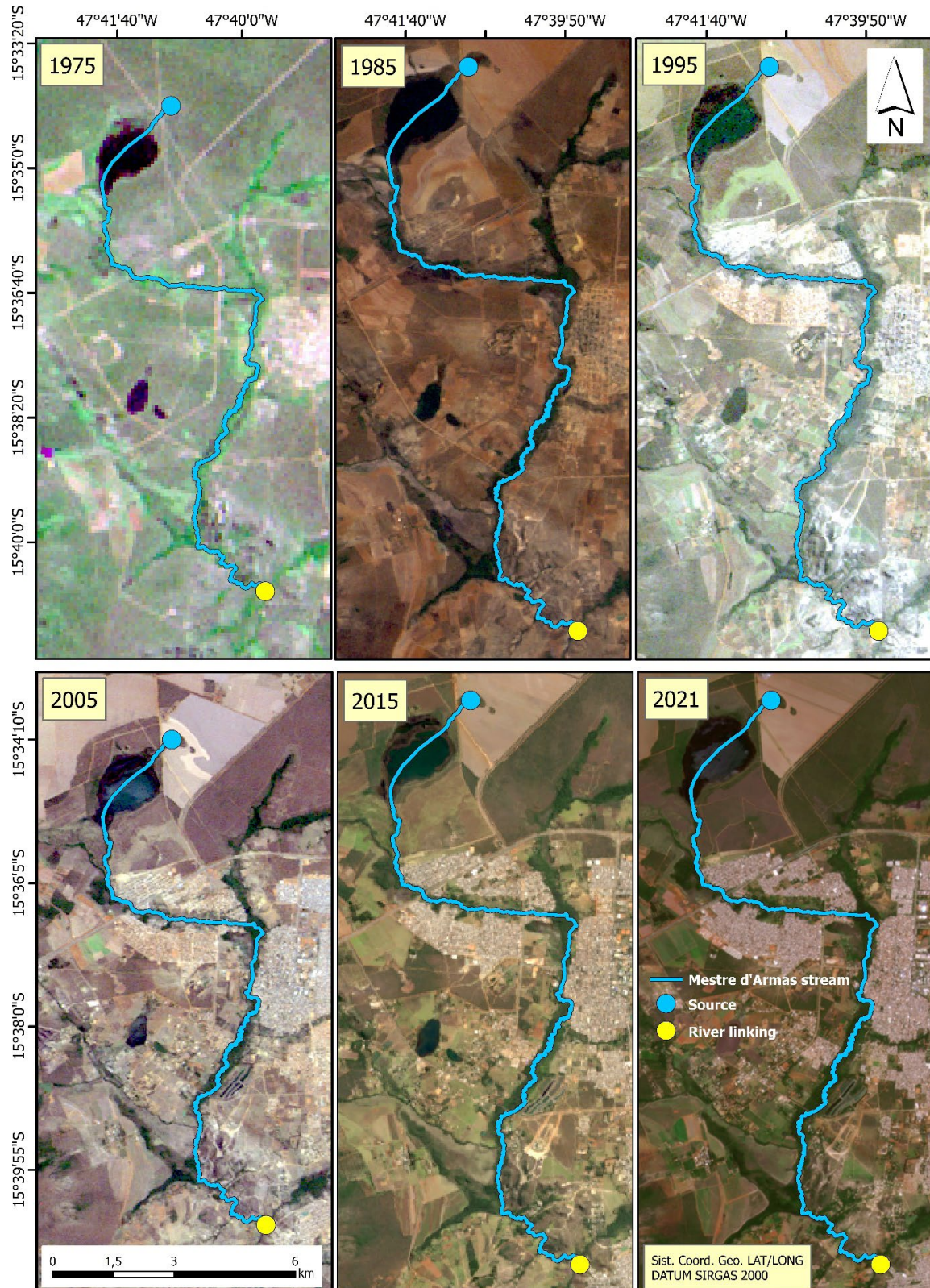
The estimation of landscape metrics in the USBRW for the native vegetation fragments (geofacilities) was performed in shapefile extension, a vector file format, which depicted the native vegetation type (geotopes) existing in the *Cerrado* biome (*Cerrado stricto sensu*, Parque de Cerrado, Palmeiral, and Vereda)¹ identified by unsupervised classification algorithm, using the ArcMap10.5 (ESRI, 2016) program. Images were acquired from the LANDSAT-1 and LANDSAT-8 satellites (Figure 4) with pass dates of June 26, 1975, and September 3, 2020, referring to orbit/point 237/071 and 221/071, respectively.

The USBRW native vegetation fragments (Figure 5) were grouped for 1975 and 2020 using vector maps in area size classes (up to 30 ha; >30 ha to 60 ha; >60 ha to 120 ha; >120 ha to 240 ha; >240 ha to 600 ha; >600 ha to 2,000 ha; >2,000 ha).

Landscape metrics were quantified and specified following the theories described by Volotão (1998), Luz *et al.* (2018) and Silva and Souza (2014). Such metrics included: area (total core area, average fragment area, core area index and edge density), shape (mean perimeter-area ratio and mean shape indicator), and proximity (distance from nearest neighbor given in meters

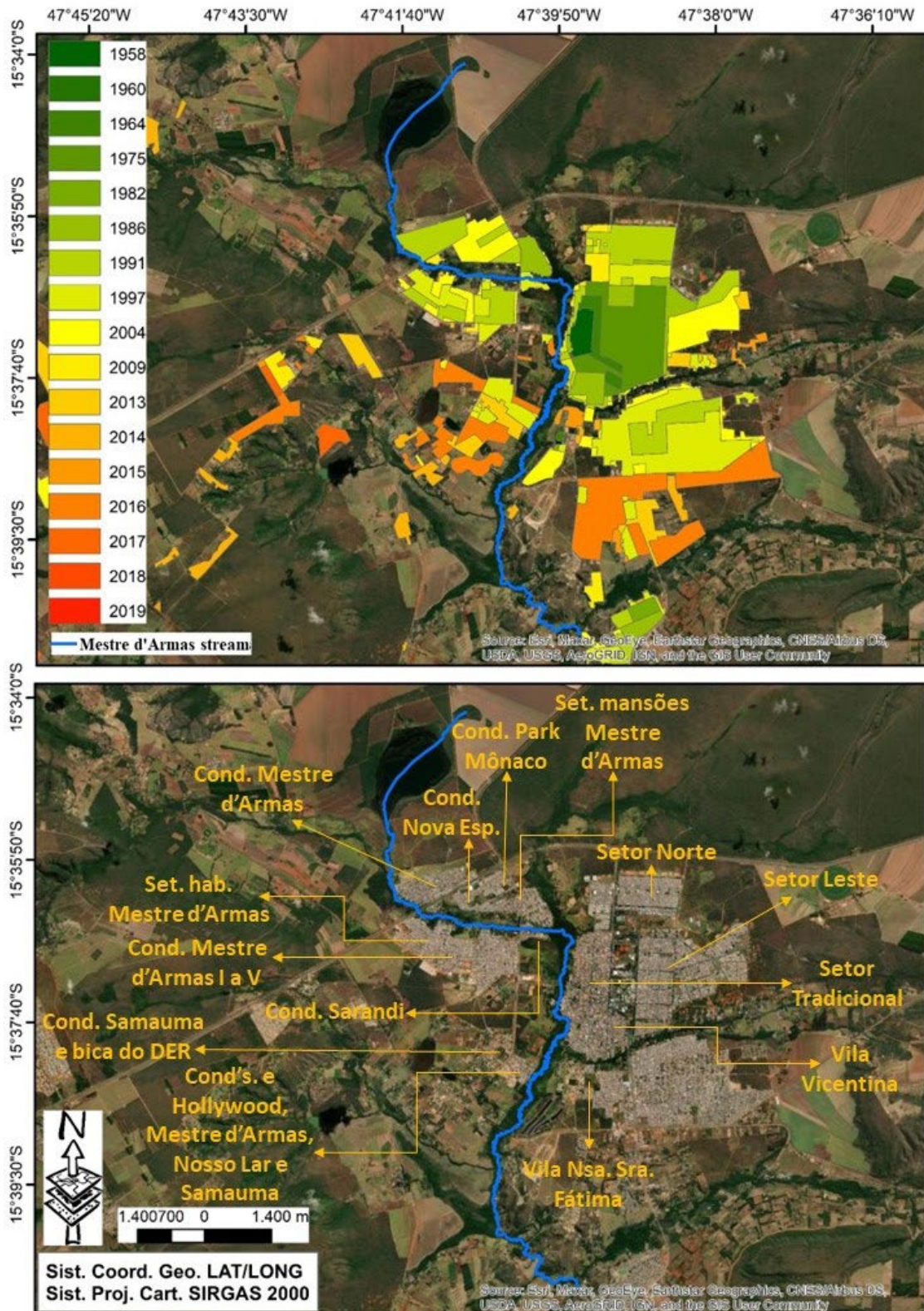
¹ In the areas with grassland formation, Campo Sujo, Campo Limpo, Campo Rupestre, Mata Ciliar, Mata de Galeria, Mata Seca, and Cerradão can be seen.

Figure 2. Images from LANDSAT 1 (1975), 5 (1985 to 2005), and 8 (2015 and 2021) obtained for the month of June referring to the human land use and temporal occupation near the banks of the Mestre d'Armas stream, Planaltina-DF, Brazil.



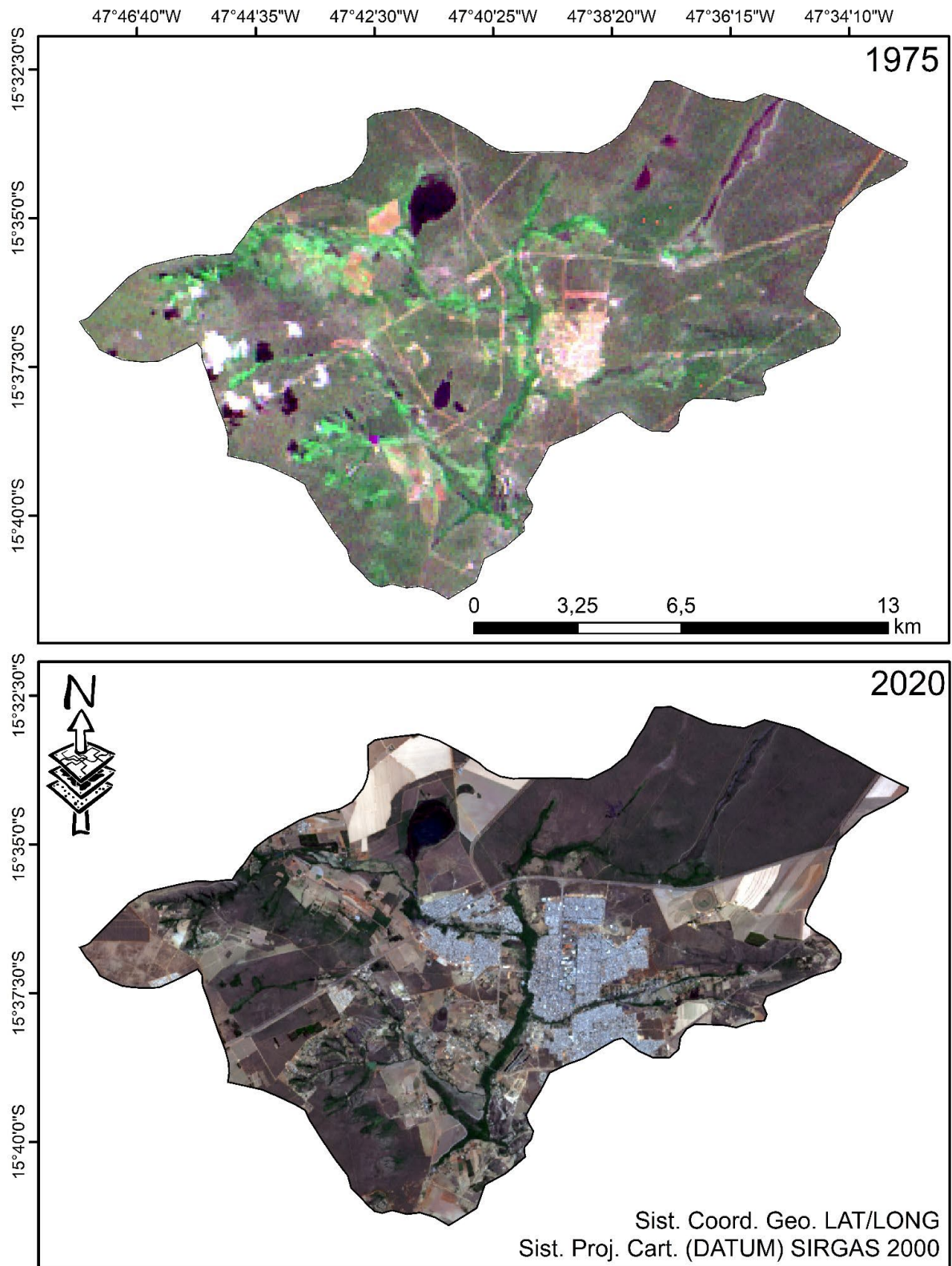
Source: prepared by the authors

Figure 3. Urban evolution from 1958 to 2019 provided by Brazilian Department of Housing and Urban Development (2022), and existing localities in the surroundings of the Mestre d'Armas stream in Planaltina-DF, Brazil.



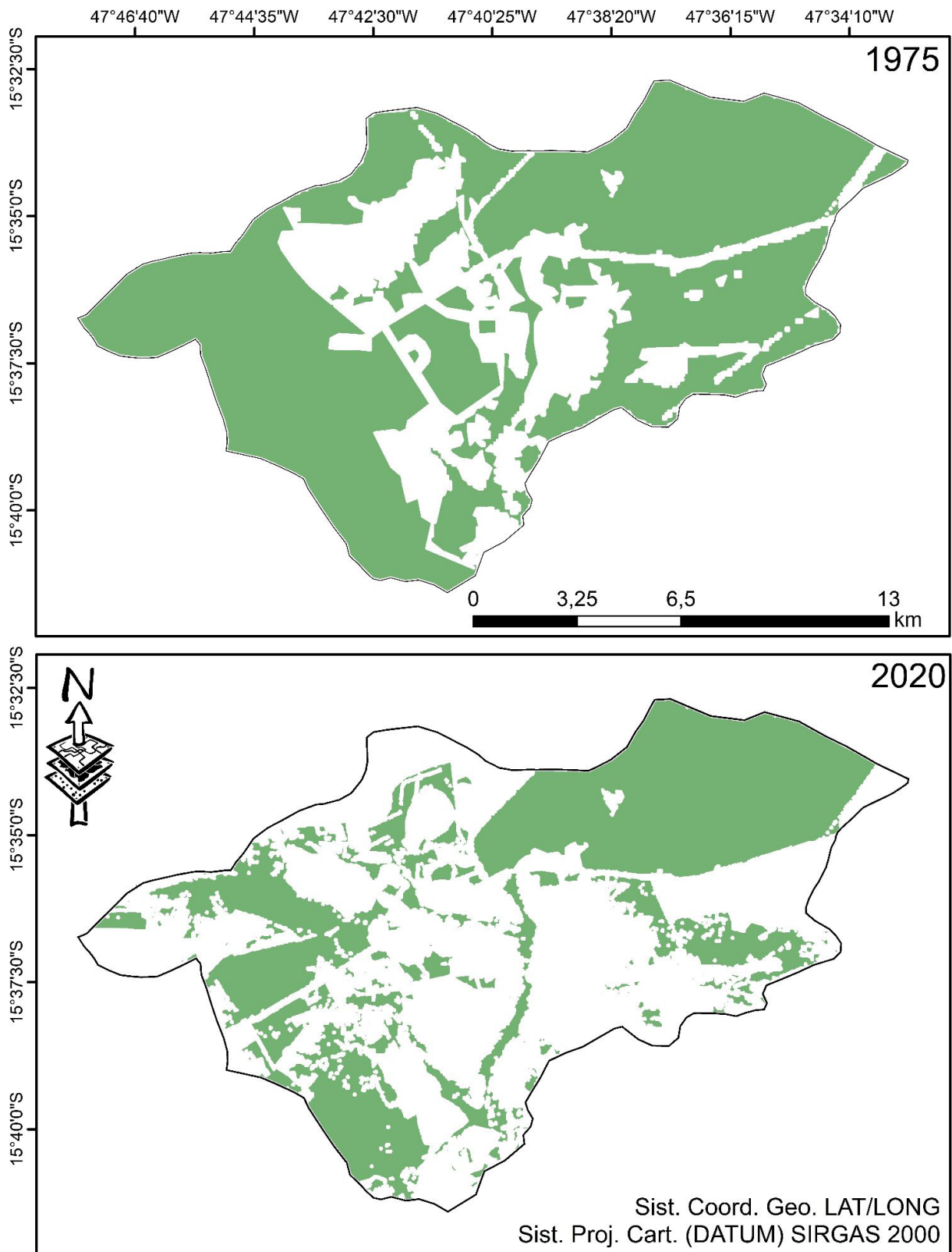
Source: prepared by the authors

Figure 4. Images acquired from the LANDSAT-1 and LANDSAT-8 satellites with pass dates of June 26, 1975, and September 3, 2020, referring to orbit/point 237/071 and 221/071, respectively, Upper São Bartolomeu River Watershed, Federal District, Brazil.



Source: prepared by the authors

Figure 5. Native vegetation fragments representing the vegetation of the *Cerrado* biome for 1975 and 2020 found in the Upper São Bartolomeu River Watershed, Federal District, Brazil.



Source: prepared by the authors

and proximity index). These metrics were calculated in the ArcMap 10.5 program using the Vector-based Landscape Analysis tools Extension (V-LATE) by LARG (2005).

Results and discussion

In 1975, fragments of native vegetation occupied 71.08 % of the total area of the USBRW (Figure 5). In 2020, this value was 40.70 %. Thus, the matrix of the landscape mosaic at USBRW was formed predominantly by fragments of native vegetation followed by human activity areas, which can be urban occupations, as well as agricultural and/or livestock activities. In 2013, Oliveira (2013) estimated 47 % of vegetative and native cover present in the landscape of the USBRW.

The fragmentation of a given unit of the environment, intensified by human activity due to the demand for land for agricultural and livestock purposes and the expansion of urban centers, for example, promotes considerable changes in the natural landscape, turning it into a mosaic (DAMAME, LONGO and OLIVEIRA, 2019; MASSOLI, STATELLA and SANTOS, 2016). The figures shown in the previous paragraph suggests not only a reduction in native vegetation cover in the USBRW from 1975 to 2020 but, above all, that this reduction is caused by the continuous parceling of land that also reduces the size of these fragments.

The continuous fragmentation of native vegetation also culminates in local extinctions and changes in species composition and abundance. Moreover, reducing the size of remnants of native vegetation hinders the maintenance of biodiversity (DRINNAN, 2005; GARCIA *et al.*, 2018), as well as the conservation of soil and water, favoring soil erosion and reducing water infiltration to supply underground and surface springs (DAMAME *et al.*, 2015). However, in scenarios of high landscape fragmentation with a greater number of small native vegetation

remnants, further attention is necessary, especially regarding their conservation as they serve as an ecological connection between areas and are at greater risk of being suppressed over the years (PIROVANI *et al.*, 2014).

According to the metric values in Table 1, a considerable increase in NF (number of fragments) and MPAR (mean perimeter-area ratio) can be seen for fragments of native vegetation smaller than 30 ha from 1975 to 2020. MPAR values below 1.00 suggest greater protection of the fragment due to the weaker relation between its internal and external areas. The MSI (mean shape index) values from 1975 to 2020 (Table 1) are far from 1.0 for all area size classes. This index is related to the edge effect (VOLOTÃO, 1998) and thus values far from 1.0 suggest a distance from the standard perfect circle shape indicated for the conservation of fragments (FORMAN, 1995). They present more jagged shapes that are associated with the fragment greater susceptibility to the edge effect (MCGARIGAL and MARKS, 1995).

Regarding the edge effect discussed in this study, it is necessary to clarify, since this work involves both forest and non-forest vegetation types, that edge effect impacts on forest vegetation types are well known and used in scientific discussions. In other types of vegetation, the edge effect is still a subject under discussion, although its interference is recognized.

According to the MPAR and MSI metrics, there is evidence that the continuous (45 years) human activity for land use and occupation in the USBRW area promotes the parceling of land into increasingly smaller portions, as well as decreasing the size of native vegetation fragments and increasing their quantity, making them less protected (by reducing their size) and more susceptible to the edge effect.

TCA (total core area), MFS (mean fragment area), and ED (edge density) values increased

Table 1. Metrics of size¹, shape², and proximity³ measuring the fragments of forest and *Cerrado* vegetation in the Upper São Bartolomeu River Watershed, Federal District, Brazil.

Area Size Class	NF	TCA1	MFS1	CAI1	ED1	MPAR2	MSI2	PROX3	DNN3
Year 1975									
Up to 30 ha	13	123.21	9.48	44.14	139.61	0.178	1.39	1.63	994.11
>30 to 60 ha	3	145.69	48.56	68.69	68.08	0.007	1.34	0.00	7,274.03
>60 to 120 ha	1	90.72	90.72	68.97	72.07	0.007	1.94	0.00	0.00
>120 to 240 ha	1	136.05	136.05	76.54	57.55	0.006	1.89	0.00	0.00
>240 to 600 ha	1	562.19	562.19	89.98	20.42	0.002	1.37	0.00	0.00
>600 to 2,000 ha	1	710.26	710.26	71.01	61.59	0.006	4.63	0.00	0.00
>2,000 ha	3	13,286.47	4,428.82	93.11	14.09	0.002	2.75	8,957.95	110.78
Year 2020									
Up to 30 ha	193	437.92	2.27	25.62	254.39	1.318	1.62	12.37	97.76
>30 to 60 ha	7	313.00	44.71	48.26	130.27	0.013	2.46	96.18	196.86
>60 to 120 ha	3	212.30	70.77	54.88	100.12	0.010	2.36	0.00	202.67
>120 to 240 ha	3	495.86	165.29	56.22	101.28	0.010	3.67	0.00	205.33
>240 to 600 ha	2	648.98	324.49	60.64	89.69	0.009	4.65	0.00	207.50
>600 to 2,000 ha	2	2,324.04	1,162.02	80.40	43.22	0.004	4.14	6.69	209.50
>2,000 ha	1	4,188.45	4,188.45	95.51	9.34	0.001	1.71	0.00	0.00

NF: number of fragments; TCA: total core area (ha) in each area size class obtained by applying a negative 50.00 m buffer from the boundaries of the vegetation fragments; MFS: mean fragment area (ha) in each area size class; CAI: core area index, being the average percentage of central area of each vegetation fragment for each area size class; ED: mean edge density in each area size class, expressed in $m\ ha^{-1}$; MPAR: mean perimeter-area ratio ($m\ m^{-2}$); MSI: mean shape indicator, being the sum of the perimeter of all the areas divided by the square of the area of the use class; PROX: Proximity Index that assigns a connectivity value to each fragment of interest, considering the proximity (distance) and size (area) of all the fragments whose edges fall within a search radius (2,000 m), determined from the fragment of interest; DNN: distance from nearest neighbor given in meters (m).

from 1975 to 2021 for each size class of fragment of native vegetation, up to the >240 to 600 ha class (Table 1), with a reduction in CAI (core area index) due to the lower participation of central areas in the fragments. This finding was expected. According to Fernandes and Fernandes (2017), fragments with a larger area also present a larger central area, which suggests greater preservation of the fragment's interior. Silva *et al.* (2019) observed a direct relation (positive correlation) between the central area and the total area of forest fragments. However, the metric behavior of the data for TCA, MFS, ED, and IAC did not occur in the area size classes >600 to 2,000 ha and >2,000 ha during the study period since there was an increase and decrease in plant fragments in these classes, respectively.

In any case, from the facts shown regarding the area metric, the consequences of the continuous parceling of land into increasingly smaller portions of the USBRW area stand out once again, as explained above.

There are differences between edge areas and those within vegetation fragments in terms of species diversity (OLIVEIRA *et al.*, 2015). Andrade *et al.* (2020) associated the high length of the edges with the high degree of fragmentation of the arboreal vegetation and stated that increasing edges favor imbalances in the ecological relations between species of fauna and flora, mainly due to the possibility of an increase in air temperature and the deficit of vapor pressure inside the vegetation fragment.

Therefore, it is noteworthy that the edge of the fragment is an indicator of its fragility and, therefore, knowing some metric indices of it can allow hypothesizing about the environmental quality of the natural plant remnants.

Moreover, note that the number and size of fragments in a landscape mosaic, together with other landscape metric values, are efficient in establishing the degree of fragility of plant remnants (FENGLER *et al.*, 2015).

According to Table 1, in 1975, native vegetation fragments were only connected among those with an area greater than 2,000 ha, with a high value of both proximity index and distance from the nearest neighbor, suggesting a “moderate” degree of isolation on the scale of Almeida (2021), developed for the Atlantic Forest biome: low – distance up to 60 m from edge to edge of the area; moderate – distance up to 120 m; high – distance up to 200 m; and very high – distance above 200 m.

The remnants of native vegetation fragments are important to improve the quality of life in urban areas in the process of expansion or consolidation. Thus, these fragments, together with environmental conservation units, parks, and/or stations created for the conservation of flora and fauna, when in a spatial pattern of isolation, do not guarantee these regions an ecologically efficient landscape mosaic (SILVA *et al.*, 2019). Therefore, it is necessary to plan the connectivity of the remnants of native vegetation fragments during the process of expansion of urban spaces to allow the biological flow of plant and animal species.

Conclusion

It was found that continuous human activity in land use and occupation has reduced the USBRW area of native vegetation by 42.7 % in 45 years, with land being divided into increasingly smaller portions. As a result, the size of native

vegetation fragments has been reduced, making them less protected due to their smaller size, more susceptible to the edge effect, and with a lower degree of connection between them.

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