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Fragmentation patterns of forest and cerrado vegetation in northeastern Mato Grosso

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Abstract

This study sought to evaluate the fragmentation patterns of the forest and cerrado vegetation in the northeast of the state of Mato Grosso. The investigation used landscape metrics after extracting those fragments from the shapefile of soil use and occupation of the state of Mato Grosso and their application on the file of a negative buffer of 50.00. Forest and cerrado fragments were grouped into size classes in hectares. The quantified and specialized landscape metrics were area (mean perimeter/area ratio, core areas index, edge density), shape (mean shape indicator) and proximity (distance from the nearest neighbor in meters and the proximity index). The northeast of the state of Mato Grosso is occupied by 34.81% and 27.22% of the forest and cerrado fragments, respectively. The sum of the areas of the larger area size classes (classes >10,000 to 30,000 ha and >30,000 ha) is higher for forest fragments, which is indicative of the more expressive presence of the Amazon biome in that region and evidence of a more significant anthropic pressure on the fragmentation of the cerrado. In the northeast of the state of Mato Grosso, larger areas of forest and cerrado fragments are more protected than the smaller areas, as they have a smaller internal/external area ratio, higher percentage of central area, and less participatory border in relation to the total area.

Keywords: Landscape ecology. Heterogeneous mosaic. Land use and coverage.

Introduction

In a broader concept, the landscape is defined as a heterogeneous mosaic formed by interactive units, with this heterogeneity existing by at least one factor, according to an observer and at a specific scale of observation (METZGER, 2001). Also according to the author, the set of interactive units of a landscape is usually given by ecosystems, vegetation cover units, or land use and occupation, and the choice in each of these three ways of representing the landscape units is made arbitrarily by the observer.

Among the main purposes of the study of landscapes, from the landscape ecology approach, is the use and planning of the territory through the interactive understanding between society and nature. In landscape ecology, the basic notion of landscape is the spatiality and heterogeneity of the space where man acts. Thus, it considers the development and dynamics of spatial heterogeneity. Given that the earth's surface is not homogeneous, it presents a diversity of formations (landscapes) generated by natural processes and shaped by social, economic, political, and cultural processes (COSTA, 2020). Therefore, the landscape, under the spatial and heterogeneous aspect, encompasses geomorphological, natural, and cultural covering factors (AZEVEDO *et al.*, 2021).

Two approaches permeate the ecology of landscapes: human ecology of landscapes (geographical approach), centered on the interactions of human beings with their environment, in which the landscape is the product of the interaction of society with nature (NAVEH; LIEBERMAN, 1994), and spatial ecology of landscapes (ecological approach), concerned with understanding the consequences of the spatial pattern (how heterogeneity is spatially expressed) on ecological processes (FORMAN; GORDON, 1986; TURNER, 1989; WIENS *et al*., 1993).

The boundaries of interactive landscape units are defined by three factors: abiotic environment (landscapes, soil types, hydro-geomorphological dynamics, and climatic parameters, in particular), natural disturbances (fire, tornadoes, floods, volcanic eruptions, and frost, for example) and human disturbances (fragmentation and alteration of habitats, deforestation, creation of reservoirs, and implementation of roads, among others). When interrelated, these three factors create differentiated patterns (interactive sets) in the geographic space (METZGER, 2001).

The observation of the degree of differentiation existing in a given landscape is directly linked to the scale of observation, as processes and patterns within the landscape vary in relation to their effects or their importance at different spatial and temporal scales (ODUM; BARRET, 2008). The observation scales that are related to the spatial dimension can be local (smaller areas of landscapes in which the results of the internal self-development of geosystems are considered), regional (landscapes of large territorial extensions distinguished by morphological, edaphic, and functional characteristics) and planetary (RODRIGUEZ *et al*., 2007).

The basic method of landscape analysis in landscape ecology provides for the understanding of the physiognomic and structural characteristics within the various analytical scales, which implies the initial knowledge of the landscape organization through its structural analysis, i.e., of how its pattern and spatial organization occur, in addition to the relationships between the components that shape it (RODRIGUEZ *et al*., 2007).

According to Casimiro (2009), the landscape structure includes the matrix (coverage with greater connectivity and dominance in the functioning of the landscape and which influences the other landscape units), patches or fragments (relatively homogeneous areas that differ from the others around them and vary in size, shape, type, and edge characteristics, influencing ecological relationships) and corridors (linear landscape structures with different characteristics from the patches and which have the function of connecting two or more previously joined fragments).

The fragmentation of native vegetation portions or the rupture of landscape units weakens the ecosystems, as they isolate the plants from animal species that inhabit there, reducing the habitats areas and causing extinctions, accentuating the edge effect in the areas of contact between the anthropized matrix and the remaining native vegetation (ETTO *et al*., 2013; HENTZ *et al*.,2015; ANDRADE *et al*., 2020). Therefore, research on the landscape structure and the spatial pattern of the fragments is necessary for environmental conservation strategies.

The patterns of fragmentation of landscape elements can be analyzed by quantifying and spatializing the results obtained with the landscape metric, producing information regarding the quantity and quality of the patches (SILVA; SOUZA, 2014). The survey of patterns of landscape fragments to understand the effects of fragmentation of native vegetation in watersheds, municipalities, and conservation units, i.e., at regional scales, can be carried out quickly and relatively inexpensively through geographic information systems and geoprocessing and remote sensing techniques (CALEGARI *et al*., 2010; AMORIM *et al*., 2021).

The fragmentation of native vegetation into smaller portions in the state of Mato Grosso stems from the continuous anthropic action of use and occupation of the state's lands, triggered by a complex and governmental colonization process attached to the project called "A Marcha para Oeste" [The march to the West], which proposed land occupation from the Center-West to the Amazon region, with an attempt of agrarian reform (LAMERA; FIGUEIREDO, 2008; CALONGA, 2015; ALMEIDA, 2021).

Currently, the northeast region of Mato Grosso is the second largest producer of soybeans, according to the 8ª Estimativa da Safra de Soja – 2020/2021 [8th estimate of the Soy Crop – 2020/2021[by the Mato Grosso Institute of Agricultural Economics (Instituto Mato-Grossense de Economia Agropecuária - IMEA), consolidating its position among the main soya producing regions in the state. This is evidenced by the continuous increases in the soybean cultivated area, either by the replacement of degraded pastures or the opening of new areas based on the fragmentation and suppression of native vegetation in the northeast of Mato Grosso.

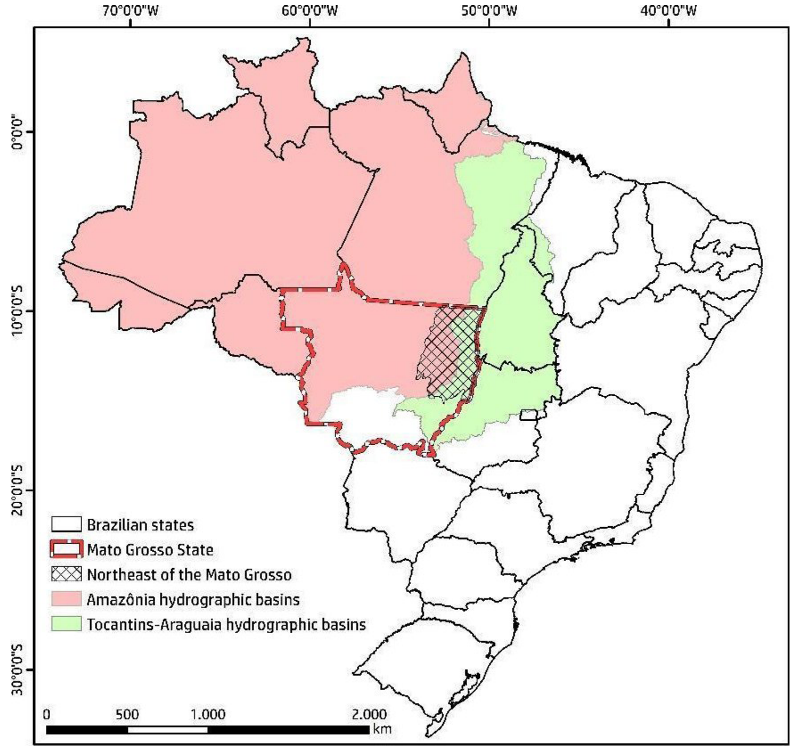
Previous or contemporary anthropic processes of land use and occupation in the state of Mato Grosso promoted the fragmentation and suppression of native vegetation. Thus, this work was carried out to evaluate patterns of fragmentation of forest and cerrado vegetation in the northeast of that state.

Material and methods

The present work was carried out in the northeast region of the state of Mato Grosso, Brazil (FIGURE 1), located between the coordinates 13°45’52.48’’S, 54°06’9.49’’W and 09°50’53.67’’S, 50°14’52.8’’W. This region has an area of 170,093.58 km^2 and is included in the Amazon and Tocantins-Araguaia hydrographic basins. Therefore, the analysis of patterns of native vegetation fragments took place at a regional scale through a structural approach to the pattern and spatial organization of the landscape.

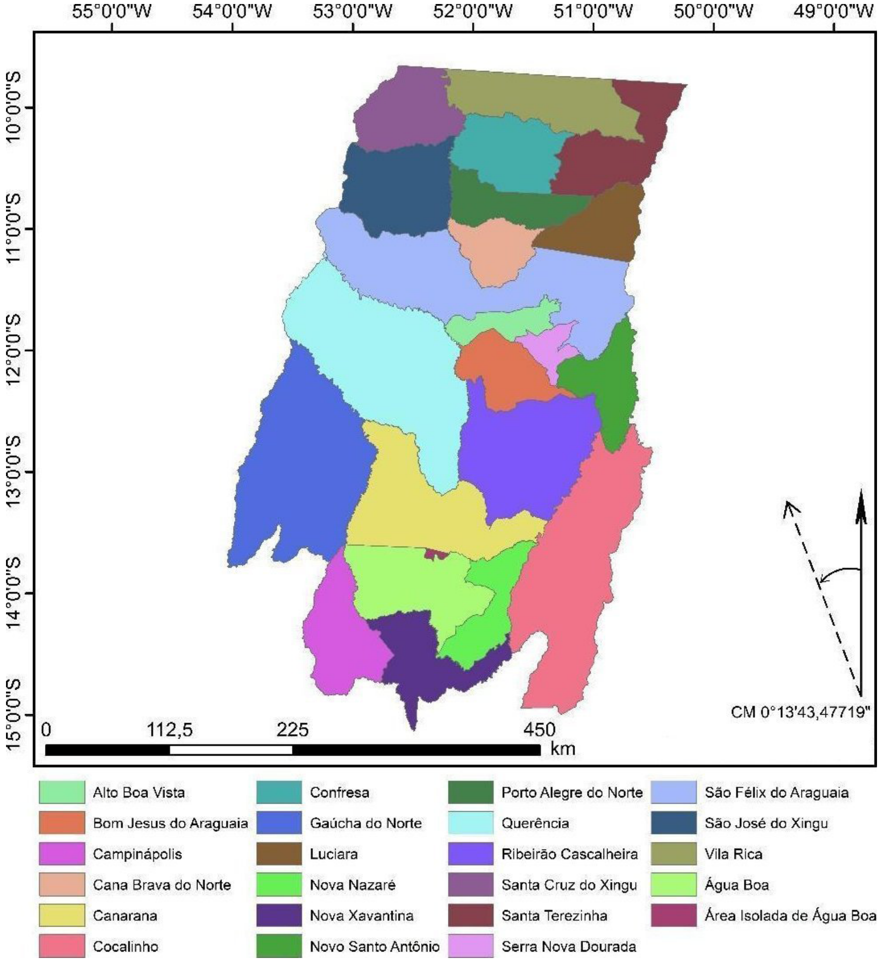
The estimation of landscape metrics in the northeast of Mato Grosso referring to the fragments of forest and cerrado vegetation cover contained in the Amazon and Cerrado biomes was carried out in a vectorized file in the extension shapefile referring to land use and occupation in Mato Grosso (IBGE, 2018), after applying a negative buffer of 50.00 m.

Figure 1 - Location of the northeast region of Mato Grosso, Brazil.



Source: Prepared by the authors (2022)

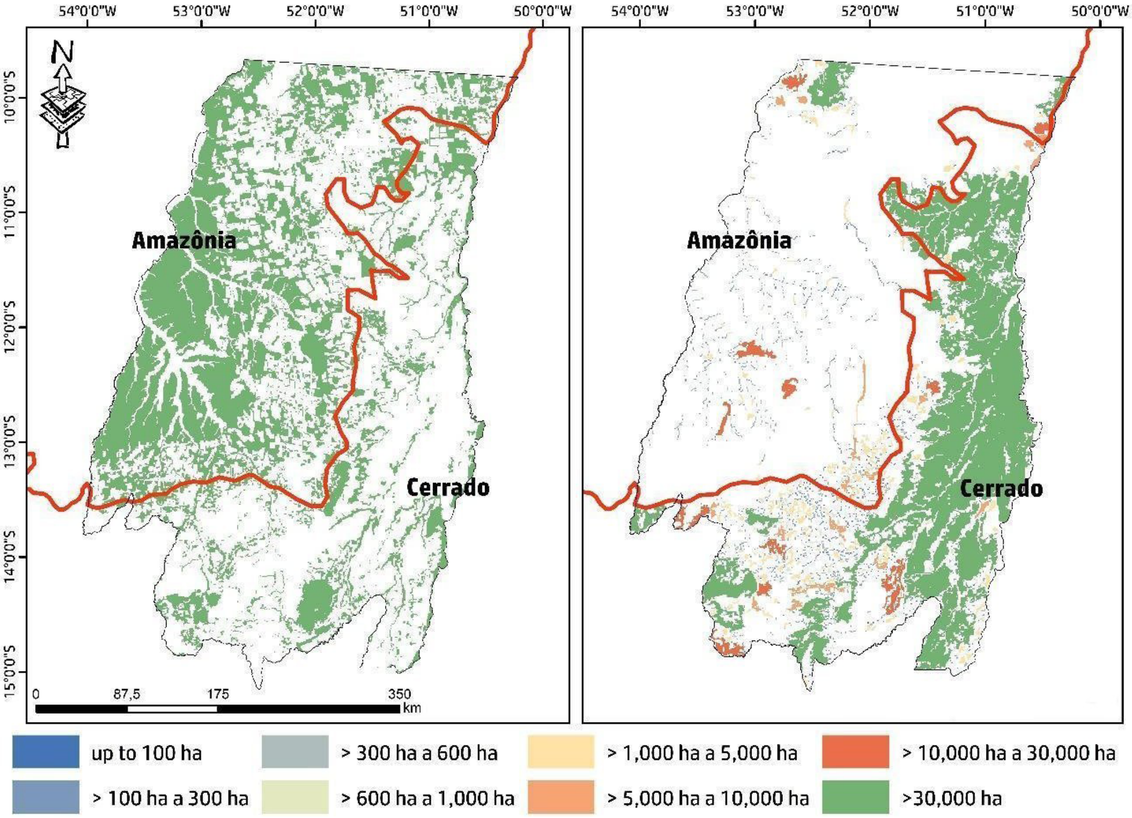
Figure 2 - Municipalities of the northeast region of Mato Grosso, Brazil.



Source: Prepared by the authors (2022)

Vegetative fragments of forest and cerrado (FIGURE 3) were grouped into area size classes (up to 100.00 ha; >100.00 ha to 300.00 ha; >300.00 ha to 600.00 ha; >600.00 ha to 1,000.00 ha; >1,000.00 ha to 5,000.00 ha; >5,000.00 ha to 10,000.00 ha; >10,000.00 ha to 30,000.00 ha; >30,000 ha). Landscape metrics were quantified and specified according to theories described in Volotão (1998), Luz *et al*. (2018), and Silva and Souza (2014), namely: area, such as the core areas index (CAI), being the average percentage of the central area of each vegetative fragment for each area size class and edge density (ED) expressed as m ha^{-1}; form, as the mean perimeter/area ratio (MPAR) expressed in mm^{-2} and mean shape indicator (MSI), being the mean perimeter/area ratio of all patches divided by the square of the class area; proximity: distance from the nearest neighbor (MDVP) given in meters, where, on the Almeida scale (2008), there is low isolation (distance up to 60.00 m from edge to edge of the spot), medium isolation (distance up to 120.00 m), high isolation (distance up to 200.00 m) and very high insolation (distance above 200.00 m) and the proximity index (PROX_2000), which assigns a connectivity value to each fragment of interest, considering the proximity (distance) and size (area) of all fragments whose edges are within a search radius (2,000 m), determined from the fragment of interest. The calculation of landscape metrics was performed by the computer application ArcMap 10.5 through the V-LATE extension.

Figure 3 – Forest (left image) and cerrado (right image) vegetation fragments existing in the northeast of the state of Mato Grosso, classified based on their areas in hectares (ha). On the left of the red line, there is the Amazon biome, and on the right, the Cerrado biome.



Source: Prepared by the authors (2022)

Results and discussion

According to the values described in Table 1, 34.81% and 27.22% of the forest and cerrado fragments occupy the territory of northeast Mato Grosso, respectively. The sum of the areas of the larger area size classes (classes >10,000 to 30,000 ha and >30,000 ha) is higher for forest fragments, which suggests the more expressive presence of the Amazon biome in that region and evidence of higher anthropic pressure on the fragmentation of the cerrado.

In Table 2, the MSI values are increasing from the smallest to the largest area size class in the forest and cerrado fragments. The main aspect of the shape is the relationship with the edge effect (VOLATÃO, 1998). Thus, and according to that author, the MSI values further away and greater than 1.0 suggest distance from the perfect square shape (standard) of the vegetative fragment, related, therefore, to smaller vegetative fragments and with different formats depending on the " cutouts". The change in the shape of the fragments (vegetative) diverges, therefore, from the perfect circle pattern indicated for its conservation (FORMAN, 1995), making it more susceptible to the edge effect (MCGARIGAL *et al*., 2002).

The MPAR values are lower than 1.0 for all classes of area size, with the behavior of such a characteristic decreasing in the sense of classes with smaller area sizes for those with larger area sizes. MPAR values below 1.00 are related to greater protection of the vegetative fragment and the lower they are, the greater the protection of such fragments because there is a lower relationship between its internal area and the external area (SILVA; SOUZA, 2014). Still, considering the direction from the smallest to the

Table 1 - Total sum of areas (hectares) by size classes of forest and cerrado vegetation fragments in the northeast* of Mato Grosso, Brazil.

Classes	Forest	Cerrado
up to 100 ha	96,697.03	104,024.95
>100 to 300 ha	133,409.97	99,799.86
>300 to 600 ha	122,561.71	80,342.82
>600 to 1,000 ha	124,026.02	68,589.72
>1,000 to 5,000 ha	488,327.39	220,574.65
>5,000 to 10,000 ha	285,162.65	151,421.82
>10,000 to 30,000 ha	548,526.55	238,402.94
>30,000 ha	4,122,774.99	3,666,182.64
SUM	**5,921,486.31**	**4,629,339.40**

*The estimated land area of northeast Mato Grosso was 17,009,358.21 hectares.

Source: Prepared by the authors (2022)

Table 2 – Shape metrics[1], size[2] and proximity[3] for the evaluation of forest and cerrado vegetation fragments in the northeast of the state of Mato Grosso, Brazil.

Classes	MPAR[1]	MSI[1]	CAI[2]	ED[2]	PROX_2000[3]	MDVP[3]
up to 100 ha	0.011	1.16	80.45	41.39	2.01	3,523.16
>100 to 300 ha	0.003	1.24	85.99	28.91	0.73	4,973.92
>300 to 600 ha	0.002	1.45	88.45	23.56	2.33	7,874.84
>600 to 1,000 ha	0.002	1.58	90.37	19.53	0.95	10,177.26
>1,000 to 5,000 ha	0.002	1.90	92.80	14.53	5.90	5,935.11
>5,000 to 10,000 ha	0.001	2.34	95.08	9.90	6.62	20,646.35
>10,000 to 30,000 ha	0.001	2.87	96.06	7.92	11.37	19,921.31
>30,000 ha	0.001	5.80	97.68	4.65	2,521.19	12,752.10
MEAN	**0.003**	**2.29**	**90.86**	**18.78**	**318.89**	**10,725.51**
up to 100 ha	0.018	1.17	80.59	41.05	1.19	2,574.98
>100 to 300 ha	0.003	1.23	85.78	29.37	0.51	5,197.82
>300 to 600 ha	0.002	1.42	88.30	23.89	0.56	9,782.71
>600 to 1,000 ha	0.002	1.59	90.21	19.86	0.24	15,236.29
>1,000 to 5,000 ha	0.002	1.87	92.80	14.53	6.94	8,859.63
>5,000 to 10,000 ha	0.001	2.53	94.47	11.11	0.00	17,969.01
>10,000 to 30,000 ha	0.001	3.07	95.92	8.18	0.00	58,088.87
>30,000 ha	0.001	6.01	98.03	3.95	143.20	22,416.63
MEAN	**0.004**	**2.36**	**90.76**	**18.99**	**19.08**	**17,515.74**

MPAR: mean perimeter/area ratio (mm^{-2}); **CAI**: core area index, being the mean percentage of the core area of each vegetative fragment for each area size class; **ED**: edge density, expressed m ha^{-1}; **MSI**: mean shape indicator, being the mean perimeter/area ratio of all patches divided by the square of the class area; **MDVP**: the distance from the nearest neighbor given in meters (m); **PROX_2000**: proximity index, which assigns a connectivity value to each fragment of interest, considering the proximity (distance) and size (area) of all fragments whose edges are within a search radius (2,000 m), determined from the fragment of interest.

Source: Prepared by the authors (2022)

largest area size class, an increase in CAI values was observed, expressing higher percentage values of the core areas in these fragments and a reduction of ED values (greater participation of the core area in the fragment).

About PROX_2000, a relatively high value is observed among all area size classes and area size class >30,000 ha for the forest and cerrado fragments, i.e., a higher degree of connectivity for the latter (class) (TABLE 2). However, such connectivity is merely comparative since based on the values of MDVP for all area size classes, a "very high" degree of isolation was established on the Almeida scale (2008): low isolation - distance up to 60.00 m from edge to edge of the patch; medium – distance up to 120.00 m; high – distance up to 200.00 m; very high – distance above 200.00 m.

In the northeast of the state of Mato Grosso, the larger areas of forest and cerrado fragments are more protected than the smaller areas, as they have a smaller internal/external area ratio, a higher percentage of core area and less participatory border in relation to the total area. Those facts reveal how relevant it is to preserve large "unopened" areas (not deforested), falling on the conservation of native vegetation. Smaller areas in the northeastern region of that state are more susceptible to the edge effect because they have more jagged shapes and lower connectivity with a "very high" degree of isolation. It is noteworthy that the isolation of fragments of natural vegetation promotes the reduction of forest species contained in them since they are subject to the effects of the small size of the fragment – and the effects of its edges – and the loss of habitat (*MORAES et al*., 2015).

Researching landscape metrics in the Amazon from a temporal perspective, Pereira *et al*. (2001) verified increased edge density values, passing from 3.00 m ha^{-1} to 25.00 m^{ha-1} between 1973 and 1997 in forest fragments, which implies more significant degradation of that environment. There was also an increase in the shape index (5 to 30) for the period mentioned of vegetative fragment, showing an increase in the complexity of the shapes of the patches. Finally, the authors above attributed to the facts described a significant decrease in the percentage of the core area of the forest fragments.

Andrade *et al*. (2020) associated the high length of the edges with the high degree of fragmentation of the arboreal vegetation and found a shape index of the fragments of 1.56, suggesting more irregular shapes of fragments, reinforcing that the increase of edges favors imbalances in the ecological relationships between species of fauna and flora, mainly due to the possibility of rising air temperature and vapor pressure deficit inside the plant fragment. The connectivity of the fragments of arboreal vegetation found by the authors mentioned was 0.40, i.e., low, bringing isolation between fragments and difficulty in moving specific species, suggesting the implementation of ecological corridors.

Fernandes *et al*. (2017) found high edge density values for native vegetation fragments (94.50 m ha^{-1}) and fragments with a low mean area value. In their study, the core area index of native forest was 0.8 and, therefore, considered very low due to the significant edge effect. Furthermore, they found that the fragments of native vegetation have good connectivity (proximity index 775.50) and a low distance from the nearest neighbor (29.60 m), which allows better locomotion of wild fauna between the fragments and a greater flow of pollen and seeds.

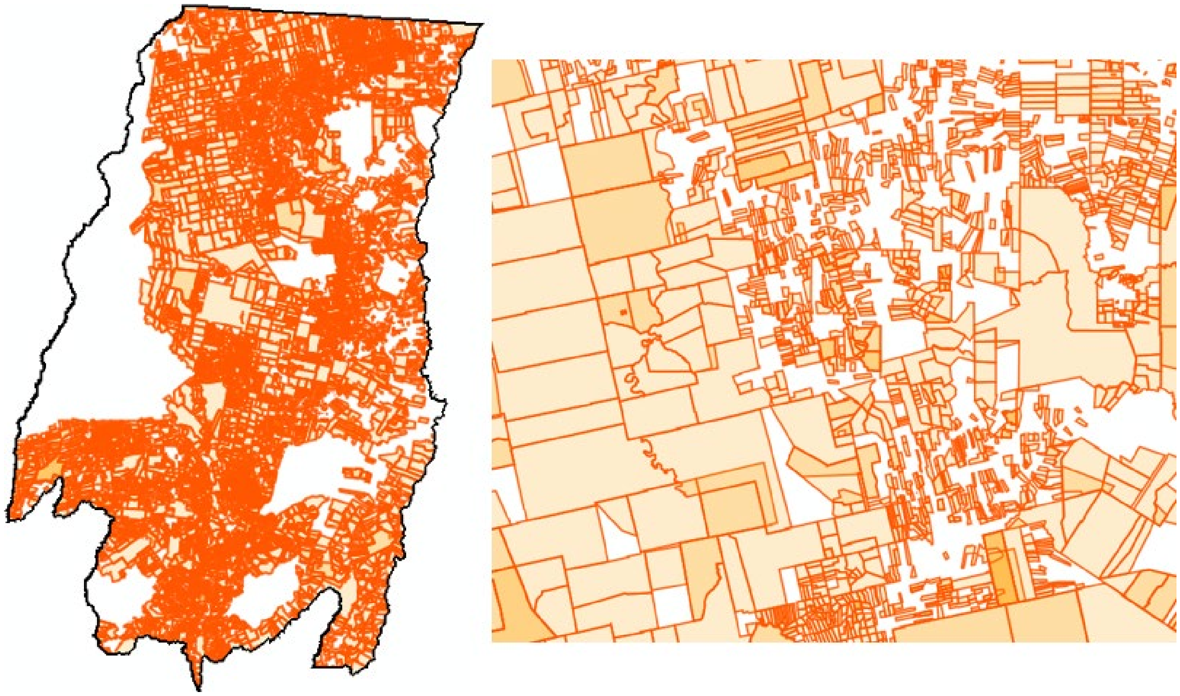
The "field scenario" in visits to the northeast of Mato Grosso reveals, among other countless natural beauties, long federal and state highways, paved or not ("estradões"), and countless unpaved roads through rural areas. Those transportation routes are the product of a long and complex process of colonization of the lands of Mato Grosso that began with the government project

"A Marcha para Oeste" [The March to the West] in 1938, aiming to occupy the land from the Central-West to the Amazon region, in an attempt of agrarian reform (LAMERA; FIGUEIREDO, 2008; CALONGA, 2015; ALMEIDA, 2021). In this scenario, smaller parcels of squatter settlements (which the local inhabitants call *posse*) can be observed, in addition to extensive areas of agriculture with successive soybean and corn crops.

Regarding the fragmentation of areas of native vegetation in the northeast of Mato Grosso, considering the landscape elements observed, the land subdivision comes from the anthropization of the areas for soil use and occupation, that comes from the territorial colonization process and that is associated with smaller portions of land, initiated from the squaring of large regular polygons of native vegetation; of soybean expansion (private colonization) from the year 2009 (BAMPI *et al*., 2017), culminating in the opening of new agricultural areas through the fragmentation of areas of greater surface by the suppression of vegetation in already fragmented areas.

Figure 4 refers to the Rural Environmental Registers requested from the Mato Grosso Environment Department and illustrates the spatial dimension of land subdivision in the northeast of that state, which impacts the fragmentation of natural areas into increasingly smaller portions. In Figure 5, there are examples of a large natural and vegetative fragment "cut out" by means of locomotion, originated from the initial colonization process or part of contemporary anthropic actions of private and continuous colonization, in addition to small natural fragments existing in smaller rural properties, the product of a long process of colonization and land subdivision.

Figure 4 – The polygons represent the Rural Environmental Registry (Cadastros Ambientais Rurais - CAR) under analysis by the Mato Grosso State Environment Department (SEMA-MT) for the northeast region of the state and a "zoom" of a random portion of the image.



Source: Prepared by the authors (2022)

Figure 5 – Large and small natural and vegetative fragment(s) “cut out” by means of locomotion in the northeast of Mato Grosso.

Source: Prepared by the authors (2022)

Conclusions

The northeast of the state of Mato Grosso is occupied by 34.81% and 27.22% of the forest and cerrado fragments, respectively. The sum of the areas of the larger area size classes (classes >10,000 to 30,000 ha and >30,000 ha) is higher for forest fragments, which suggests a more expressive presence of the Amazon biome in that region and evidence of higher anthropic pressure on the fragmentation of the Cerrado.

In the northeast of the state of Mato Grosso, the larger areas of forest and cerrado fragments are more protected than the smaller areas, as they have a smaller internal/external area ratio, a higher percentage of the core area, and less participatory border in relation to the total area. It is noteworthy that landscape metrics in interpreting the evolution of natural vegetative fragmentation should be used carefully, as such metrics are not spatially explicit.

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