RESEARCH PAPER

FOREST FRAGMENTATION AND LANDSCAPE STRUCTURE IN THE GUAMÁ RIVER BASIN, EASTERN AMAZON

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ABSTRACT. The Guamá River basin, in the northeastern state of Pará, eastern Amazon, Brazil, encompasses approximately 1,200,000 hectares. It presents great economic and social importance and is under significantly changes in land use and land cover. The objective of this work was to analyze and characterize the landscape structure of this basin through landscape ecology indexes (density, size, metric variability, shape, core area, proximity indexes, and patch area index). Land use and land cover maps were developed using images from the RapidEye system through supervised digital classification. The vegetation and landscape structure were quantified in patches, classes, and land cover. The forest patches were associated with partial conservation of some areas where production sectors had not yet directly affected, or those from natural regeneration of abandoned areas, mainly pastures. The class vegetated area was the second class most representative of the Guamá River basin covered about 37% considering the total area. The basin landscape presented more than 34,000 vegetated area patches It showing that this class are very fragmented by the presence of a large number of small patches, with this the basin landscape is compromised regarding its ecological integrity, since more than half of its forest patches are in edge environments. The indexes enabled a good joint analysis of the sub-basins of the Guamá River basin, resulting in a more detailed overview of the forest fragmentation process.

KEYWORDS: forest fragmentation, landscape ecology, land use

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INTRODUCTION

The Amazon region has presented increases in anthropogenic actions on natural environments in the last decades, intensifying processes that replace natural vegetation by other land covers. These interventions had converted extensive and continuous areas covered with forests into agriculture, urban areas, and other covers, causing environmental impacts. In many cases, the lack of planning for these processes threatens water sustainability of basins in the Amazon region (Yesuph & Dagnew 2019).

The maintenance of forest cover is essential, since it is responsible for several environmental services, such as soil physical and mechanical protection, climate and soil microbiota regulation, and protection of slopes against erosion, biodiversity, water sources, and groundwater (Mascarenhas et al. 2009). However, agriculture and cattle raising are, among others, the causes that contribute the most to the fragmentation of primary vegetation (Batista et al. 2012). Thus, studies on forest fragmentation have diagnosed factors and applied different indexes that assist in understanding the landscape dynamics and functions and the changes in the landscape caused by anthropogenic actions (Pereira et al. 2015). Studies on dynamics of land use and land cover (LULC), mainly in large areas such as the Amazon region, are based on the analysis of remote sensing data (Klimanova et al. 2017).

The sustainability and development of the Amazon region require deforestation diagnoses and LULC studies, in addition to public policies focused on environmental services, mainly for the recovering of degraded areas, biodiversity conservation, maintenance of water resources, and mitigation of climate changes (Freitas & Freitas 2018). In this context, the Guamá River basin, in northeastern state of Pará, Brazil, encompasses 19 municipalities which together form one of the largest agricultural production centers in Pará (Brazil 2010); it is also important for the historical and economical context of the production dynamics in the Amazon region (Rebello et al. 2011). Thus, the understanding of the landscape structure is needed, grounding the application of methods related to conservation and preservation of the forest cover. Therefore, the objective of this study was to analyze the forest structure of the landscape of the Guamá River basin, considering its sub-basins, and to determine its forest fragmentation patterns based on Landscape Ecology indexes.

MATERIALS AND METHODS

The Guamá River basin (Fig. 1) is between 03ºS and 1º40'S and 48º45'W and 46º45'W; it has approximately 1,200,000 ha, encompassing 19 municipalities of the state of Pará, Brazil: Ananindeua, Acará, Belém, Benevides, Bonito, Bujarú, Capitão Poço, Castanhal, Concórdia do Pará, Garrafão do Norte, Inhangapi, Irituia, Mãe do Rio, Marituba, Ourém, São Domingos do Capim, São Miguel do Guamá, Santa Izabel do Pará, and Santa Luzia do Pará. Together they host approximately 2,700,000 inhabitants (Brazil 2010). For analysis purposes, the Guamá River basin is divided into eight sub-basins: Lower Guamá River (163,960.76 ha), Apeú Creek (74,737.99 ha), Bujarú River (99,019.23 ha), Middle Guamá West Sector (142,137 ha), Middle Guamá East Sector (191,134.49 ha), Mãe do Rio Creek (155,244.52 ha), Sujo River (46,012.53 ha), and Upper Guamá River (331,639.30 ha).

Forty-three orthorectified satellite images of the RapidEye system were selected to cover this area and make the LULC classification. The image selection was based on cloudiness percentages (priority), data quality, data availability, and season. RapidEye images presented 5 m of spatial resolution and five spectral bands positioned at: 440-510 nm (Blue), 520-590 nm (Green), 630-690 nm (Red), 690-730 nm (Red edge), 760-880 nm (Near-infrared). The data of the selected images were: 06/29/2011, 07/28/2011, 08/04/2011, 2011, 10/23/2011, 07/31/2012, 08/02/2012, 09/13/2012, 10/24/2012, 08/01/2013, 09/04/2013, 08/17/2014, and 11/25/2014. The images were acquired from the Geo Catalog of the Brazilian Ministry of the Environment.

The algorithm of maximum likelihood classification (MLC) was used for the supervised classification, and 236 points collected during a fieldwork in 11 municipalities were used for the training. Training samples were selected by delimiting polygons around representative sites for each LULC type. The LULC classes found and their respective keys were:

a) Vegetated area: secondary vegetation in different succession stages, reforestation areas, and native forests;
b) Agriculture: permanent and temporary crops used for subsistence and commercialization;
c) Occupation areas: urban areas, villages, and commercial and industrial areas;
d) Uncovered soil: roads; access routes; paved, unpaved and gravel roads; and mineral extraction areas;
e) Pasture: intensive and extensive husbandry, with animals or abandoned, with predominance of forage species;
f) Water body: rivers, lakes, streams, and creeks.

In addition to these classes, we obtained the categories described as "non-bserved areas", represented by clouds and their shadows, and as "others", such as river banks, stretches of sand, and rocky outcrops, which were considered only as spatial representation classes. The processing included a sample quality accuracy analysis to quantify and evaluate the classification and to obtain a high Kappa index, which is used to evaluate, validate, and report the reliability level of the classification (Pan et al. 2020), and an evaluation in a cross-tabulation (transition) matrix (Twisa & Buchroithner 2019).

The vegetation and landscape structure were quantified in patches, use classes, and land cover (Mcgarigal & Marks 1994; Mcgarigal et al. 2009), considering the following indexes:

a) Density, size, and metric variability: number of patches (NP) - number of patches that comprise each class; patch density (PD) - number of patches per unit of area (100 ha);

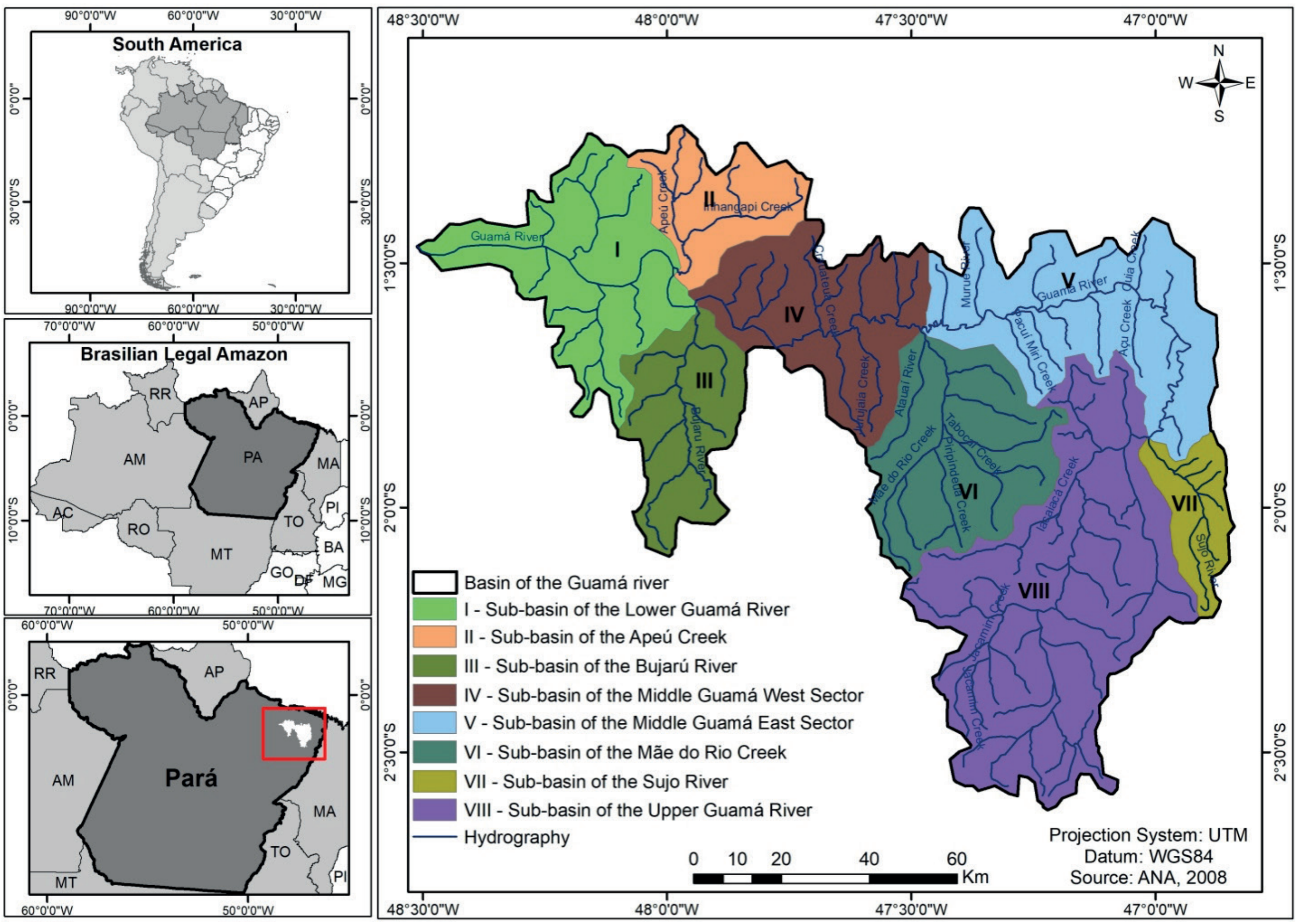

Fig. 1. Guamá River basin: division into sub-basins

mean patch size (MPS) - calculated based on the total area of the class and its respective number of patches; patch size standard deviation (PSSD) – a measure of absolute variation, which shows the variation of a patch size in relation to the mean; and patch size coefficient of variation (PSCV) – a measure of relative variation, which quantifies the variance of the data according to the mean.

b) Shape: mean shape index (MSI) - mean shape of the patches of the assessed class, according to mean perimeter to area ratio of their patches, compared to a standard shape; area-weighted mean shape index (AWMSI) - calculated similarly to the mean shape index; fractal dimension (FRAC) – the shape complexity of the patches that comprise the analyzed class; it varies from 1 (spots with simpler and more regular shapes) to 2 (spots with more complex shapes).

c) Core area: number of core areas (NCA) - number of patches that have a core area after the removal of the edge effect for each class; total core area (TCA) - sum of all core areas found; mean total core area (MTCA) - total core area divided by the number of patches that have core areas; total core area index (TCAI) - percentage of the class occupied with the core area after the removal of the stretch referring to the edge effect (edge = 100 m width).

d) Proximity indexes: mean proximity index (MPI) - mean distance between patches of different classes, based on a radius previously determined (100 m); mean nearest-neighbor distance (MNN) - mean distance between patches of the same class; nearest-neighbor standard deviation (NNSD) - variation of distance in relation to the MNN; nearest-neighbor coefficient of variation (NNCV) - variation of the data according to the mean.

e) Patch area index: area of each patch (ha).

RESULTS AND DISCUSSION

The Guamá River basin has a total area of 1,203,886.12 ha, which are distributed over eight sub-basins. The classes pasture and vegetated area covered, respectively, 49.78% and 37.43% of the total area (Fig. 2 and Table 1). This pattern, mixed by pasture and vegetated areas is usually found in opened areas in the Amazon region, where pasture areas are the predominant LULC (Pereira et al. 2015). All sub-basins analyzed had most of their areas with pastures, indicating a significant change in the original landscape due to the advance of animal husbandry, except for Lower Guamá River and Bujarú River. Watrin et al. (2009) point out that extensive and intensive pastures are the dominant land use in the northeast region of Pará. More than 20% of the areas in the Legal Amazon region were deforested (Castro & Andrade 2016). It is associated with large land properties that use this areas for grazing cattle. When the pasture yield reduce the pasture is abandoned and become a secondary vegetation (Carvalho et al. 2019). The sub-basins Lower Guamá and Bujarú (West region) have predominantly native forests and secondary vegetation, including reserve areas (80% of the forest cover is preserved in rural properties) and permanent preservation areas (forest cover in vulnerable areas, such as river banks, hilltops, and slopes), which is according to the Brazilian federal Law 12.651/2012 (Barroso et al. 2015).

The agricultural areas covered approximately 6% of the Guamá River basin, with the sub-basins ranging from 2% to 9%. According to the Agriculture Census of 2017 of the Brazilian Institute of Geography and Statistics (IBGE), these agricultural areas present mainly crops of orange (*Citrus sinensis*), manioc (*Manihot esculenta L.*), palm oil (*Elaeis guineenses Jacq.*), and black pepper (*Piper nigrum L.*), and this information was confirmed through

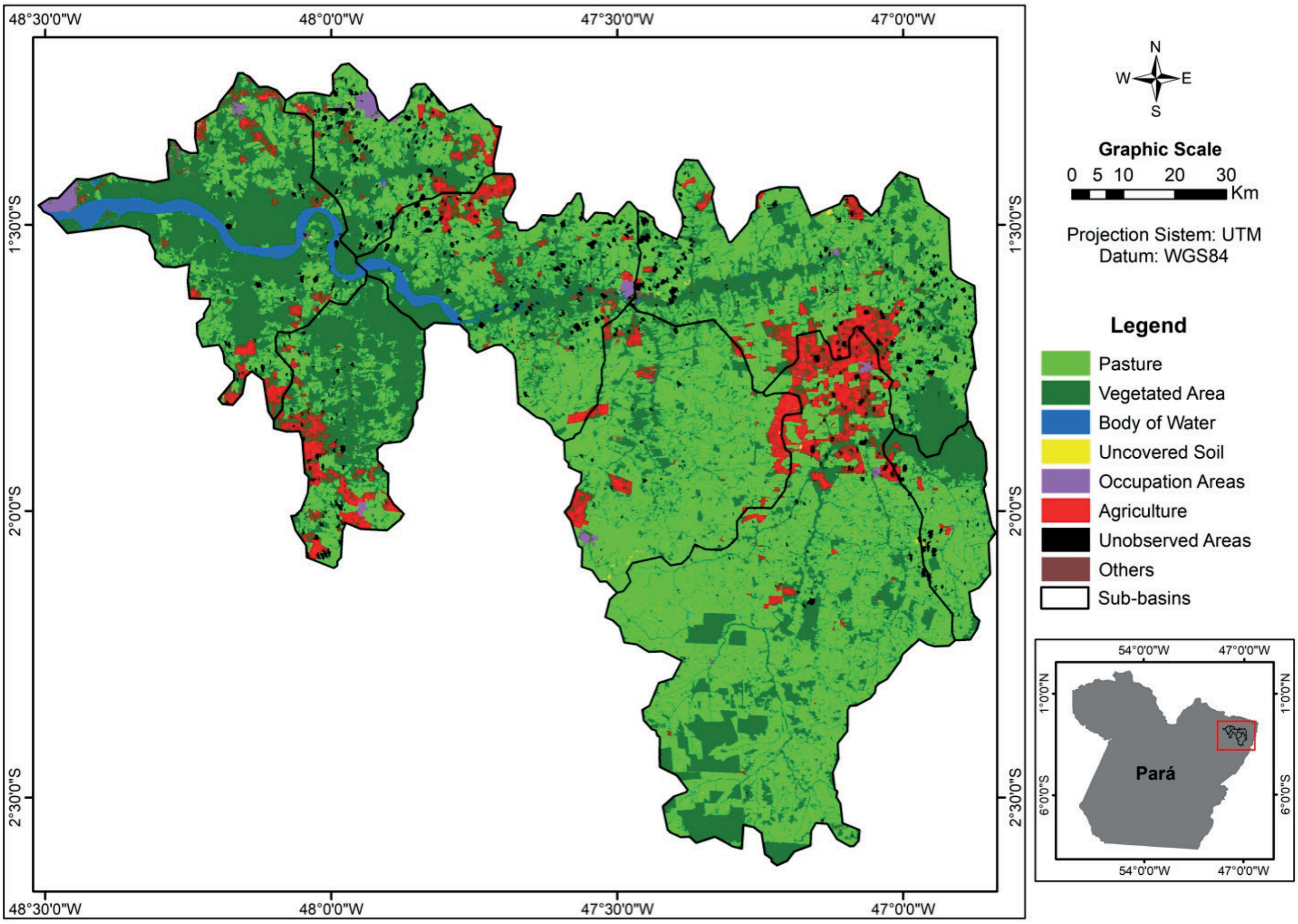

Fig. 2. Land use and land cover in the Guamá River basin

Table 1. LULC quantification matrix in sub-basins of the Guamá River

Land Use and land cover	Sub-basin area (ha)							
	Upper Guamá	Apeú Creek	Middle Guamá West	Lower Guamá	Mãe do Rio Creek	Middle Guamá East	Bujarú River	Sujo River
Vegetated Area	96,444.02	29,318.04	53,676.70	94,885.30	37,359.57	66,943.62	54,964.38	17,046.30
Agriculture	21,670.75	4,510.68	7,326.20	7,471.78	9,133.91	12,168.01	9,607.55	1,121.28
Pasture	204,207.79	32,601.57	65,790.25	38,121.28	104,811.65	97,848.97	30,131.77	25,761.48
Uncovered Soil	2,697.34	647.03	713.04	1,287.22	1,070.63	1,352.47	723.69	212.18
Occupation Areas	1,456.51	2,383.10	932.37	3,551.84	1,119.91	563.83	630.30	91.56
Water bodies	1,315.22	305.42	5,679.57	14,926.79	282.91	1,361.14	163.81	18.25
Others	149.97	104.04	614.94	346.94	122.74	484.29	156.21	73.02
Unobserved Areas	3,697.70	4,868.11	7,404.23	3,369.61	1,343.20	10,412.16	2,641.52	1,688.46
Total	331,639.30	74,737.99	142,137.30	163,960.76	155,244.52	191,134.49	99,019.23	46,012.53

field visits. The other classes had lesser representativeness in the basin, with less than 3% for each one of them.

The landscape presented 34,616 vegetated area patches, which was the second most representative class of the Guamá River basin, occupying an area of 450,637.93 hectares (Table 2). The analysis of the landscape structure was carried out considering only land covers shown by all vegetated areas.

The sub-basins that present the highest number of patches were those in the Upper Guamá (9,681) and Middle Guamá East (6,540), and the first had the largest area in relation to the vegetation areas. The data showed a high degree of fragmentation in the sub-basins, which represents the effects of human occupation. The sub-basins Sujo River (1,652) and Bujarú River (1,752) presented the lowest numbers of patches, and the Sujo River presented the lowest total vegetated area (17,046.30 ha).

The patch density index allows for the comparison of landscapes of different sizes. The sub-basins Mãe do Rio Creek, Sujo River, and Middle Guamá East showed the largest number of patches per area. The Lower Guamá River and Bujarú River had the lowest patch density and number of patches per area, denoting a minor degree of fragmentation.

The sub-basins Mãe do Rio Creek, Middle Guamá East, and Upper Guamá had greater fragmentation than the others, presenting the smallest sizes of forest patches (3.90 ha, 5.87 ha, and 5.96 ha, respectively), making them the most fragmented units of the basin. The distribution of vegetated areas is associated with land use, in this case, predominantly pastures. These sub-basins also presented the largest numbers of water sources; thus, forest preservation actions should consider it to increase the preservation of these areas.

The mean patch size is a good indicator of the degree of fragmentation because it is consistent with the number of patches and total area occupied by a class (Pirovani et al. 2014). According to McGarigal and Marks (1994), the lowest values of mean patch sizes found for a landscape characterizes it as the most fragmented one. The correlation between density index and mean patch size showed that the sub-basins that have a larger mean patch size and a lower patch density have higher patch concentrations than the mean. Thus, the correlation between number of patches and area occupied by them is inversely proportional.

The high standard deviation and coefficient of variation found indicated a large number of small patches in the areas. Thus, there is a wide difference between the sizes of forest patches of each sub-basin, denoting a spatial heterogeneity of spots in them. According to Azevedo et al. (2016), the mean patch size should be analyzed together with standard deviation and coefficient of variation because high values may represent the existence of large patches, even when their mean size is low. The assessment of these indexes shows a more detailed interpretation regarding

Table 2. Sub-basin areas, total area of the vegetated patches, number of patches (NP), patch density (PD), mean patch size (MPS), patch size standard deviation (PSSD), and patch size coefficient of variation (PSCV)

Sub-basins	Area (ha)	Total area - patches (ha)	NP	PD	MPS (ha)	PSSD (ha)	PSCV (%)
Upper Guamá	331,639.30	96,444.02	9,681	2.92	5.96	119.88	2,011.13
Apeú Creek	74,737.99	29,318.04	1,964	2.63	7.76	225.97	2,911.37
Middle Guamá West	142,137.30	53,676.70	4,107	2.89	6.91	157.00	2,272.18
Lower Guamá	163,960.76	94,885.30	3,105	1.89	13.83	600.86	4,344.12
Mãe do Rio Creek	155,244.52	37,359.57	5,815	3.75	3,90	58.42	1,497.23
Middle Guamá East	191,134.49	66,943.62	6,540	3.42	5.87	121.27	2,066.05
Bujarú River	99,019.23	54,964.38	1,752	1.77	14.77	716.60	4,850.35
Sujo River	46,012.53	17,046.30	1,652	3.59	6.25	209.26	3,347.79
Total	1,203,886.12	450,637.93	34,616				

the degree of fragmentation in the sub-basins. Tables 3 and 4 present the number of patches and their area distributed by class size for a better assessment of the forest structure in the landscapes.

The remaining patches are connecting elements (stepping stones) between large area patches and, together, they are essential for the maintenance of ecological processes (Mcgarigal et al. 2009). Patch size is an important factor for the population dynamics because it affects the richness of species. Larger patches usually shelter more complex biodiversity, allowing for the expansion and maintenance of the biodiversity.

The northeast region of Para presents a tendency of fragmentation; therefore, the restoration of forest cover is needed (Tamasauskas et al. 2016). Studies focused on water production, increase in connectivity between patches, and soil protection contribute to researches and analysis of landscapes for the conservation of natural resources (Moraes et al. 2015). The pasture management in the study area increases the edge effect. The distribution of patches in the landscape and their interaction with each other is important to reduce the impact of land use on vegetated areas and changes in the forest fragmentation pattern (Lustig et al. 2015; Vizzari et al. 2018).

Table 5 presents the shape and core area indexes. The sub-basins Bujarú River, Lower Guamá River, and Apeú Creek presented higher indexes of area-weighted mean shape; the larger patches had an elongated shape near watercourses. The shape index and fractal dimension (near 1) denote the regularity of most patches, which was also observed by Tuong et al. (2019).

Table 3. Number of vegetation patches

Patches (ha)	Upper Guamá	Apeú Creek	Middle Guamá West	Lower Guamá	Mãe do Rio Creek	Middle Guamá East	Bujarú River	Sujo River
< 50	9,519	1,934	4,043	3,078	5,710	6,418	1,722	1,625
50 - 100	73	11	31	8	55	57	11	14
100 - 200	43	10	17	7	30	26	8	8
200 - 500	20	6	8	5	16	24	6	3
500 - 1.000	16	0	3	3	2	6	4	1
> 1.000	10	3	5	4	2	9	1	1
Total	9,681	1,964	4,107	3,105	5,815	6,540	1,752	1,652

Table 4. Vegetation patches in hectares

Patches (ha)	Upper Guamá	Apeú Creek	Middle Guamá West	Lower Guamá	Mãe do Rio Creek	Middle Guamá East	Bujarú River	Sujo River
< 50	15,766.01	2,578.14	5,860.97	2,961.16	10,171.83	9,990.84	2,765.22	2,220.24
50 - 100	5,225.55	762.41	2,241.80	573.11	3,631.24	3,985.78	704.98	889.02
100 - 200	5,864.82	1,338.48	2,258.69	976.03	4,236.75	3,608.88	1,170.26	984.54
200 - 500	6,051.60	1,867.33	2,560.76	1,870.22	5,601.84	7,477.07	1,780.03	890.24
500 - 1.000	11,082.01	0.00	3,175.70	2,199.67	1,328.90	4,239.79	3,417.08	565.83
> 1.000	52,454.03	22,771.68	37,578.78	86,305.11	12,389.01	37,641.26	45,126.81	11,496.43
Total	96,444.02	29,318.04	53,676.70	94,885.30	37,359.57	66,943.62	54,964.38	17,046.30

Table 5. Mean shape index (MSI), area-weighted mean shape index (AWMSI), fractal dimension (FRAC), number of core areas (NCA), total core area (TCA), mean total core area (MTCA), and total core area index (TCAI)

Sub-basin	MSI	AWMSI	FRAC	NCA	TCA (ha)	MTCA (ha)	TCAI (%)
Upper Guamá River	1.34	8.82	1.05	160	43,452.70	271.58	45.05
Apeú Creek	1.32	26.57	1.05	53	10,419.70	196.60	35.54
Middle Guamá West	1.34	18.63	1.05	123	16,283.67	132.39	30.34
Lower Guamá River	1.25	39.39	1.04	61	42,763.30	701.04	45.07
Mãe do Rio Creek	1.35	11.16	1.05	180	6,222.96	34.57	16.66
Middle Guamá East	1.34	12.46	1.05	198	23,483.43	118.60	35.08
Bujarú River	1.29	41.91	1.04	45	19,472.32	432.72	35.43
Sujo River	1.32	12.70	1.05	34	7,469.86	219.70	43.82
Total				854	169,567.94		

The shape of forest patches is an important parameter, but it cannot be analyzed singly, since other aspects, such as the edge effect, should be considered. It determines the magnitude of the effect of external factors (Lustig et al. 2015; Vizzari et al. 2018). The core areas (Table 5) corresponded to the central (internal) areas of each patch, which were determined based on a continuous border of 100 m and according to the studies of Pirovani et al. (2014) and Pereira et al. (2015).

According to Herrmann et al. (2005), forest patches with square shape and edge effects are correlated as follows: patches with more than 100 m extension towards their interior presented 1 ha affected by the edge effect; those with 10 ha presented almost 90% affected area; those with 100 ha have 35% affected area; and those with 1,000 ha have more than 10% affected area.

Considering the patches with core areas, 854 patches (2.47%) could maintain the species in their interior. The sub-basins Middle Guamá East and Mãe do Rio Creek presented, respectively, 198 and 180 patches with core areas. Sujo River and Bujarú River presented the smallest number of patches.

The Guamá River basin had 62.37% forest patches exposed to edge effect. Patches that had no core area should not be disregarded in the landscape analysis, since they are important for the conservation of the forest composition, biological flow corridors, and connectivity between patches.

Core area is a better indicator of patch quality than its total area (Mcgarigal & Marks 1994). The sub-basins Upper Guamá River (43,452.70 ha) and Lower Guamá River (42,763.30 ha) presented the largest total patch areas with no direct impact of the edge effect, and the smallest core areas were found in the sub-basins Mãe do Rio Creek (6.222,96 ha) and Sujo River (7,469.86 ha).

According to Metzger (2003), the minimum mean core area required for the maintenance of sustainability of species and integrity of their natural structure is around 25 ha; all sub-basins analyzed had higher values than this minimum mean. Lower Guamá River and Bujarú River had the largest, and Mãe do Rio Creek and Middle Guamá East had the smallest mean core areas.

The sub-basins Lower Guamá, Upper Guamá, and Sujo River presented core area indexes of approximately 45.07%, 45.05%, and 43.82%, respectively. Mãe do Rio Creek presented the lowest core area index (16.66%), denoting that it is the most vulnerable to the edge effect and most affected by anthropogenic impacts.

Similar results were found for the mean distance from the nearest patch (defined as the mean length between patches of the same class), and the sub-basins Upper Guamá River and Sujo River presented 118.72 m and 118.68 m, respectively, denoting a high degree of isolation, which makes them more vulnerable to the edge effect (Table 6).

The degree of isolation of a patch affects the forest quality. It shows the dynamics of the circulation and dispersion of species and the degree of proximity between forest fragments. The sub-basin Upper Guamá River had the highest, and the Lower Guamá River and Bujarú River had the lowest variability of distance between forest patches. A high degree of isolation of a forest patch denotes an increase in the development of species (Souza et al. 2014). The proximity indexes found for the sub-basins Lower Guamá River (26,957.84) and Bujarú River (21,899.02) showed a low interaction with the other uses and covers that comprise their landscapes. Mãe do Rio Creek (660.02) and Upper Guamá River (904.95) were the most fragmented sub-basins, presenting a higher integration between classes. Metzger (2003) described two forms to reconnect populations of forest fragments for the recovery of fragmented forest environments: the first is to improve the network of corridors, and the second is to increase the permeability of the landscape matrix.

The evaluation of indexes and zoning by hierarchical analysis (Sun et al. 2019) described the sub-basins in two groups: (1) those that show the number of patches (NP), patch density (PD), mean patch size (MPS), patch size standard deviation (PSSD), patch size coefficient of variation (PSCV), mean proximity index (MPI), mean nearest-neighbor distance (MNN), nearest-neighbor standard deviation (NNSD), and nearest-neighbor coefficient of variation (NNCV); and (2) those that show the relationship between shape and preservation of core areas: mean shape index (MSI), area-weighted mean shape index (AWMSI), mean fractal dimension (FRAC), number of core areas (NCA), total core area (TCA), mean total core area (MTCA), and total core area index (TCAI) (Figure 3).

Despite the differences between the sub-basins of the Lower and Upper Guamá rivers, they presented similar responses. The Lower Guamá River had presence of conservation units and some areas were not exposed to the expansion of the Metropolitan Region of Belém (MRB); and the Upper Guamá River presented a large number of dispersed forest fragments, which contributed to make the other metrics similar to those of the Lower Guamá River.

Physical modification and unrestricted water extraction cause considerable degradation of springs.

Table 6. Mean nearest-neighbor distance (MNN), nearest-neighbor standard deviation (NNSD), nearest-neighbor coefficient of variation (NNCV), and mean proximity index (MPI)

Sub-basin	MNN (m)	NNSD (m)	NNCV (%)	MPI
Upper Guamá	118.72	76.18	64.17	904.95
Apeú Creek	105.66	65.64	62.12	7,190.69
Middle Guamá West	106.64	60.47	56.70	2,876.13
Lower Guamá	97.11	51.35	52.87	26,957.84
Mãe do Rio Creek	116.53	74.62	64.04	660.02
Middle Guamá East	111.32	67.56	60.69	1,499.01
Bujarú River	105.10	51.61	49.10	21,899.02
Sujo River	118.68	70.93	59.77	1,244.31

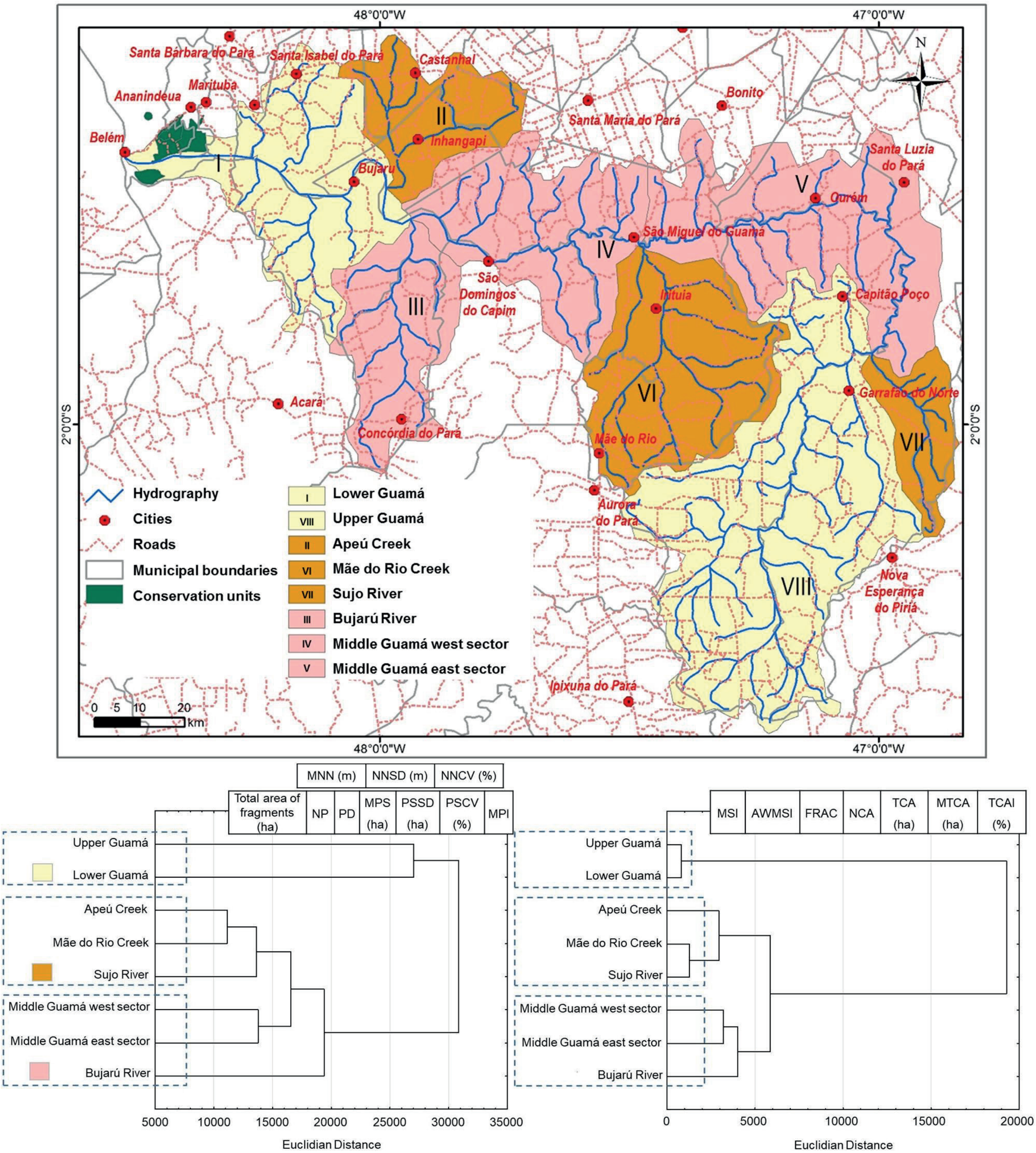

Fig. 3. Zoning of the basin according to the components of landscape metrics

Therefore, groundwater drawdown has been one of the losses in ecosystem services. Therefore, there is an interest in preserving natural resources, preventing housing and agricultural expansion, or only maintaining the traditional farming practices in areas with big changes in LULC (Rossini et al. 2018; López &, Saavedra 2021).

LULC change the relationship between land surface and atmosphere, soil and vegetation, vadose zone and groundwater, surface water and groundwater, and soil and stream. These interfaces interact with different variables and dynamic system compartments in a watershed, including social and economic factors (Reiss & Chifflard 2017).

The sub-basins Apeú River and Mãe do Rio Creek are directly affected by the urban occupation component, denoted by an intense anthropogenic action in forest fragmentation, which reflects in the spatialization and geometry of the forest fragments. Vale et al. (2015) reported that the sale of lands by small farmers to large ones caused the migration of these small farmers to urban areas in the basin region.

The degree of dispersion of forest fragments found denoted a region formed by several municipalities along the Guamá River and tributaries, which is affected by expansion of production sectors (mining, cattle raising, and agriculture) and opening of access roads to integrate the territory (Vieira et al. 2007; Enríquez 2009; Coutinho et al. 2012; Alves et al. 2012; Castro & Castro 2015) and can be considered a zone of great threat to water sustainability due to changes in the land cover pattern.

Mello et al. (2009) pointed out the existence of commercialization chains of secondary forest products, which ensures the maintenance of secondary vegetation as a rural income source associated with economic sectors (wholesalers, retailers, agribusiness). This factor may contribute to the maintenance of vegetation cover in the region. According to Nascimento and Fernandes (2017), the dynamics of the classes pasture and secondary vegetation area in this region denote the formation of a cycle of land use and occupation where the inactive pasture areas can favor the regeneration of the vegetation.

CONCLUSIONS

The fragmentation of vegetated areas in the Guamá River basin is associated with land occupation processes in the eastern Amazon. Pasture areas are more expressive in the landscape matrix, corresponding to almost 50% of the total area of the Guamá River basin. Vegetated areas are very fragmented by the presence of a large number of small patches, confirming the great impact of anthropogenic activities.

The zoning, which was carried out considering the grouping of metrics, shows that changes in land cover in the Guamá River basin have not met the basic criteria for the maintenance of recharge areas and watercourse margins, which are essential to ensure the hydrological potential of the region. The sub-basins that comprise the central axis of the Guamá River basin require greater attention from society, since actions for the planning, use, and management of these areas are essential for the processes of conservation of forests and recovery of degraded areas and for the maintenance of ecological processes. ■

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