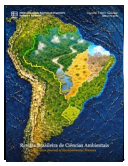
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Spatial-temporal evolution of landscape degradation on the Guamá River Basin, Brazil

Evolução espaço-temporal da degradação da paisagem da Bacia do Rio Guamá, Brasil

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ABSTRACT

The goal of this study was to determine the anthropization evolution of the Guamá river basin in the years 2000, 2008 and 2018 by means of the Anthropic Transformation Index. Land use and cover maps were obtained from two databases, Project Mapbiomas (Brazilian Annual Land Use and Land Cover Mapping Project) and PRODES (Project for the Satellite Monitoring of the Brazilian Amazon Forest). The main classes defined in the mapping process are: forest, natural non-forest vegetation, agriculture and livestock farming, secondary vegetation, urban infrastructure, water and others. Secondary vegetation was considered as the area where the forest classes of Mapbiomas intersects with the deforested areas of PRODES, as determined by the map algebra operator. The expansion of agriculture and livestock farming achieved an increase of about 10%, while the forest was reduced in almost 10%. The Guamá river basin obtained an Anthropic Transformation Index of 4.44 in 2000, 5.04 in 2008 and 5.09 in 2018, going from a regular to a degraded state in 18 years. The occupation process caused major alterations in the natural components of the landscape over the course of 18 years, notably in the amount of forest. Protection of 35% of the remnant primary forest in the Guamá river basin is vital for the conservation of water resources vulnerable to changes in land use.

Keywords: PRODES; Mapbiomas; land use change; geoprocessing; Amazon.

RESUMO

Este estudo teve como objetivo determinar a intensidade da antropização da bacia hidrográfica do rio Guamá nos anos de 2000, 2008 e 2018 por meio do Índice de Transformação Antrópica. Os mapas de uso e cobertura da terra foram obtidos em duas bases de dados: Projeto Mapbiomas e PRODES. As classes majoritárias definidas no mapeamento são: floresta, formação natural não-florestal, agropecuária, vegetação secundária, infraestrutura urbana, água e outras. A vegetação secundária foi classificada como a área das intersecções entre as classes de floresta do Mapbiomas e a área desmatada do PRODES, utilizando o operador de álgebra de mapas. O processo de ocupação resultou na expansão da agropecuária, que cresceu cerca de 10%, ao passo que a floresta apresentou uma redução de quase 10%. A bacia do rio Guamá obteve um Índice de Transformação Antrópica de 4,44 em 2000; 5,04 em 2008 e 5,09 em 2018, passando de um estado regular para degradado em 18 anos. Esses resultados estão relacionados à expansão da agricultura e da pastagem, especialmente em áreas de ocupação antiga. O processo de ocupação provocou grandes alterações nos componentes naturais da paisagem, ao longo de 18 anos, principalmente na quantidade de floresta. A proteção dos 35% da floresta primária remanescente na paisagem da bacia hidrográfica do rio Guamá é vital para a conservação dos recursos hídricos vulneráveis às mudanças no uso do solo.

Palavras-chave: PRODES; Mapbiomas; mudanças de usos da terra; geoprocessamento; Amazônia.

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Introduction

In Brazilian Amazon, human activities have irreversibly changed many ecosystems, especially the forest (Vieira et al., 2018). Many studies have demonstrated that the main drivers of those changes are large-scale deforestation, forest fires and the shifts in land use and cover (Asner et al., 2009; Arima et al., 2014; Shimabukuro et al., 2019; Santos et al., 2020). Particularly in the last five decades, agriculture and livestock farming have been the main economic activity associated with such changes (INPE and EMBRAPA, 2014; EMBRAPA, 2018) and are responsible for 80% of the deforestation in the region (INPE and EMBRAPA, 2014). From the perspective of land use and cover in Amazonian environment, many studies are being carried out, in different time and spatial scales, to analyze landscape degradation patterns looking for actions and adjustments to be adopted by rural activities (Gouveia et al., 2013; Rodrigues et al., 2014; Almeida and Vieira, 2019).

In a broader scale, landscape degradation refers to changes in the configuration and quality of land-cover patches, disturbing the functioning of ecosystems in a given region (Ghazoul and Chazdon, 2017). Degradation at a landscape level encompasses deforestation, forest fragmentation and changes in land use, which modify landscape composition, its connectivity, and the ecosystem functions, such as nutrient cycling, climate regulation and the water cycle of the river basins (Sartori et al., 2012; Rosa et al., 2017; Almeida et al., 2020). The Anthropic Transformation Index (ATI) was developed in order to analyze the levels of change and transformation in the landscape (Gouveia et al., 2013), and it is applied in Brazil to determine landscape degradation at river basin scale (Gouveia et al., 2013; Ribeiro et al., 2017; Almeida and Vieira, 2019), as it better reflects the impact caused by human actions on the original vegetation and on land use in river basins. The latter are a natural system that is well defined in space, comprising land masses topographically drained by a watercourse and its tributaries (Rodrigues et al., 2014). River basins are considered units of environmental management and planning, as they are technically and legally established under the Brazilian legislation (Brasil, 1997).

The disordered process of occupation of the river basin causes innumerable environmental losses, such as the deforestation of areas with native and secondary vegetation in favor of expanding relatively intense agricultural activities (Tamasauskas et al., 2016). Deforestation is usually associated with the use of fire (Santos et al., 2020), and its indiscriminate application becomes a serious socioenvironmental problem (Gonçalves et al., 2012). Planning of land use and occupation in the basin is necessary in order to reconcile productive activities and limited natural resources (Tucci, 2002; Zacchi et al., 2012).

This is the case of the Guamá river basin (RGHB), which shows great anthropic pressure on the forests, from the headwaters (in the municipality of Nova Esperança do Piriá, State of Pará) to the river mouth (in Guajará Bay, State of Pará), responsible for a water supply of about 75% in the Metropolitan Region of Belém (COSANPA, 2015), which serves a population of approximately 676,510 inhabitants (IBGE, 2010).

The RGHB is located in a region of ancient occupation that underwent intense deforestation due to the construction of a railroad in the late 19th century, its effects being intensified with the opening of the Belém-Brasília highway (Silva and Silva, 2008). The RGHB is highly urbanized, with extremely concentrated economic activities, poverty increase, non-resolution of social problems, and low sustainability (Rocha and Lima, 2020).

In this study we evaluated the intensity and evolution of anthropization of the RGHB in the years 2000, 2008 and 2018 by means of the ATI, and examined how the new dynamics of land use affects the areas of native forest and secondary vegetation under the hypothesis that the intensity of landscape degradation in the RGHB, increased along eighteen years (2000-2018) is associated with the expansion of agriculture and livestock farming.

Methodology

Study area

The RGHB is located in the East of the State of Pará, between parallels 1º 10' 57" S and 5º 04' 30" S and meridians 48º 36' 47" W and 47º 41' 39" W; it encompasses an area of 80,412.34 km² within the Northeastern Atlantic Coast Hydrographic Region, as established in the State Water Resources Policy (Pará, 2001). This river basin occupies 6.2% of the State of Pará and includes 33 municipalities, as well as 2.6% of the State of Maranhão, with three municipalities (Figure 1).

Temperatures range from a minimal 22 to 23°C to a maximal 30 to 34°C, with relative air humidity between 85 and 91%. Rain is abundant in the region: rainfall index is 2.250 to 2.500 mm/year (Cordeiro et al., 2017). Vegetation comprises floodplain dense forest in lowland areas, broadleaf secondary forest in uplands and dense forest in low plateau and terraces (IDESP, 2013).

The RGHB is in the fifth-order category, with a course of 490,660 km in the main canal, divided in three zones: Lower Guamá (LGm), Middle Guamá (MGm) and Upper Guamá (UGm). Guamá river begins in the municipality of Nova Esperança do Piriá, above Paragominas, runs through Capitão Poço and Garrafão do Norte (UGm) and arrives at the municipality of Ourém. From there, it runs through São Miguel do Guamá and other three municipalities (MGm). Then, it joins river Capim in the city of São Domingos do Capim, widening forward until it opens into Guajará bay in Belém (LGm). Its main tributaries, on its left bank, are Capim, Acará and Moju rivers (Figure 1).

The UGm zone comprises the municipalities of Capitão Poço, Garrafão do Norte, Ourém and Santa Luzia do Pará, with a population of 1,814,334 inhabitants (Table 1) and only 9% of primary forest. Overall, this region harbors 26.18% (3,505,310) of the livestock heads in the RGHB and is an exponent in citrus production, with 87.56% (11,389,197 tons) of the yield (IBGE, 2017). In the 1980s, citrus culture had a strong boost and turned the municipalities of Capitão Poço,

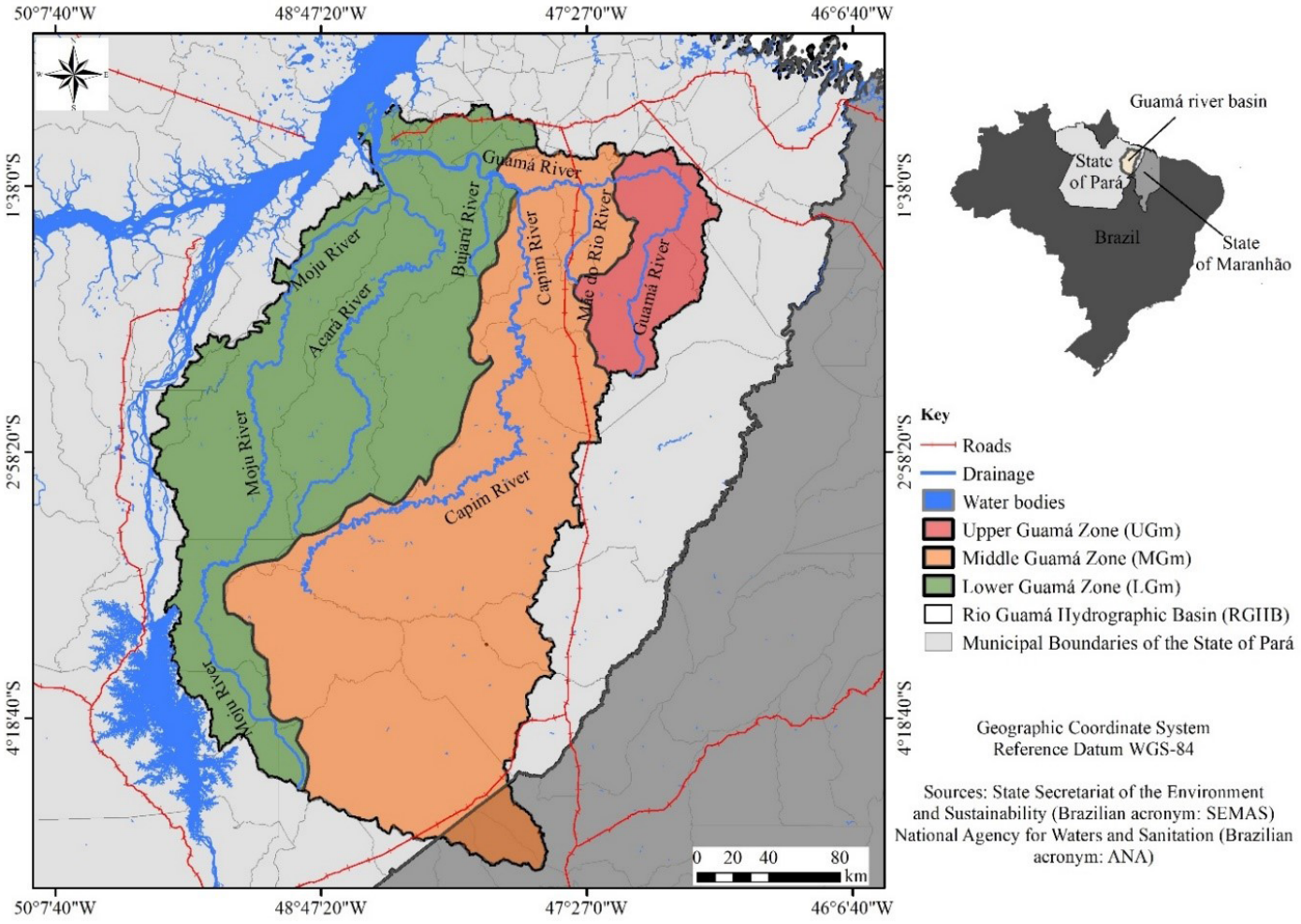


Figure 1 – Spatial location of the Guamá river basin (RGHB) and the Upper (UGm), Middle (MGm), and Lower zones of Guamá river (LGm), Brazil.
Source: prepared by the authors with information from the State Secretariat of the Environment and Sustainability (SEMAS, 2018) and the National Agency for Waters and Sanitation (ANA, 2018).

Ourém and Irituia into the greatest producers of citrus in the State of Pará (Rebello and Homma, 2017).

In the MGm zone, the municipalities of Aurora do Pará, Dom Eliseu, Goianésia do Pará, Ipixuna do Pará, Irituia, Mãe do Rio, Paragominas, Rondon do Pará, São Domingos do Capim and São Miguel do Guamá sum up 25.03% of the livestock farming in the Guamá basin and a population of 6,978,846 inhabitants; it dominates the production of soy, 98.21% (4,203,409 tonnes) of the yield in the basin (IBGE, 2017).

The LGm zone, comprising the municipalities of Acará, Ananindeua, Belém, Benevides, Breu Branco, Bujaru, Castanhal, Concórdia do Pará, Inhangapi, Marituba, Mocajuba, Moju, Santa Izabel do Pará, Tailândia and Tomé-Açu, concentrates most of the RGHB population with 82.55% (41,593,736 people) of the state residents. Agriculture is headed by the cultivation of oil palm, with a production of 17,869,270 tons (98.62%) of the total state yield.

Data processing

Data on land use, cover and deforestation for years 2000, 2008 and 2018 were obtained respectively from two databases: Mapbiomas — Brazilian Annual Land Use and Land Cover Mapping Project (Mapbiomas, 2019) and PRODES — Project for the Satellite Monitoring of the Brazilian Amazon Forest (INPE, 2019) — the latter being under the responsibility of the INPE (the National Institute for Space Research).

Mapbiomas is based on images of the Landsat satellite series (i.e., 5 — TM, 7 — ETM+ and 8 — OLI), with 1985 and 2019 data, in partnership with Google: all processing is done in the Google Earth Engine (GEE) platform and the data are stored in Google Cloud (Moore and Hansen, 2011; Ribeiro et al., 2019; Souza Junior et al., 2020).

The Mapbiomas project, now in its version 5, works with the concept of data collection. It employs a process of automatic classification of Landsat image mosaics, pixel by pixel, in scales of up to 1:100,000, analogous

Table 1 – Socioeconomic information on the Guamá River basin subdivisions, Pará, Brazil.

Sub-divisions	Population (Inhabitants)	Oil palm (tons)	Manioc (tons)	Soy (tons)	Citrus (tons)	Livestock (heads)
UGm	1,814,334	49,704	4,062,926	9,895	11,389,197	3,505,310
MGm	6,978,846	199,537	22,374,632	4,203,409	900,695	3,351,324
LGm	41,593,736	17,869,270	19,440,483	66,829	716,773	6,530,094
Total	50,386,916	18,118,511	45,878,041	4,280,133	13,006,665	13,386,728
Sub-divisions	**Population (%)**	**Oil palm (%)**	**Manioc (%)**	**Soy (%)**	**Citrus (%)**	**Livestock**
UGm	3.60	0.27	8.86	0.23	87.56	26.18
MGm	13.85	1.10	48.77	98.21	6.92	25.03
LGm	82.55	98.62	42.37	1.56	5.51	48.78

Source: IBGE (2017).

to a minimum area of 900 m² (30m x 30m), by means of Random Forest decision-tree algorithms available in the GEE platform (Ganem et al., 2017). All 13 classes presented by Mapbiomas were considered within the Guamá river basin and regrouped into the six major classes defined for the mapping process: forest, natural non-forest vegetation, agriculture and livestock farming, urban infrastructure, water and others (Chart 1).

The deforestation identification process in Project PRODES was entirely done by means of visual photo interpretation by a team of specialized interpreters using the TerraAmazon geographic information system, developed by INPE (2019). It employs Landsat images in color composition associating the medium-infrared (1.560–1.660 µm) spectral band, where dense vegetation is shown in deep red – and the near-infrared (0.845–0.885 µm) and red (0.630–0.680 µm) spectral bands, respectively, in green and blue. Visual identification of target areas takes into account the main elements of photo interpretation, such as color, tone, texture, shape and context.

Annual mapping of PRODES is applied to deforested areas larger than 6.25 ha by interpreting approximately 210 images from Landsat (spatial resolution, 30 m), with the production and disclosure of the rate of clear-cut deforestation in Legal Amazonia and related maps (INPE, 2019). PRODES utilizes the concept of cumulative mask, accruing deforestation mapped in previous years into an integrated base including all detected clear-cut deforestation areas. The PRODES mask prevents the possibility of previously detected deforestation areas being identified and mapped again, so as to keep a consistent historical series over the years (INPE, 2019).

The secondary vegetation class was obtained by crossing the forest class from the Mapbiomas Project and the deforestation class from Prodes, using the tool of map algebras of the software ArcGIS 10.2.2., which allowed mapping the area of intersections between these two classes. We consider secondary vegetation as a type of vegetation cover derived from natural regeneration following the abandonment of an agricultural area, which is considered an indicator of forest landscapes that underwent man-made alterations (Vieira and Almeida, 2013).

Chart 1 – Regrouping of land use and cover classes of Project Mapbiomas for the purposes of this study.

ID#	Mapbiomas Classes	Regrouping
3	Forest Formation	Forest*
4	Savanna Formation	
5	Mangrove	
12	Grassland Formation	Natural Non-Forest Vegetation
13	Other Natural Non-Forest Formations	
32	Hypersaline Tidal Flats	
15	Pasture	Agriculture and Livestock Farming
19	Annual and Perennial Crop	
24	Urban Infrastructure	Urban Infrastructure
33	River, Lake, Ocean	Water
23	Beach and Dune	Others
30	Mining	

#Key codes for pixel values in Mapbiomas Collection 4; *Mapbiomas considers Mangrove and Savanna Formations as Forest, in sublevels 2 and 3 (Mapbiomas, 2019), but these formations are not representative in BHRG. Source: Project Mapbiomas (2019).

Classification validation

The MapBiomas Project assesses the overall accuracy for each use and cover class through estimates based on the evaluation of a pixel

sample (reference database), composed of ~75,000 samples. The number of pixels in the reference database was predetermined by statistical sampling techniques. For each year, every pixel of the sample is evaluated by technicians trained in visual interpretation of Landsat images (Pontius Jr. and Millones, 2011).

To validate the Secondary Vegetation class in 2018, field work collected 200 samples to ensure the accuracy of the secondary vegetation data, since it is practically impossible to have an error-free mapping. Therefore, procedures were taken to determine commission and omission errors. A commission error derives from the interpretation of points or pixels that do not exist in the field (digital media classification); while an omission error occurs when points or pixels existing in the field (reference or real data) are ignored (Silva, 1999).

For that matter, for more elaborate evaluations on the veracity of spatial classification of secondary vegetation, the Kappa index (Hudson and Ramm, 1987) was calculated, as it measures the accuracy of spatial data by using an error matrix correlating the classes identified in the mapping to those identified in the field work. Values above 0.8 are considered excellent (Landis and Koch, 1977; Almeida and Vieira, 2019; Silva and Vieira, 2020).

Determination of the anthropization degree

In this study, ATI was used to quantify anthropic pressure on the Guamá river basin for the years 2000, 2008 and 2018. That index, proposed by Lemechev and modified by Mateo (1984), is calculated from percentage values corresponding to the area of each land use and cover class quantified for the basin and its respective weights (Rodrigues et al., 2014), as shown in Equation 1:

$$ATI = \Sigma(\%USE^{*}WEIGHT)/100 \quad (1)$$

Where:
USE = the percentage of area of each class of land use and cover;
WEIGHT = the value given to the classes of land use and cover with respect to their degree of anthropic alteration.

To calculate ATI, weight values for each class of land use and cover were defined from studies carried out in the area of influence of the RGHB and from specialists in the field (Mateo, 1984; Perim and Cocco, 2016), on a scale of weight variation from 1 to 10, lower to higher pressure exerted by a given class on the landscape (Chart 2). This is a numerical determination of the anthropogenic burden applied to the landscape (Ortega, 2017).

The results obtained in this study were categorized in four anthropization intervals (Cruz et al., 1998), as shown on Table 2.

Results and Discussion

The quantification of land use and cover classes in the RGHB (Table 3) showed that the forest class shrank over the years under

Table 2 – Classification of Anthropic Transformation Index (ATI) intervals.

Classification	ATI Intervals	Anthropic Pressure
Little Degraded	0–2.5	Lower
Moderate	2.5–5	-
Degraded	5–7.5	-
Highly Degraded	7.5–10	Higher

Source: Cruz et al. (1998).

Chart 2 – Weights attributed to land use and cover classes in the Guamá river basin, Pará, Brazil.

Class	Weight	Characteristics
Forest (F)	2	Includes the physiognomies of Ombrophilous Dense Forest (alluvial, lowland, and submontane) and Ombrophilous Open Forest (IBGE, 2013). The weight of 2 is justified for including primary forests that were eventually disturbed by fire or timber extraction.
Natural Non-Forest Vegetation (N-NFV)	2	Type of land cover associated with areas of campinaranas and lavrado with shrub and undergrowth vegetation and some points with Rocky Outcrop. This class is not subject to intense disturbance, which justifies weight 2.
Secondary Vegetation (SV)	3	This vegetation cover is the result of a process of succession of areas where, in the past, there was clear cutting of primary forest (IBGE, 2013). It is associated with the agriculture production system, which justifies weight 3.
Agriculture and Livestock Farming (AL)	9.5	This land use class is associated with pasture and it has the presence of grass and/or abandoned pastures with weed plants, and annual and perennial culture (the latter with a cycle above eight years), in accordance with the classes established in Mapbiomas. Weight 9.5 denotes anthropic areas that are constantly modified.
Urban Infrastructure (URBI)	10	This class referred to urban areas, such as towns, communities, villages, roads and narrow side roads. Weight 10 means lack or death of natural or planted vegetation.
Water (W)	1	Rivers and other water courses: the justification for weight 1 was that this class showed no significant alterations in landscape.
Others	9.5	Class associated with areas of mining, and those with beaches and dunes (Mapbiomas, 2019). Weight 9.5 denotes anthropic areas that are constantly modified.

Table 3 – Quantification of land use and cover classes and Anthropic Transformation Index (ATI) in the years 2000, 2008 and 2018 in the Guamá River basin, Pará, Brazil.

Land Use and Cover Classes	Weight	Areas						ATI		
		2000		2008		2018		2000	2008	2018
		km²	%	km²	%	km²	%			
Forest (F)	2	36,952.97	45.96	30,334.27	37.73	28,510.91	35.46	0.92	0.75	0.71
Natural Non-Forest Vegetation (N-NFV)	2	414.68	0.52	523.45	0.65	792.81	0.99	0.01	0.01	0.02
Secondary Vegetation (SV)	3	18,353.64	22.83	18,411.85	22.90	19,687.72	24.48	0.68	0.69	0.73
Agriculture and Livestock Farming (AL)	9.5	23,509.78	29.24	29,917.80	37.19	30,131.61	37.47	2.78	3.53	3.56
Urban Infrastructure (URBI)	10	251.96	0.31	293.02	0.36	340.02	0.42	0.03	0.04	0.04
Water (W)	1	901.12	1.12	914.47	1.14	865.22	1.08	0.01	0.01	0.01
Others	9.5	28.19	0.04	17.47	0.02	84.05	0.10	0.00	0.00	0.01
Total		**80,412.34**	**100%**	**80,412.34**	**100%**	**80,412.34**	**100%**	**4.44**	**5.04**	**5.09**

study. In 2000, the forest occupied 45.96% (36,952 km²) of the basin area, while in 2018 it comprised 37.73% (30,334.27 km²), and in 2018 only 35.46% (28,510.91 km²), which represents a loss of almost 10% (8,442.06 km²) of forests over 18 years. On the other hand, agriculture and livestock farming increased in the same proportion, with an expansion of 8.23% (6,621.83 km²) in the same period. From that we can deduce that the forest area was deforested to give way to agricultural and livestock farming activities (Walker et al., 2009) and infrastructure projects encouraged by public policies of occupation of upland areas in Amazonia.

The overall performance of secondary vegetation classification was 0.87% for the Kappa index. This high value indicates a satisfactory rating (Landis and Koch, 1977). Regarding the MapBiomas classification, the global accuracy was 91.2% on the scale of 1:100,000, and considered excellent (Congalton and Green, 2019).

The result of forest loss (10%) caused major changes in the natural components of the landscape, implying an increase in agricultural activity (8.23%), secondary vegetation (1.66%), and urban infrastructure (0.11%) over 18 years. In fact, the Amazon region became the stage of various landscape transformations that gave way to the deforestation of wide areas, with landscape-level consequences that can be disastrous. Among the main effects, we can mention the loss of biodiversity and changes in the structure of the landscape, with a high intensity of forest fragmentation (Almeida et al., 2020).

Secondary vegetation had little variation over the years. In 2000, it corresponded to 22.83% (18,353.64 km²), increasing to 24.48% (19,687.72 km²) in 2018. Carvalho et al. (2019) found the same pattern and suggested that the decrease of secondary vegetation in Pará is associated with changes in the dynamics of land use and land cover in relation to the decrease in deforestation, being converted into other types of land uses. In general, secondary forests are associated with recently abandoned pastures or agricultural fallow stages and are highly dynamic in the landscape. These dynamics can be seen in Figure 2, where secondary vegetation begins concentrated in the northern part of the basin (year 2000), extends into the areas taken over by agriculture and livestock farming (year 2008), and arrives at the southeastern portion of the basin (year 2018). Overall, the average time secondary vegetation thrives in the landscape is only five years (Aguiar et al., 2012), and this land cover is quite vulnerable to deforestation (Pereira e Vieira, 2001; Coelho et al., 2018; Wang et al., 2020).

Agriculture and livestock farming class showed the greatest variation in terms of land use area. There was an increase from 2000 (29.24%, or 23,509.78 km²) to 2018 (37.47%, or 30,131.61km²), representing an expansion of almost 9% (6,621.83 km²) of this land use class.

Occupation and alteration of landscape in the RGHB began at the edges (limits), where the main roads and highways are concentrated, reducing the forest area into many fragments in the central part of the basin (Figure 3). It should be noted that the more deforested areas are located along highways BR-010, BR-222 and PA-150, PA-252 and PA-256 (Figure 3), matching the same phenomenon detailed by Soares-Filho et al. (2004) on the impacts of the expansion of the agricultural border, unleashing potential changes in land use and cover and high rates of deforestation.

The development of agriculture and livestock farming in the RGHB in the 1970s was the main trigger for the expansion of deforestation, a complex activity involving many social players. A portion of this region was cut by the Belém-Brasília highway and, during its occupation, squatters, farmers, and loggers got involved in forest felling to exploit timber and open areas for agriculture and pasture. Indeed, the intense anthropization associated with the occupation was a determining fac-

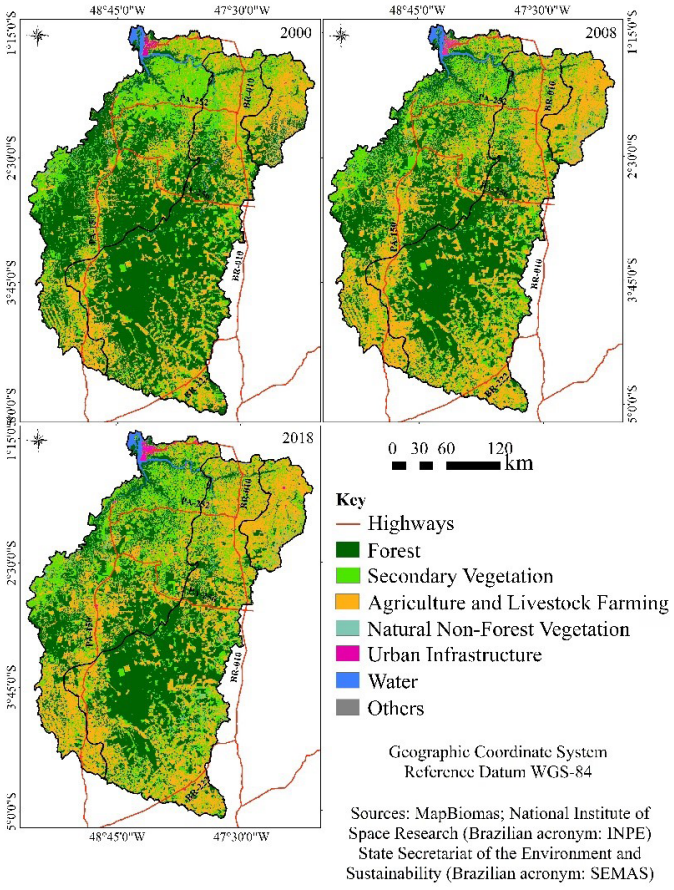


Figure 2 – Vegetation cover and land use in the years 2000, 2008 and 2018 in the Guamá River basin, Pará, Brazil.
Source: prepared by the authors with information from the Mapbiomas Project (2019), INPE (2019) and SEMAS (2018).

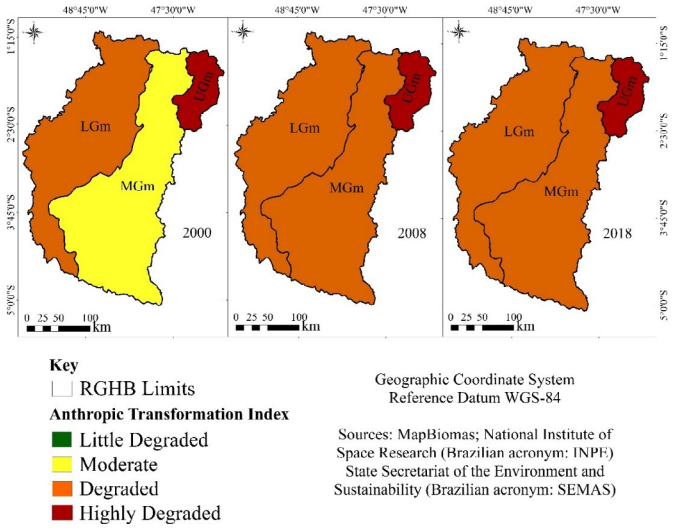


Figure 3 – Distribution maps of the Anthropic Transformation Index for years 2000, 2008 and 2018 for the Upper (UGm), Middle (MGm) and Lower Guamá (LGm) in the Guamá River basin, Pará, Brazil.
Source: Authors, with information from Project Mapbiomas (2019), INPE (2019) and SEMAS (2018).

tor for changes in the Amazonian landscape, as only about 35% of the original primary forest still exist in the region (Cordeiro et al., 2017).

The urban infrastructure, natural non-forest vegetation, water and others (mining, beaches and dunes) classes encompass places with high populational density, open areas and lakes, weirs and levees, homogeneous reforestation and exposed soil, which amounted to 2.59% in 2018, not showing any significant variation over the years.

Table 4 shows the relative area occupied by land use and ATI values in each zone of the RGHB in the years 2000, 2008 and 2018. There is clearly a differentiation of land use in the three RGHB subdivisions: forests predominate in Middle Guamá river and Lower Guamá river, while agriculture and livestock farming occupy about 65% of Upper Guamá river.

The ATI values had a slight increase between 2000 and 2018, except for UGm, in which ATI stayed above 7.8, indicating a situation of high degradation or under high anthropic pressure. In 2000, the ATI values for MGm and LGm were respectively 5.96 (moderate) and 5.01 (degraded). In 2008, however, ATI in MGm was higher, indicating a degraded state (5.59), while LGm continued as degraded (5.52). In 2019, the ATI values changed substantially but the three regions kept the same pattern (Figure 3).

The high value of ATI in the UGm zone occurs because it has the largest area occupied by agricultural and livestock farming activities, characterizing an intense process of anthropization, dominating over 50% of the region.

In a study conducted in the northeastern region of the State of Pará, it was ascertained that, in a period of only four years, the degree of anthropic transformation shifted from moderate to degraded (Almeida and Vieira, 2019), which seems to happen often in this old region of agricultural border. High anthropic pressure is mainly attributed to opening pastures for agricultural introduction, such as the cultivation of citrus, responsible for its impact on the landscape of the UGm zone, comparable to clearing the way for highways such as PA-124, PA-127, PA-136 and PA-140; this allowed for wider circulation of people, goods, and services. Thus, the anthropic action in the region involves wide extensions of land, making up a special arrangement formed by crops of different ages, areas of expansion and reserve, nurseries, roads, and agro-industrial infrastructure (Nahum and Santos, 2016).

The greatest loss of forest (12.86%) between 2000 and 2008 took place in the MGm zone and contributed to the highest level of anthropic transformation and the acceleration of the environmental degradation processes. This loss was caused by livestock farming, responsible for 88% of the economy in the region (IBGE, 2017). In the last decade,

Table 4 –Anthropic Transformation Index for the Guamá River basin zones, Pará, Brazil in the years 2000, 2008 and 2018.

Land use and cover classes (area in %)								
Zones	**F**	**SV**	**AL**	**N-NFV**	**URBI**	**W**	**Others**	**ATI**
Year 2000								
UGm*	8.23	21.85	66.25	3.39	0.12	0.15	0.00	7.89
MGm**	52.66	18.08	28.45	0.22	0.05	0.53	0.00	4.86
LGm***	44.12	27.99	24.68	0.47	0.67	1.99	0.08	5.01
Year 2008								
UGm	7.60	19.65	68.90	3.54	0.14	0.16	0.00	8.00
MGm	42.01	19.78	37.18	0.40	0.06	0.53	0.04	5.59
LGm	37.80	27.06	31.95	0.45	0.75	1.98	0.00	5.52
Year 2018								
UGm	9.01	23.23	64.64	2.80	0.20	0.13	0.00	7.82
MGm	39.80	21.04	37.37	1.16	0.08	0.47	0.08	5.66
LGm	34.85	28.73	33.04	0.46	0.86	1.92	0.15	5.69

*Upper Guamá Zone; **Middle Guamá Zone; ***Lower Guamá Zone.

the expansion of soy in the State of Pará had a huge increase in area, totaling 433,813 ha in 2016, representing 29% of the agricultural area of Pará (Fapespa, 2017). According to the Soy Moratorium, an initiative aimed at ensuring that the soy produced and marketed in the Amazon biome is not associated with the suppression of forest, out of the 66 municipalities that have soy plantations in disagreement with the Moratorium, 14 of them are in the State of Pará, including Altamira, Novo Progresso and Paragominas, which had the largest deforested areas in the period between 2009 and 2018; among these, Paragominas had the largest area of soy planted over deforested areas (8.7%). This explains why the MGm zone, as the region with the largest soy production, with the municipality of Paragominas accounting for 25.84% of the total crop in Pará (Fapespa, 2017), lost more than 12% of forest in the last 18 years, while agriculture and cattle raising now occupy about 9% of the region. In addition to forest conversion, pastures increase the risk of fire and are a significant degrader of riparian and aquatic ecosystems in the Amazon region.

The greatest increase in agriculture and livestock farming in a decade (2008-2018) and a slight expansion of secondary vegetation were observed in the LGm zone and could be associated with the abandonment of pastures, which, due to natural regeneration processes, resulted in the forest regrowth (Silva et al., 2019). More recently, this region has been featuring extensive monoculture of oil palm (Nahum and Malcher, 2012), following the flow of deforestation in northeastern Pará, as confirmed by Almeida et al. (2020), and more recently by the TerraClass project (INPE and EMBRAPA, 2014). Nevertheless, although agriculture and livestock farming were predominant in the study area and in the Guamá river basin zones, secondary vegetation has expanded over time. Homma (2015) mentions that government policies related to deforestation and fires are promoting the increase in secondary vegetation and the advance of agriculture and livestock farming. Insofar as the occupation of a region is consolidated, deforestation, use and abandonment of the land are intensified, and secondary vegetation thrives (Almeida et al., 2010).

It is important to highlight that in 2008 there was a recovery of secondary vegetation, which may be associated with regularization measures implemented in consolidated rural properties, forcing the restoration of marginal strips in Permanent Preservation Areas and the recovery by compensation in areas destined to be Legal Reserves, as established in Ordinance 7830/2012, which regulates the Environmental Register System. Furthermore, Normative Instruction 08, of October 28, 2015, protects secondary vegetation areas in advanced stages of succession (Vieira et al., 2014). These areas have been considered important repositories of biodiversity in anthropic landscapes (Lenox et al., 2018; Almeida and Vieira, 2019) and provide high-value ecosystem services available through natural regeneration.

Lastly, it should be emphasized that, considering the region's carrying capacity, the expansion of inadequate forms of land use could result in serious environmental impacts (Ribeiro et al., 2017), such as the decrease in availability of water resources, the intensification of degradation processes, soil compaction and elimination of plant and animal species. Thus, studies focused on the more anthropized areas

of a basin (Coelho et al., 2018) could be useful to define priority areas in projects of environmental restoration of river basins, enabling the protection and conservation of their integrity.

Conclusion

The high intensity and dynamics of anthropization in BHRG in the years 2000, 2008 and 2018 revealed great diversification in the three zones of the basin, with emphasis on the decrease in forest cover and a greater intensity of landscape degradation associated with the expansion of agriculture, confirming the initial hypothesis.

The ATI allowed for the qualification of the levels of environmental degradation due to land use. Thus, only the Upper Guamá river was found to be highly degraded in 2018, despite having the lowest rate of area occupied by agriculture and livestock farming and being the farthest from any urban infrastructure.

Considering the human pressure on the environment, the conservation of native forests becomes more and more dependent on strong economic and political incentives. Land value and the expansion of the agricultural frontier, among other factors, have put forward new pressures on Amazonia, even in anciently colonized, well-established regions. These changes in landscape, associated with the decrease of native forests, require quite a lot of attention from public authorities.

Protection of the remnant primary forest, covering 35.46% of the RGHB landscape, is vital for the conservation of water resources vulnerable to changes in land use: accordingly, the use of ATI to monitor anthropic transformations proved to be an alternative to quantifying and overseeing these changes. The study of indexes related to the spatialization of landscape degradation contributes to monitor regions with a history of changes in forest cover and land use. River basins are study units that ensure a better management of decision-making to prioritize areas for forest conservation and for the expansion of agriculture and livestock farming without the need to open further new areas.

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