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# Temporal Analysis of Forest Fragmentation in the Amazon Rainforest of Tocantins State, Brazil

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## Abstract

The Amazon Rainforest presents intense pressure from agricultural and cattle farming activities on its forest remnants, which promotes forest fragmentation. The present study aimed to quantify structural changes in the Amazon Rainforest landscape in the state of Tocantins, Brazil, that occurred between 1985 and 2020 using Mapbiomas data and landscape metrics. MAPBIOMS images were used to delimit forest fragments and size classes. Landscape metrics were estimated using the Fragstats® software. In the state of Tocantins, the Amazon Rainforest, grassland, and savanna showed a fragmentation process between 1985 and 2020, with a reduction in their total area and the number of fragments, with less rounded shapes and loss of core areas, in need of environmental policies to protect forest remnants and interrupt the process of Forest fragmentation, especially the Amazon Rainforest.

**Keywords:** Landscape ecology, land cover change, Amazonia, remote sensing.

## 1. INTRODUCTION AND OBJECTIVES

Forest fragmentation and deforestation are issues of great concern in tropical regions of South America, contributing to a rapid loss of tropical forest areas, with serious implications for ecosystem development. Despite the reduction in deforestation rates in recent years, the Brazilian Amazon, as the largest continuous region of tropical forest in the world, has suffered the greatest recorded losses, which has favored continuous habitat fragmentation and territory reduction (Cabral et al., 2018).

The replacement of forest areas by agriculture and pasture and the removal of forest and soil by mining activities cause disturbances in the dynamics of the Amazon ecosystem such as reduction of environmental complexity, modifying ecosystem functions and with drastic impacts on regional biodiversity. In addition, these factors also intensify habitat fragmentation, which can affect the ecology of tropical forests in a number of ways, including changing the diversity and composition of biotas, ecological processes such as nutrient cycling and pollination, increased tree mortality rates and gap formation (Laurance et al., 1997; Sales et al., 2019).

In this context, landscape metrics have often been used to assess forest fragmentation and land cover patterns over time in many environments and regions (Rosa et al., 2017). The use of metrics to analyze changes in landscape pattern and deforestation is essential for understanding ecological processes (Zhang et al., 2020). Indexes are applied to these metrics to describe the level of uniformity or spatial fragmentation of a landscape, with calculation based especially on total area, shape, edge, core area, proximity, isolation, contrast, contagion and diversity (McGarigal & Marks, 1995).

Following forest governance reforms by the Brazilian government, deforestation rates in the Amazon fell by almost 80% between 2004 and 2012. However, since 2013, official deforestation rates have been on an upward trend, worsening in the last two. The 2020 deforestation rate is 182% higher than the established target of 3,925 km2 and represents a reduction of only 44% instead of the 80% established in law (Silva et al., 2021).

Since then; however, deforestation has slowly increased again, casting doubts on the long-term sustainability of the previous achievements of conservation policies. Clearly, deforestation rates and local factors associated with changes in land use and cover differ considerably across the region, and adapting public policies to dynamic local contexts and constellations of actors remains a major challenge for decision-makers (Schielein & Börner, 2018).

The number of cattle per municipality has been one of the factors with the highest correlation with deforestation in the Amazon (Santos et al., 2021). Thus, cattle farming in the Amazon region is the main economic factor that promotes the opening of large deforestation areas, since cattle farming is practiced extensively. The states of the Amazon region had the greatest positive variation in the number of cattle in the period from 1985 to 2019 (IBGE, 2019).

In this context, the present study aimed to quantify structural changes in the Amazon Rainforest landscape in the state of Tocantins, Brazil that occurred between 1985 and 2020 using Mapbiomas data and landscape metrics.

## 2. MATERIALS AND METHODS

### *2.1. Study area and characterization*

The Amazon Rainforest in Brazil occupies an area of 4,554,420.8033 km², and in the state of Tocantins, the Biome occupies about 9%, corresponding to 25,603.6629 km (Figure 1) (IBGE, 2021).

The climate of the study area according to the Köppen classification is C2wA´a´ with humid to sub-humid climate, with moderate water deficit in winter and rainfall ranging from 1,400 to 1,700 mm (Seplan, 2012). The region has average annual temperature ranging from 25 to 27° C (Seplan, 2012).

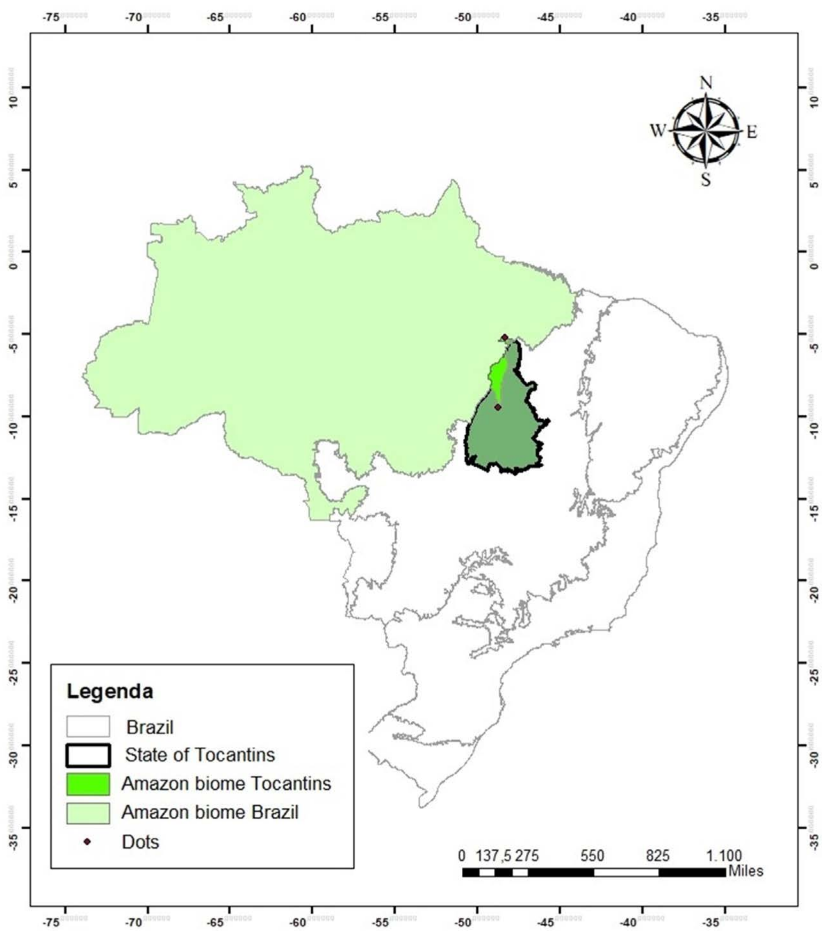


**Figure 1.** Geographic location of the Amazon Rainforest biome in the state of Tocantins, Brazil.

The Amazon Rainforest area in the state of Tocantins has three phytophysiognomies: forest formation, savanna formation and grassland formation (IBGE, 2021). The forest formation presents canopy formation, predominant arboreal stratum and species with well-defined functional groups. The savanna formation does not form canopy, has codominance of herbaceous and arboreal-shrubby strata and species without well-defined functional groups. The grassland formation is represented by the predominance of herbaceous strata and low density or absence of arboreal-shrubby individuals (Seplan, 2012).

## 2.2. Database

The georeferenced database used in this work is composed of two classes of files: rasters and vectors. Among vector-type files, Unidades de Conservação e Terras Indígenas, sub-basins, hydrography, precipitation, temperature and climate of the state of Tocantins made available by the Secretariat of Planning and Budget (SEPLAN) were acquired; and the shapefile of Brazilian biomes was acquired through the website of the Brazilian Institute of Geography and Statistics (IBGE).

The files in the matrix format of land use and cover (LULC) from 1985 to 2020 were acquired from the Mapbioms project version 6.0 (http://Mapbioms.org/), prepared for the Amazon Rainforest biome. The Mapbioms classification is generated based on annual land use and cover maps, from an automatic classification routine using Randon Forest-type decision tree algorithms available on the Google Earth Engine platform.

The accuracy of the LULC maps for the study area was assessed using a confusion matrix (Congalton & Green, 2008), which allows the calculation of the accuracy and the Kappa agreement index (Landis & Koch, 1977). Based on the characteristics of the LULC type distribution in the study area, 600 samples were randomly selected from the Sentinel image data for the year 2020, classified by MapBiomas. These homogeneous sample areas were easily identified through visual observation, and the same image classified by MapBiomas was used as a reference. The distribution of sample pixels was uniform and well represented throughout the study area. Randomly selected sample pixels were used to quantitatively assess the accuracy of the LULC classification using the indicators of producer accuracy, user accuracy, omission error, commission error, general accuracy, and Kappa agreement index (Congalton & Green, 2008; Mather & Tso, 2016).

Therefore, the accuracy assessment estimated 82.45 of the Kappa agreement index. According to (Landis & Koch, 1977), this result of the Kappa index demonstrates the performance of the classifier to be substantial and a good level of reliability of the classification results (Araya & Cabral, 2010; Keenan et al., 2015).

In the present study, the highest level of the hierarchy of land use and land cover classes of the Mapbioms Project were used, which were observed in the area, corresponding to the following macro-classes: Forest, Non-Forest Natural Formation, Agriculture, Livestock, Non-vegetated Area and Water Bodies. These classes and the others from version 6.0 of the Mapbioms Project are shown in Table 1.

After composing the georeferenced database in order to maintain an official cartographic standardization established by IBGE Resolution No. 01/2015, files were converted into the UTM projection system, using Datum WGS84.

**Table 1.** Land use and cover classes from version 6.0 of the Mapbioms project.

| | |
|---|---|
| **1. Forest** | 1.1. Natural Forest |
| | 1.1.1. Forest Formation |
| | 1.1.2. Savanna Formation |
| | 1.1.3. Mangrove |
| **2. Non-Forest Natural Formation** | 1.2. Planted forest |
| | 2.1. Non-Forest Natural Wet Area |
| | 2.2. Grassland formation |
| | 2.3. Apicum |
| | 2.4. Other Non-Forest Natural Formation |
| **3. Agriculture and Livestock** | 3.1. Pasture |
| | 3.2. Agriculture |
| | 3.2.1. Annual and Perennial Culture |
| | 3.2.2. Semi-Perennial Culture |
| | 3.3. Agriculture and Pasture Mosaic |
| **4. Non-vegetated area** | 4.1. Beach and dune |
| | 4.2. Urban infrastructure |
| | 4.3. Rocky Outcrop |
| | 4.4. Mining |
| | 4.5. Other Non-Vegetated Area |
| **5. Water Bodies** | 5.1 River, Lake and Ocean |
| **6. Not observed** | 6. Not observed |

## 2.3. Geoinformation processing

In all stages of geoinformation processing, the ArcGIS software version 10.5 and Fragstats was used, as well as its respective plugins and extensions, which allowed a range of spatial analysis. With land use and land cover rasters, these files were cut in accordance with the territorial limits of the Amazon region of the state of Tocantins. Subsequently, rasters were converted into polygon shapefiles. With the processing results, a color palette was created for land use and cover elements, following standards of the MAPBIOMS project, considering macro classes presented above. To map the dynamics of land use and land cover classes, the previously cut images were converted into vector format and layers intersection commands from 1985 to 2020 were performed in GIS environment.

### 2.4. Analysis of size classes and forest fragment metrics

To characterize the structure of forest fragments, the vectors belonging to land use and cover class were individualized into new vector shapes, and then their areas were calculated through the attribute table. After calculating the areas of vectors corresponding to forest fragments, a new text-type attribute was created in its table, which was filled in with the nomenclature of fragment size classes as follows: 1 – small (up to 10 ha); 2 – medium (between 10 and 100 ha) and 3 – large (greater than 100 ha), thus allowing associating the number and size of forest fragments expressed in size classes, which are essential for the description of aspects of landscape patterns, as it constitutes a measure of their degree of subdivision (Calegari et al., 2010).

The analysis of landscape ecology indexes was performed based on the generated forest fragment map, which values were obtained using the Fragstats® software version 4.2 (McGarigal & Marks, 1995). Metrics were calculated using the raster data version of the forest cover file obtained in the previous step. For the calculation of landscape metrics (Table 2), indexes that allowed quantifyinglandscape elements were selected, thus estimating area, density, edge, core area, shape, proximity, isolation, contagion and dispersion (Fernandes et al., 2015; McGarigal & Marks, 1995) (Table 2).

To calculate the core area metrics of fragments, distances of 100 m from the edge were used (Oliveira et al., 2002).

**Table 2.** Spatial metrics used in the quantification of landscape structures in the Amazon region of the state of Tocantins.

| Metrics | Acronym and range (unit) | Group |
|---|---|---|
| Class Area (CA) | CA > 0 (ha) | Area, Density and Edge |
| Average size of fragments | MPS > 0 (ha) | |
| Edge density (ED) | ED ≥ 0 ($m.ha^{-1}$) | |
| Number of fragments (NumP) | NP ≥ 1 (dimensionless) | Forma |
| Mean Shape Index | MSI (dimensionless) | |
| Mean core area index (CAI_MN) | 0 ≤ CAI_MN ≤ 100 (%) | |
| Total core area (TCA) | TCA ≥ 0 (ha) | Core area |
| Average proximity between classes (PROX_MN) | PROX_MN ≥ 0 (dimensionless) | Proximity |

## 3. RESULTS

### 3.1. Analysis of size classes of forest fragments

In mapping the size classes of forest fragments in 1985, 17,523 fragments were identified and in 2020, 25,980 forest fragments were identified in the area that comprises the Amazon region of the state of Tocantins (Table 3). In 1985, 72.60% of small fragments, 23.76% of medium fragments and 3.64% of large fragments were observed (Table 3). In 2020, small fragments represented 76.27%, medium fragments 20.44%, showing few oscillations over time, and large fragments occupied areas corresponding to 3.29% (Table 3).

In 1989, drastic reduction in the amount of small fragments was observed. However, in 2012, the number of small fragments increased, adding 14,007. In 2013, great reduction in small, medium and large fragments was observed, which indicates greater fragmentation and increased deforestation (Figure 2).

**Table 3.** Number of fragments and percentages from 1985 to 2020 in size classes in the Amazon region.

| YEAR | Number of fragments and percentage | | | | | | |
|---|---|---|---|---|---|---|---|
| | Small | % | Medium | % | Large | % | Total |
| 1985 | 12.722,00 | 72.60 | 4.163 | 23.76 | 638 | 3.64 | 17.523 |
| 1990 | 12,207.00 | 70.89 | 4.284 | 24.88 | 728 | 4.23 | 17.219 |
| 1995 | 13,007.00 | 70.73 | 4.601 | 25.02 | 782 | 4.25 | 18.390 |
| 2000 | 13,120.00 | 71.32 | 4.451 | 24.20 | 825 | 4.48 | 18.396 |
| 2005 | 13,131.00 | 71.18 | 4.507 | 24.43 | 810 | 4.39 | 18.448 |
| 2010 | 17,613.00 | 72.05 | 5.807 | 23.76 | 1.025 | 4.19 | 24.445 |
| 2015 | 14,807.00 | 71.82 | 4.923 | 23.88 | 886 | 4.30 | 20.616 |
| 2020 | 19,815.00 | 76.27 | 5.311 | 20.44 | 854 | 3.29 | 25.980 |

Source: Author (2021).

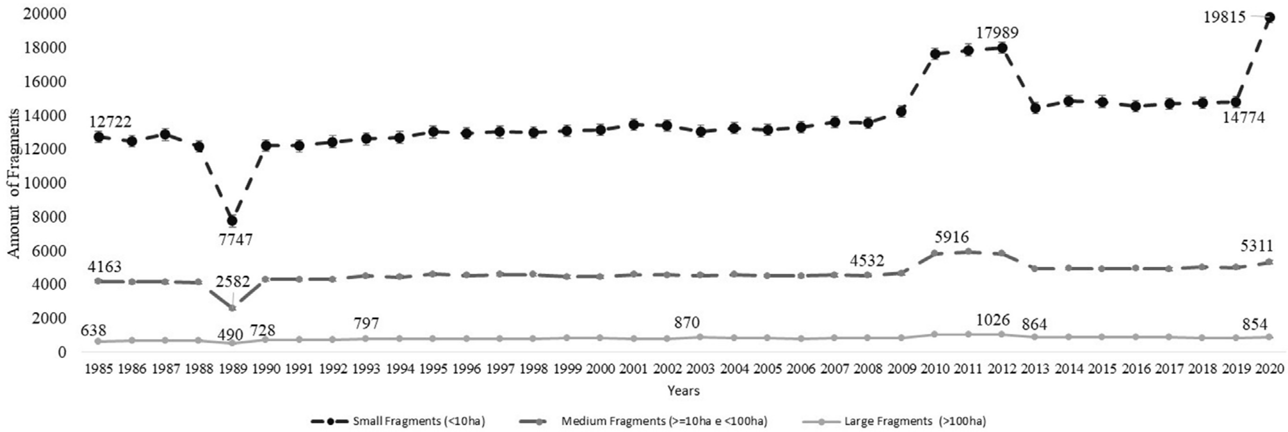


**Figure 2.** Class of fragments in the Amazon region.

### *3.2. Forest fragment metrics*

Forest fragments of grassland and savannah formations showed reduction in CA and NumP metrics from 1985 to 2020 (Table 4). This indicates that fragments lost area, and smallest fragments became extinct. The forest formation lost around 200% of its CA from 1985 to 2020, but there was an increase in NumP (Table 4), which demonstrates that the fragments of this formation are being fragmented, where larger fragments are divided into smaller and more numerous fragments.

In all FC, FF and FS formations, reduction in MPS was observed between 1985 and 2020, corroborating CA and NumP data (Table 4). In the 35 years the Amazon Rainforest in the state of Tocantins, its forest remnants became smaller and lost part of their area.

Increase in MSI was observed from 1985 to 2020 in all Amazon Rainforest formations (Table 4), that is, fragments are more elongated and subject to greater edge effect. The edge effect can be confirmed with the reduction in TCA in the three forest formations from 1985 to 2020, demonstrating that forest fragments lost core area, mainly the forest formation, which lost more than 300% of its core area in 35 years (Table 4).

PROX_MN of grassland and savanna formations decreased between 1985 and 2020, but did not reach zero; all fragments have neighbors within a radius of 100 m. The forest formation showed increase in PROX_MN in this period; however, FF is the formation that presents the lowest PROX_MN.

**Table 4.** Landscape metrics for grassland formation (FC), forest formation (FF) and savanna formation (FS) classes in the Amazon Rainforest in the years 1985 and 2020 in the state of Tocantins, Brazil.

| Metrics | 1985 | | | 2020 | | |
|---|---|---|---|---|---|---|
| | FC | FF | FS | FC | FF | FS |
| CA | 39105.30 | 1208060.00 | 177074.00 | 28111.90 | 540862 | 157579.00 |
| NumP | 4688 | 10304 | 8240 | 3516 | 15057 | 7406 |
| MPS | 8.34 | 117.24 | 21.48 | 7.99 | 35.92 | 21.27 |
| ED | 3.14 | 22.56 | 9.51 | 2.28 | 22.98 | 8.86 |
| MSI | 1.79 | 1.94 | 1.97 | 1.81 | 2.18 | 2.05 |
| TCA | 8695.62 | 897101.82 | 70302.60 | 6491.34 | 270903.87 | 59361.21 |
| PROX_MN | 703.02 | 203.26 | 374.96 | 629.66 | 219.14 | 349.69 |

CA: Class Area; NumP: Number of fragments; MPS: Average fragment size; ED: Edge density; MSI: Mean Shape Index; TCA: Total core area; PROX_MN: Average proximity between classes.

## 4. DISCUSSION

According to Table 3, the Amazon Rainforest inserted in the state of Tocantins maintained between 1985 and 2020 a pattern of more than 70% of its forest fragments smaller than 10 ha and approximate 30% of medium and large fragments (greater than 10 ha). This pattern, with predominance of fragments smaller than 10 ha in the region of Tucurui in the state of Pará, is inserted in an anthropic matrix consisting of agricultural and livestock activities (Gonçalves et al., 2019).

In 2012, increase in accessibility and creation of new roads and slaughterhouses was observed in the Amazon region, which promoted increase in deforestation and conversion into pasture areas (Schielein et al., 2021). In 2013, deforestation rates in the Amazon began to increase, reversing a decade-long trend of declining annual deforestation rates (INPE, 2018).

In 2012, the new Brazilian forest code came into force, which proposed amnesties for those who had deforested areas until July 2008, reduced the need to recompose riparian forests - legally defined as Permanent Preservation Areas (APP), as well as deforested Legal Reserves from July 2008. This led to the deforestation of almost 1 million hectares of forest between 2012 and 2017 (Albuquerque Sant'Anna & Costa, 2021).

Increase in the number of small and medium patches from 2019 to 2020 was observed, reaching the highest number of patches smaller than 10 ha in 2020. The annual deforestation rate for 2019 was 30% higher (9,700 km$^2$ in total) compared to 2018, reaching its peak since 2012 (INPE, 2020).

Two types of transformative processes at the frontiers of deforestation in the Amazon context have been observed. Firstly, recent frontier development is characterized by intensification of livestock farming and a growing share of agricultural activities in the production portfolio, which could be the result of better access to modern technologies and markets, combined with scarcity of land for forest governance-induced expansion of historically dominant extensive pasture. Second, the share of medium- and large-scale deforestation decreased at the beginning, but recovered during the observation period in all border types after 2012 (Albuquerque Sant'Anna & Costa, 2021).

Large size class fragments, despite their low quantity, are important, in which larger area fragments serve as source of plant propagule and smaller area species, in addition to contributing to the displacement of animals (Laurance & Vasconcelos, 2009). In a study by Almeida (2016), despite the scarcity of large number of large fragments, these areas are fundamental, as they guarantee the maintenance of biodiversity and all ecological processes on a large scale, thus maintaining the greatest diversity of species.

It should be highlighted that the MPS of FC in 1985 to 2020 were less than 10 ha, and the other formations, despite the reduction of MPS in this period, maintained MPS above 10 ha. The concentration of large number of fragments in areas smaller than 10 ha and the low percentage of the area occupied by them can lead to the isolation of forest species, resulting in reduction in biodiversity, since these small fragments are subject to edge effects (Laurance et al., 2018).

The grassland and savannah formation had reduction in ED from 1985 to 2020; however, the forest formation showed increase in this metric (Table 4) in the analyzed period, which indicates increase in the edge effect. In general, the increase in the edge effect indicates increase in landscape heterogeneity (Alves et al., 2021). Greater increase in the forest formation MSI was observed from 1985 to 2020, which favors increase in ED. The increase in edge density (ED) occurs due to the elongation in the shape of forest fragments, which increases the contact of the fragment with the surrounding anthropic matrix and the formation of new polygons in the landscape (Pirovani et al., 2015).

Irregularly shaped fragments have regions where the edge effect excludes and/or reduces and/or segments their corer area. In this way, the fragment will have smaller core areas, protecting fewer species from the matrix effects, or it will be divided, and will form more than one core area, since the establishment of its internal structure is related to a minimum area capable of maintaining the typical species of the type of forest formation to which the fragment belongs (Silva et al., 2021).

The more regular shaped fragments generally have similar measurements that make up the perimeter, and thus tend to be less influenced by external factors (changes in luminosity, temperature, humidity and wind speed), precisely because their shape favors the " isolation" of the core area, which reduces the impact of the edge effect (Santos et al., 2018).

Regarding the proximity of forest fragments, this was evaluated using PROX_MN, calculated from a search radius of 100 meters (Francesco et al., 2019). This metric is strongly influenced by the reduction in the area of classes and by the proximity (considering the search radius) between remnants of the same class in the landscape (Cabacinha et al., 2010).

## 5. CONCLUSIONS

In 2012, the new Brazilian forest code came into force and one of the measures was the amnesty of illegally deforested areas and the restoration of riparian forests and legal reserves. In this sense, it could be concluded that this change in forest legislation favored the expansion of deforestation in the Amazon Rainforest, with increase in the number of small fragments in 2012, and reduction in the number of fragments of all size classes.

Grassland, savanna and forest formations showed a process of fragmentation between 1985 and 2020, with reduction in their total area and in the number of fragments, with less rounded shapes and loss of core areas. The forest fragments of the Amazon Rainforest need environmental policies to protect forest remnants and interrupt the process of forest fragmentation. Payment for environmental services and forest restoration projects can be measures that help combat deforestation and forest fragmentation in the Amazon Rainforest in the state of Tocantins, Brazil.

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