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Fragmented landscapes: aspects of the process of transformations of the landscape structure in the Upper Cuiabá River Basin (1985 and 2022)

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SUMMARY
The Upper Cuiabá River Basin (BARC) comprises an important source for the water supply of the Metropolitan Region of the Cuiabá River Valley and has undergone major transformations in the period between 1985 and 2022, especially the conversion of land use and occupation to anthropogenic activities. It strongly represents the occupation model adopted in the westernmost portion of the Brazilian Cerrado and concomitantly a pole through which the occupation of the Amazon Rainforest spread, especially the northern region of the State of Mato Grosso. This article aims to analyze the changes that have occurred in BARC by making a comparative analysis between the map of the MapBiomas series collection 8 from the beginning and the end of the available historical series (1985-2022), through the metric comparison of the diversity of the landscape structure using programs based on Geographic Information Systems (GIS). The specific objectives include the elaboration of thematic maps containing the classes of land use and occupation in a raster image and the evaluation of landscape metrics using the Fragstats© software. For this, the metrics were analyzed using the Fragstats© program on BARC's raster images. Finally, it was concluded that there was a process of conversion of forest and savannah formations that were replaced by agricultural crops and the expansion of urbanized areas, changing the composition of the landscape structure through the process of fragmentation and shredding of natural patches.

KEYWORDS: Landscape analysis, Upper Cuiabá River Bay, Landscape structure.

1 INTRODUCTION

The Upper Cuiabá River Basin (BARC) is of fundamental importance for the Metropolitan Region of the Cuiabá River Valley (RMVRC), as it is home to the two largest cities in terms of population in the State of Mato Grosso; Cuiabá and Várzea Grande, a conurbation that includes the administrative capital of the state.

The water supply for the population, industries and energy generation needs to be preserved, which is only possible if the Cuiabá River and its tributaries are protected and managed, in order to ensure the provision of important environmental services. The preservation of environmental resources is fundamental beyond the socioeconomic issue, especially for the maintenance of the existing biodiversity in BARC.

However, the process of land use and occupation in the last 3 and a half decades has generated an intense modification of the regional landscape, as pointed out in the environmental booklet of the Master Plan for Integrated Development of the RMVRC:

> [...] The lack of treatment of effluents discharged and the degradation of preservation areas are worrisome in the Cuiabá River Basin in its entirety, which affects the quality and quantity of available water, bringing losses such as the increase in costs for its treatment and the impediment of uses that have been practiced in the region since ancient times, such as recreation and fishing. for instance. (PDDI - IBAM, 2018, p. 202-203).

One of the tools for the diagnosis of environmental transformations is the structural analysis of the landscape, according to LANG *et al* (2009) the metrics related to the structure of the landscape have several examples of practical application such as: cultural landscape research, landscape shredding studies, analysis of shrub expansion in abandoned pasture sites, degradation of wetland complexes, Implementation of concepts related to the target species for conservation, planning of urban green areas, analysis of the vertical forest structure, among others.

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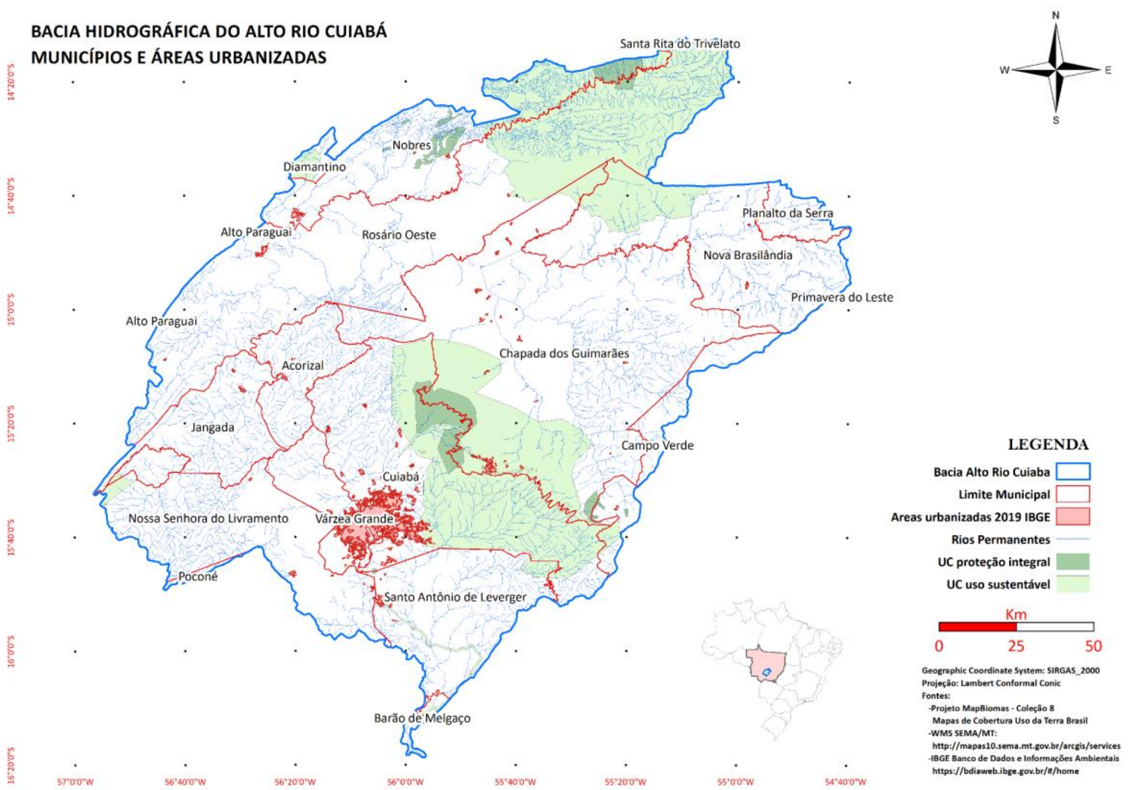
The hydrographic basin of the Cuiabá River valley has approximately 7,248.26 km², comprises a great diversity of land uses and occupations that have undergone a marked transformation of the landscape structure until the present day. The following map (Figure 1) represents the boundaries of BARC and the municipalities that have areas under their jurisdiction that are part of the Basin, including the Federal, State and Municipal Conservation Units, both of Full Protection (PI) and of Sustainable Use (US). From the map, it can be seen that many springs of the Cuiabá River are located within Sustainable Use Conservation Units such as the Chapada dos Guimarães Environmental Protection Area and the Cabeceiras do Rio Cuiabá Environmental Protection Area, both managed by the State of Mato Grosso and whose category allows the possession and ownership of areas by private individuals.

Figure 1 – Upper Cuiabá River Basin



Source: WMS SEPLAN/MT (2024)

Considering the APAs inserted within the limits of BARC, it is noteworthy that the regulations for the use and occupation of the soil in these areas are governed by specific rules issued by the Mato Grosso State Department of the Environment (SEMA/MT). In the case of the first, there is a macrozoning recognized by Law No. 9,449, of October 19, 2010, and in the second area, there is a rapid ecological study carried out on the occasion of the actions developed by the Agroforestry Development Program (PRODEAGRO) at the end of the 1990s, which was the basis for the creation of the aforementioned APA of the headwaters of the Cuiabá River.

In this context, understanding environmental transformations will be extremely relevant given the climate emergency we find ourselves in, and it is possible to rethink the

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readjustment of the urban area in order to increase resilience to climate change, re compose the landscape, identify priority areas for nature conservation, among other territorial planning actions. These transformations can be evaluated through products made available by the MapBiomas initiative[1], which freely and openly provides the scientific community with a historical series with a high degree of accuracy.

Thus, the understanding of the dynamics of transformations that the regional landscape went through between the years from 1985 to 2022 in BARC's cut-off region could be analyzed by land use and occupation maps with the use of methodologies based on geoprocessing programs associated with specific metrics developed for this purpose. Highlighting that the location of BARC has a relatively large number of municipalities that are in part or all of their area within the limits of the Hydrographic Basin under study, which in theory causes a need for articulation between the municipalities for an efficient management of the Basin.

2 LITERATURE REVISION

Landscape ecology is an integrative subject and strongly dependent on the scale at which a given study is carried out. By dealing with the exchange of biotic and abiotic materials between ecosystems and incorporating human actions into its study context, it has the potential to support concepts applicable in other disciplines such as landscape architecture, regional planning, restoration ecology and environmental resource management (ODUM; BARRET, 2007).

Several authors have focused on the theme of landscape ecology, such as McHarg (1969), Naveh and Lieberman (!984), Hansen and di Castri (1992), among others. According to Odum (2007), the fundamental issue in landscape structure studies is to understand th e causes and consequences of spatial patterns in the landscape. To this end, the author proposes the adoption of constituent elements of the landscape that would form what is called landscape mosaic, composed of a base matrix, defined as the largest portion of the mosaic in the study scale. Inside the matrix there are spots that have a homogeneity, but that differ in their typology from the typology of the matrix and finally the corridors that interconnect two or more spots. In this way, the mosaic is identified as a heterogeneous area that has several patches, including different typologies formed by distinct communities or ecosystems. It is important to understand the fact that spots or even matrices can have natural or anthropic origin and, as previously pointed out, can vary depending on the scale adopted. On a given scale, what is considered an anthropogenic-based matrix may be a stain on a larger scale, or vice versa.

Based on research involving the need to quantify landscape patterns with the intention of better studying the relationships and processes involved, several authors have developed metrics and indices related to the composition of landscape mosaics, among them we can mention O"Neill et al 1988, McGarigal and Marks, 1995 and Turner and Gardne r, 1991. Studies on landscape metrics have gained great momentum from the acquisition of images generated by remote sensing, especially satellite images, as well as the advancement of technologies related to computerized Geographic Information Systems (GIS).

[1] MapBiomas Project – Collection 8 of the Annual Series of Land Cover and Land Use Maps of Brazil, accessed on January 29, 2024 through the link: https://code.earthengine.google.com/5bd388e0ef72a0e9942632f321648205

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BARC lacks a study related to the structure of the landscape that allows to verify the evolution of the structural changes that have occurred over a long period, especially in the last decades that have been characterized by a strong conversion of land use and occupation in this Hydrographic Basin. A structured GIS analysis and a methodological treatment based on landscape metrics can assist in the regional planning of this area, which has a strategic importance for the supply of water to the entire Metropolitan Region of the Cuiabá River Valley, where almost a third of the population and the two largest cities in the State of Mato Grosso are located. including the administrative capital of the State of Mato Grosso.

3 MATERIALS AND METHODS

The MapBiomas collection 8 launched in August 2023 is based on Landsat 5 and Landsat 8 satellite images[2] with a resolution of 30 m, processed pixel by pixel and covers a spectrum of 29 classes of land use and occupation[3]. All raster files were adjusted to the WGS 1984 coordinate system in order to avoid displacements, and the images have an accuracy of 84.7% in the historical series from 1985 to 2022 for the Cerrado Biome at level 1 of the class legend, [4]whose colors followed the standard of the Brazilian Institute of Geography and Statistics – IBGE (Technical Manual of Land Use – Table 1). The study region included the limits of the Upper Cuiabá River Basin (BARC).

3.1 Data collection

For the analysis in a GIS environment, the collection 8 MapBiomas was initially downloaded referring to the political administrative limit of the State of Mato Grosso, available on the Google Earth engine platform[5] of the entire historical series between the years 1985 to 2022. The images were treated in the ArcGis 10.1® software with the conversion of colors and captions to the standard adopted by the MapBiomas platform (Chart 1) and the spatial clipping of the Upper Cuiabá River Basin was made, defined according to data obtained from the Web Map Service (WMS)[6] of the Mato Grosso State Department of the Environment (SEMA/MT) [2].

The years 1985 and 2022 were selected, respectively the first and last available year of the historical series of collection 8 developed by the MapBiomas project of the region delimited by BARC. After applying the spatial clipping of the raster images, there were 5 levels and 12 classes for the year 1985 and 5 levels and 17 classes for the year 2022 of categories classified by the representative colors presented in Table 1.

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[2] https://brasil.mapbiomas.org/wp-content/uploads/sites/4/2023/08/Cerrado-Appendix-ATBD-Collection-8.pdf
[3] https://brasil.mapbiomas.org/wp-content/uploads/sites/4/2023/08/Legenda-Colecao-8-LEGEND-CODE.pdf
[4] https://brasil.mapbiomas.org/estatistica-de-acuracia/colecao-8/
[5] https://code.earthengine.google.com/
[6] http://mapas10.sema.mt.gov.br/arcgis/services

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Table 1 - Class Legend

Class	Sub class	Description	Hexacode color	
1		**Forest**	#32a65e	
	3	Forest Formation	#1f8d49	
	4	Savannah Formation	#7dc975	
	6	Flood Forest (beta)	#026975	
2		**Non-Forest Natural Formation**	#ad975a	
	11	Wetland and Swampy Area	#519799	
	12	Camp Formation	#d6bc74	
	29	Rocky Outcrop	#ffaa5f	
3		**Agricultural**	#FFFFB2	
	9	Silviculture	#e6ccff	
	15	Pasture	#edde8e	
	20	Cane	#db7093	
	21	Mosaic of Uses	#ffefc3	
	39	Soy	#f5b3c8	
	41	Other Temporary Crops	#f54ca9	
	62	Cotton	#ff69b4	
4		**Non-vegetated area**	#d4271e	
	24	Urbanized Area	#d4271e	
	25	Other Non-vegetated areas	#db4d4f	
	30	Mining	#9c0027	
5		**Body of Water**	#0000FF	
	33	River, Lake	#2532e4	

Source: MapBioma collection 8.

It is reinforced that the colors followed the standards established within the scope of the MapBiomas project and have a correlation with the classes of the Brazilian Institute of Geography and Statistics (IBGE).[7] Highlighting that the increase in the number of classes between the two years is related to the change of the satellite used, LandSat 5 (TM) used in 1985 to Landsat 8 (OLS) used in 2022, were treated according to the processing algorithm used by the MapBiomas project for the Cerrado (Algorithm Theoretical Basis Document – ATBD)[8].

3.2 Data processing

From the raster format files, the native tool of the ArcGis 10.1 program (export data raster) was applied to create the file in *.img image format, with 16 bits and square cell size of 29.539732576432 m, defined in the WGS 1984 UTM 21 S Projected Coordinates system, thus allowing the subsequent treatment of the image in the Fragstats© program[9] developed by Eduard Ene & Kevin Mcgarigal (2024) to evaluate the metrics of the landscape.

Subsequently, the image files of the respective years of study were uploaded to the Fragstats© 4.3 software and the system was configured to process the metrics related to landscape diversity, as shown in Chart 2.

[7] https://brasil.mapbiomas.org/codigos-de-legenda/

[8] ATBD Methodology: available at: https://brasil.mapbiomas.org/wp-content/uploads/sites/4/2023/08/Cerrado-Appendix-ATBD-Collection-8.pdf

[9] McGarigal K., S. A. Cushman, and E Ene. 2023. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors available at the following web site: https://www.fragstats.org

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Table 2 - Landscape diversity metrics based on patches - characteristics

Class	code	unit	Belt
Staining Richness	PR	none	PR ≥ 1, no limit
Staining Richness Density	PRD	No. / 100 ha	PRD > 0, no limit
Relative blot richness	RPR	%	0 < RPR ≦ 100
Shannon Diversity Index	SHDI	information	SHDI ≥ 0, no limit
Simpson's Diversity Index	SIDI	none	0 ≦ SIDI < 1
Modified Simpson Diversity Index	MSIDI	none	MSIDI ≥ 0, no limit
Shannon Equity Index	SHEI	none	0 ≦ SHEI ≦ 1
Modified Simpson Equity Index	MSIEI	none	0 ≦ MSIEI ≦ 1

Source: Fragstats - Eduard Ene & Kevin Mcgarigal (2024)

The main objective was to conduct a quantitative research comparing the changes that occurred between the years 1985 and 2022 in the indicators of landscape diversity. These indicators were used because they are at the "landscape" level, i.e., they incorporate metrics of proportional abundance of class, richness, equity and diversity of patches. The metrics studied are in the scope of analysis that focus on the composition of the landscape structure.

Among the numerous metrics available for this study, the ones used in this analysis are those available in the Fragstats© 4.3 program, because it is a tool recognized by researchers in the area as a reference standard and because the developers incorporate into the program the metrics scientifically proven by the reference authors in studies on landscape ecology.

Chart 3, Chart 4 and Chart 5 describe, respectively, what the indicator represents in the analysis of the landscape structure, the formulas used and the legends.

Table 3 - Landscape diversity metrics based on patches - representativeness

Class	Representativeness
PR - Richness of stains	No. of spots present in the landscape
PRD - Stain Richness Density	No. different types of patches divided by the total landscape area per 100 ha
RPR - Relative blot richness	n. of different types of stains divided by the maximum potential of types of stains in %
SHDI - Shannon Diversity Index	Indicates the diversity of types of stains. The greater the number, the greater the richness of the landscape.
SIDI - Simpson Diversity Index	It indicates the diversity of types of stains, but less sensitive to the existence of rare stains
MSIDI - Modified Simpson Diversity Index	Index increases as the number of different types of blot (richness) increases more equitably
SHEI - Shannon Equity Index	Indicates an even distribution of area between types of spots (sum of spots / logarithm spots)
MSIEI Modified Simpson Equity Index	Indicates an even distribution of area between the types of spots (logarithm of the sum of spots/logarithm spots)

Source: Fragstats© 4.3 - Eduard Ene & Kevin Mcgarigal (2024)

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Table 4 - Composition of the Formula

Class	Formula
PR - Richness of stains	PR = m
PRD - Stain Richness Density	PRD = $\frac{m}{A}(10.000)(100)$
RPR - Relative blot richness	RPR = $\frac{m}{m_{max}}(100)$
SHDI - Shannon Diversity Index	SHDI = $\sum_{i=1}^{m}(P_i \ln P_i)$
SIDI - Simpson Diversity Index	SIDI = 1 - $\sum_{i=1}^{m} P_i^2$
MSIDI - Modified Simpson Diversity Index	MSIDI = $-\ln \sum_{i=1}^{m} P_i^2$
SHEI - Shannon Equity Index	SHEI = $\frac{-\sum_i^m (P_i \ln P_i)}{\ln m}$
MSIEI Modified Simpson Equity Index	MSIEI = $\frac{-\ln \sum_{i=1}^{m} P_i^2}{\ln m}$

Table 5 - Legends

Symbol	meaning
m	No. of types of spots (classes) present in the landscape, excluding the edge of the landscape, if present
The	Total landscape area
m_{max}	No. of maximum spot types (classes) present in the landscape, excluding the edge of the landscape, if present
P_i	Proportion of landscape occupied by patch type (class) i

With the results obtained, the table was organized observing the BARC in the years 1985 and 2022, focusing on the evaluation of the transformations that occurred in the diversity of the landscape structure.

3 RESULTS

The following categorical maps represent the situation of the landscape structure in the years 1985 (Figure 2) and 2022 (Figure 3) respectively:

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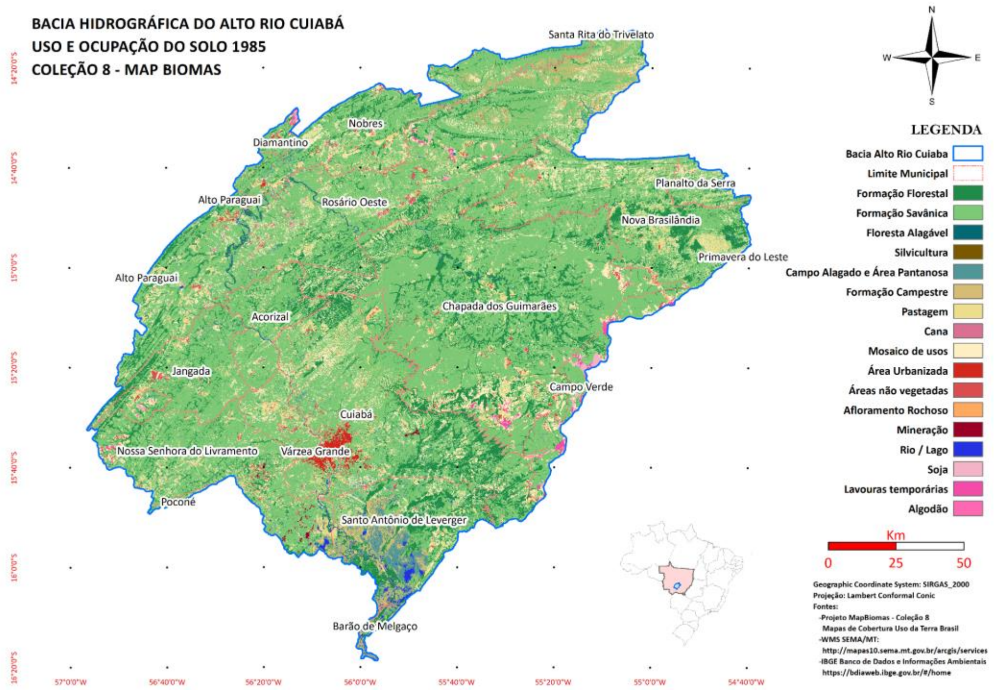
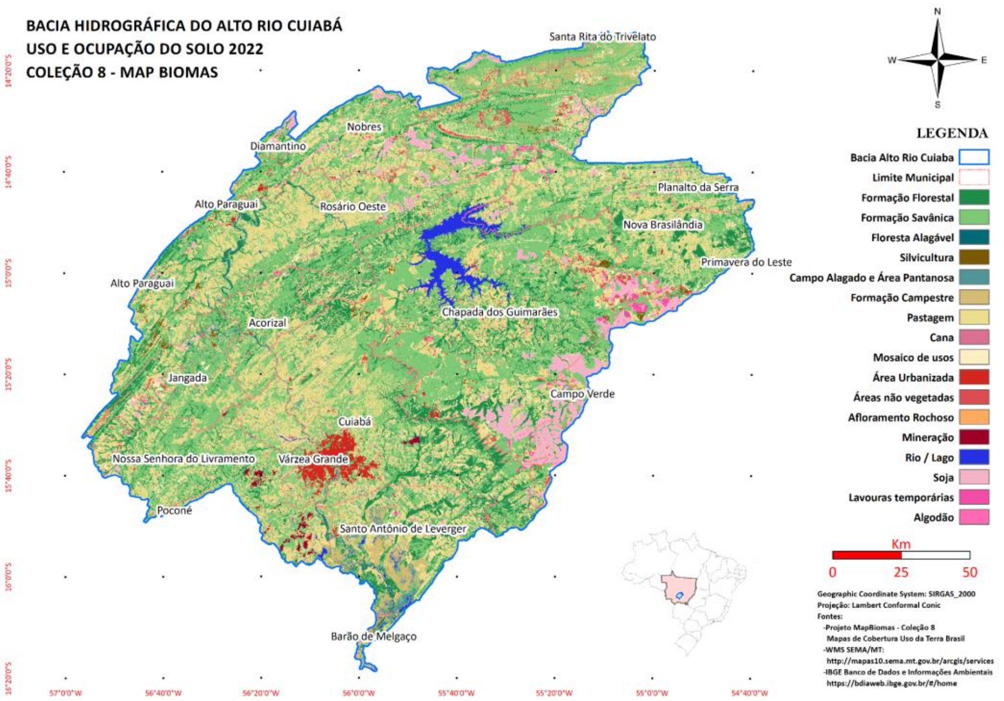
Figure 2 – Land use and occupation 1985 - BARC



Data source: collection 8 MapBiomas 2024, map made by the author

Figure 3 – Land use and occupation 2022 - BARC



Data source: collection 8 MapBiomas 2024, map made by the author

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From the data contained in the raster images, the images were inserted into the Fragstats© 4.3 program and processed as described in section 2, and the results shown in Table 5 were obtained.

Table 5 – BARC Landscape Diversity Metric 1985/2022

	METRIC	PR	PRD	RPR	SHDI	SIDI	MSIDI	SHEI	MSIEI
YEAR									
1985		12	0,0004	60,00 %	1,2652	0,5667	0,8364	0,5092	0,3366
2022		15	0,0005	75,00 %	1,6539	0,7289	1,3052	0,6107	0,4820

Source: Fragstats 4.3

Analyses indicated an increase in the richness of patches or patches (**PR**), a result that was already expected since there was an increase in the number of classes identified between the years 1985 and 2022, due to the difference in the treatment of images obtained by different satellites, Landsat 5 and Landsat 8 respectively.

The density of Spot Richness (**PRD**) increased indicating an increase in different types of spots present at the BARC boundaries. This indicator can represent an increase in the diversity of patches or a greater fragmentation of the landscape, with the formation of islands resulting from the process of shredding (Lang et al., 2007).

The Relative Richness of the Spot (**RPR**) is a direct consequence of the increase in the number of classes mapped between the years 1985 and 2022, as it represents the increase in the number of different types of spots. In 2022, data on land use and occupation classes related to Silviculture, sugarcane and cotton cultivation were added, which were not present in the survey carried out in 1985.

The Shannon Diversity Index (**SHDI)** has undergone an increase that can be interpreted as a more proportional distribution of the area of different types of classes. A reduction in the proportion of Forest Formation and Savannah Formation and the increase of other classes, especially patches related to human activities, explain the variation in the index.

The Simpson Diversity Index (**SIDI)** has its conceptual origins in the ecology of communities and has the characteristic of being less susceptible to the presence of rare spots, that is, those spots that have an insignificant area when compared to the other classes. In the case of BARC, the index corroborated the analysis that there was an increase in the proportional distribution of the types of spots in the boundaries of the study region.

The increase in the Modified Simpson Diversity Index (**MSIDI)** also indicates an increase in spot richness, but the calculation of the index brings it closer to another class of landscape diversity index, the Shannon class.

The Shannon Equity Index (SHEI) and the Modified Simpson Equity Index (**MSIEI)** indicate the uniformity of an area, with indices close to zero indicating the dominance of a certain type of stain and higher values indicating an equity in the distribution of stains, which in the context of the data obtained, translates into an increase in the richness of typologies.

The analysis of the landscape structure indicators indicated that in the comparison between the year 1985 and the year 2022 there was an increase in the equity of spot typologies, which could be considered an increase in richness in general terms. However, as pointed out by Lang (2007), there is an ambivalence in certain metrics because an increase can, depending on the context of analysis, be considered positive or negative changes in relation to the parameters of nature conservation

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4. CONCLUSION

This study provided a detailed analysis of the transformations that occurred in the Upper Cuiabá River Basin (BARC) from 1985 to 2022, with a particular focus on the alteration of landscape structure caused by human activity. Using advanced Geographic Information Systems (GIS) techniques and analysis of landscape-related metrics by the Fragstats© software, it was possible to quantify the extent and nature of landscape fragmentation resulting from agricultural expansion and urbanization. The results indicate not only an increase in landscape heterogeneity, but also a substantial decline in natural vegetation areas, with important consequences for the environmental sustainability and ecological resilience of the region.

The study reveals a clear correlation between the growth of anthropogenic activities and the loss of native vegetation cover. This transformation of the landscape, although increasing the diversity of land use patches, suggests a deterioration of ecological integrity, manifested by the decline of forest and savannah formations. Such changes have direct implications for local biodiversity, ecosystem services and the quality of life of communities dependent on these natural resources. Based on the study carried out, it will be important to carry out further investigations to verify, for example, the impacts of these landscape changes on the local fauna and flora. Studies focused on indicator species can help to better understand the long-term ecological consequences of observed changes. Also important will be the analysis of existing public policies and the development of new strategies that emphasize sustainable land use and occupation practices. Studies that integrate socioeconomic and environmental assessments can contribute to the improvement of territorial management and planning.

By suggesting these avenues for future investigations and interventions, this article hopes to contribute to scientific knowledge in the field of landscape ecology and also offer a path for adopting sustainable practices that harmonize human needs with environmental preservation

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