ANALYSIS OF THE VEGETATION FRAGMENTS CONNECTIVITY: A CASE STUDY IN THE TIETÊ-JACARÉ HYDROGRAPHIC BASIN – SP, BRAZIL

ANÁLISE DA CONECTIVIDADE DOS FRAGMENTOS DA VEGETAÇÃO: UM ESTUDO DE CASO NA BACIA HIDROGRÁFICA DO TIETÊ-JACARÉ – SP, BRASIL

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Abstract: This work aims to analyze the connectivity of landscape fragments present in the Tietê-Jacaré Watershed - SP, through the application of metric indices of Connectivity and Fragmentation. Considering the 10-year interval, there was an expansion of agricultural activities with an increase of 24,507.53ha of cultivated areas and loss of vegetation of 32,149ha. A decrease in the number of fragments was also evidenced, as well as an increase in the average size of the fragments, due to the growth of the agricultural matrix with consequent reduction in fragment diversification.

Keywords: Landscape analysis; Fragmentation; Landscape indexes.

Resumo: Este trabalho tem como objetivo analisar a conectividade dos fragmentos de paisagem presentes na Bacia Hidrográfica do Tietê-Jacaré - SP, por meio da aplicação dos índices métricos de Conectividade e Fragmentação. Considerando o intervalo de 10 anos, houve expansão das atividades agrícolas com aumento de 24.507,53ha de áreas cultivadas e perda de vegetação de 32.149ha. Também foi evidenciada a diminuição do número de fragmentos, bem como o aumento do tamanho médio dos fragmentos, decorrente do crescimento da matriz agrícola com consequente redução da diversificação do fragmento.

Palavras-chave: Análise da paisagem; Fragmentação; Índices de paisagem.

1. INTRODUCTION

With the development and growth of societies, the compatibility between the use of natural resources and the preservation of ecosystems becomes necessary, since the destruction of these resources changes the landscapes, reflecting on their ability to contribute with goods and services to society[1]. The substitution of native forests for other land uses alters the landscape configuration, which assumes the character of a fragmented mosaic[2].

When these occur without adequate planning to mitigate impacts, they can generate ecosystems with low resilience and resistance to natural or man-made disorders[3]. The landscapes have a diversified mosaic among their elements, such as fragments and corridors that exercise the function of connecting the elements and the matrix, known as the dominant unit in the fragments mosaic[4].

In the fragmentation process, the forest remnants are often isolated and immersed in an anthropogenic matrix, whether agricultural or urban, which is most often inappropriate for the survival of certain species[5]. This has negative effects on the pattern of habitat use, such as reducing the original extension, increasing the number of fragments, and increasing the degree of isolation[6]. The habitat fragmentation is one of the most cited causes of species extinction and loss of biological diversity, is defined as the process by which a continuous area of habitat is reduced in size and divided into fragments separated by a different matrix from the original[7][8].

The decrease in the size of the fragments increases the influence of the perimeter-area, the so-called edge effect, which provides microclimate changes among the main negative impacts, the increase in the activity of predators on the edges, the increase in species mortality due to unfavorable conditions of the matrix environment and greater

[1] ENCIMA, C. C. C.; MARQUES, M. R.; DIODATO, M. A.; MOTTA, J. S.; GODOI, R. F.; OLIVEIRA, J. R. S.; GAMARRA, R. M.; DALMAS, F. B.; PARANHOS FILHO, A. C. Analysis of Plant Structure of Cerrado Biome Fragments Through Remote Sensing. Geosciences Institute Yearbook, v.41, p. 585 – 597, 2018. http://dx.doi.org/10.11137/2018_2_585_597

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probability of invasion of exotic species[9,10]. The decrease in connectivity limits the dispersion of organisms, causing negative consequences in populations since it reduces the genetic flow, and may, on a large scale, lead to loss of genetic diversity. In degraded environments, forest restoration is essential as a means of recovering and increasing connectivity between fragments and consequently promoting ecosystem services essential for the conservation and maintenance of ecosystems[11,12].

Studies involving the processes of connectivity between fragments and ecological flows have been considered a priority in the investigation of landscape ecology. Currently, the analysis of landscape fragmentation is done through mapping of land use and land cover, making it possible to identify different patches and determine the degree of fragmentation or connectivity[13,14]. The changes that have occurred in a landscape, as well as the analysis of forest fragmentation patterns, can be studied through the evaluation of landscape indexes or metrics for quantitative and qualitative characterization, which also allow for comparing landscapes, identifying differences and determining relationships between processes and their respective standards[15,16].

For example, the study developed by Encima et al., (2018)[17] aimed to analyze the vegetation structure of Cerrado (Brazilian Savanna) fragments through multitemporal composition, based on the Normalized Difference Vegetation Index and Normalized Difference Moisture Index, being possible to detect changes in vegetation cover and humidity over the thirty years between 1985 and 2015.

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[17] ENCIMA, C. C. C.; MARQUES, M. R.; DIODATO, M. A.; MOTTA, J. S.; GODOI, R. F.; OLIVEIRA, J. R. S.; GAMARRA, R. M.; DALMAS, F. B.; PARANHOS FILHO, A. C. Analysis of Plant Structure of Cerrado Biome Fragments Through Remote Sensing. Geosciences Institute Yearbook, v.41, p. 585 – 597, 2018. http://dx.doi.org/10.11137/2018_2_585_597

In this way, through the analysis of mappings carried out with data from orbital sensors from different eras or years, it is possible to analyze the evolution and dynamics of landscape fragmentation. In this context, geoprocessing tools and statistical analyzes based on land use and land cover mapping assist in assessing the degree of fragmentation or connectivity of the landscape[18][19].

Given these considerations, this work aims to analyze the landscape connectivity of the fragments present in the territory of the Tietê-Jacaré Hydrographic Basin - SP, through the application of the metrics indexes of Connectivity and Landscape Fragmentation, in order to observe and evaluate the dynamic and temporal process of fragments in 2007 and 2017.

2. MATERIAL AND METHODS

2.1 Study area

The State Laws n.7.663, of 12/30/91 (São Paulo, 1991) and 9.934 of 12/27/1994 institute the management of water resources in São Paulo state, which has been carried out through the Water Resources Management Units (WRMU). The state currently has twenty-two (22) WRMU, which were delimited from the concept of a river basin, according to which each unit encompasses the water resources that converge to a mainstream, necessitating a link between research and management (São Paulo, 1994)[20].

[18] GOERL, R. F.; SIEFERT, C. A. C.; SCHULTZ, G. B.; DOS SANTOS, C. S.; DOS SANTOS, I. Elaboration and application of fragmentation and connectivity indexes for watershed analysis. Brazilian Journal of Physical Geography, v.5, p.1000-1012, 2011. https://periodicos.ufpe.br/revistas/rbgfe/article/download/232678/26690

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[20] SÃO PAULO. State Law No. 9,034, of 12/27/1994. 1994. Available in<https://www.al.sp.gov.br/repositorio/legislacao/lei/1994/lei-9034-27.12.1994.html> Access on February 26, 2019.

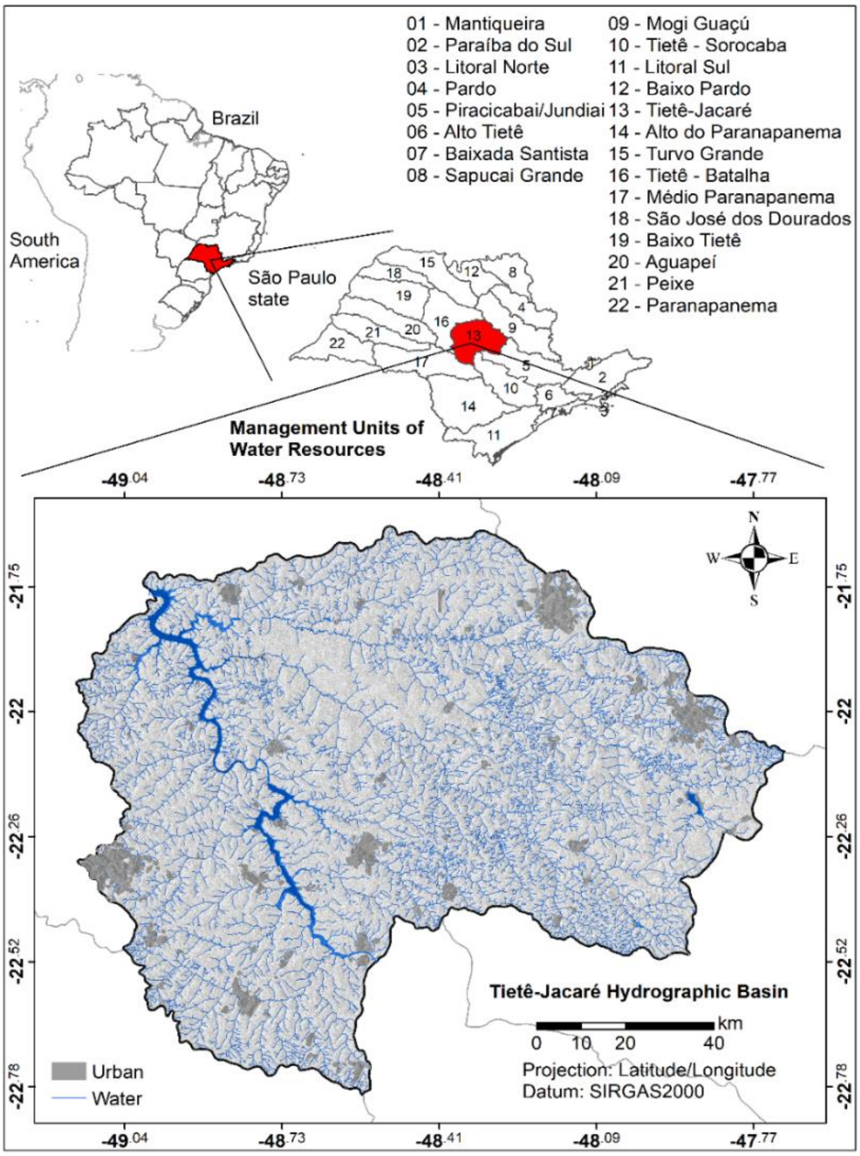

Figure 1: Tietê-Jacaré Hydrographic Basin - SP, Brazil

The Tietê-Jacaré Hydrographic Basin (Figure 1) is São Paulo state, Brazil, between 49º14' and 47º70' west and 21º62' and 22º79' south, with a population of 1,462.855 inhabitants and a total area of 1,181,090 hectares distributed in 37 municipalities. With a drainage area of 8,669.09km, the Tietê-Jacaré Hydrographic Basin contains three main rivers: the Tietê River, the Jacaré-Guaçu River, and the Jacaré-Pepira River. The climate by classification of Köppen-Geiger is between humid tropical climate (from October to March) and dry winter (from April to September)[21][22].

The main economic activities are related to agroindustry (sugar, alcohol, and citrus processing). In the largest municipalities such as Bauru, São Carlos, Araraquara, and Jaú,

[21] TUNDISI, J. G.; MATSUMURA-TUNDISI, T.; PARESCHI, D. C.; LUZIA, A. P.; VON HAELING, P. H.; FROLLINI, E. H. The Tietê-Jacaré Watershed: a case study in research and management. Advanced Studies, v.22 n.63 São Paulo, p.159-172, 2008. https://doi.org/10.1590/S0103-40142008000200010

[22] CBH-SM. Serra da Mantiqueira River Basin Committee. Water Resources Management Unit. 2015. Available in < https://www.comitesm.sp.gov.br/institucional.php?k=ugrhi> Accessed on June 8, 2019.

other sectors of the industry such as paper, beverages, footwear, and metalworking also stand out[23][24]. The region of the Tietê-Jacaré Hydrographic Basin is inserted in the biomes of the Atlantic Forest (23%) and Brazilian Savanna (Cerrado) (77%), considered biodiversity hotspots. For presenting consolidated development characteristics, which integrate several municipalities with a high degree of urbanization and industrial and agricultural potential, and inserted in important regions of natural ecosystems, the Tietê-Jacaré Hydrographic Basin becomes a potential area for analyzing the connectivity relationships between the landscape compartments and their interrelationships with anthropic development and natural areas, assessing how they influence the conservation of ecosystems.

2.2 Methodology

The information was analyzed in Geographic Information Systems (GIS), using the ArcGis 10.5 and DepthMapX 0.5 software (**Figure 2**). For the landscape characterization, a georeferenced database of the Tietê-Jacaré Hydrographic Basin was prepared in the geographic projection latitude/longitude, datum SIRGAS2000 for the entire information plan. The delimitation of the Tietê-Jacaré Hydrographic Basin was obtained from the digital database of the Brazilian Institute of Geography and Statistics (IBGE), version 2015.

[23] TUNDISI, J. G.; MATSUMURA-TUNDISI, T.; PARESCHI, D. C.; LUZIA, A. P.; VON HAELING, P. H.; FROLLINI, E. H. The Tietê-Jacaré Watershed: a case study in research and management. Advanced Studies, v.22 n.63 São Paulo, p.159-172, 2008. https://doi.org/10.1590/S0103-40142008000200010

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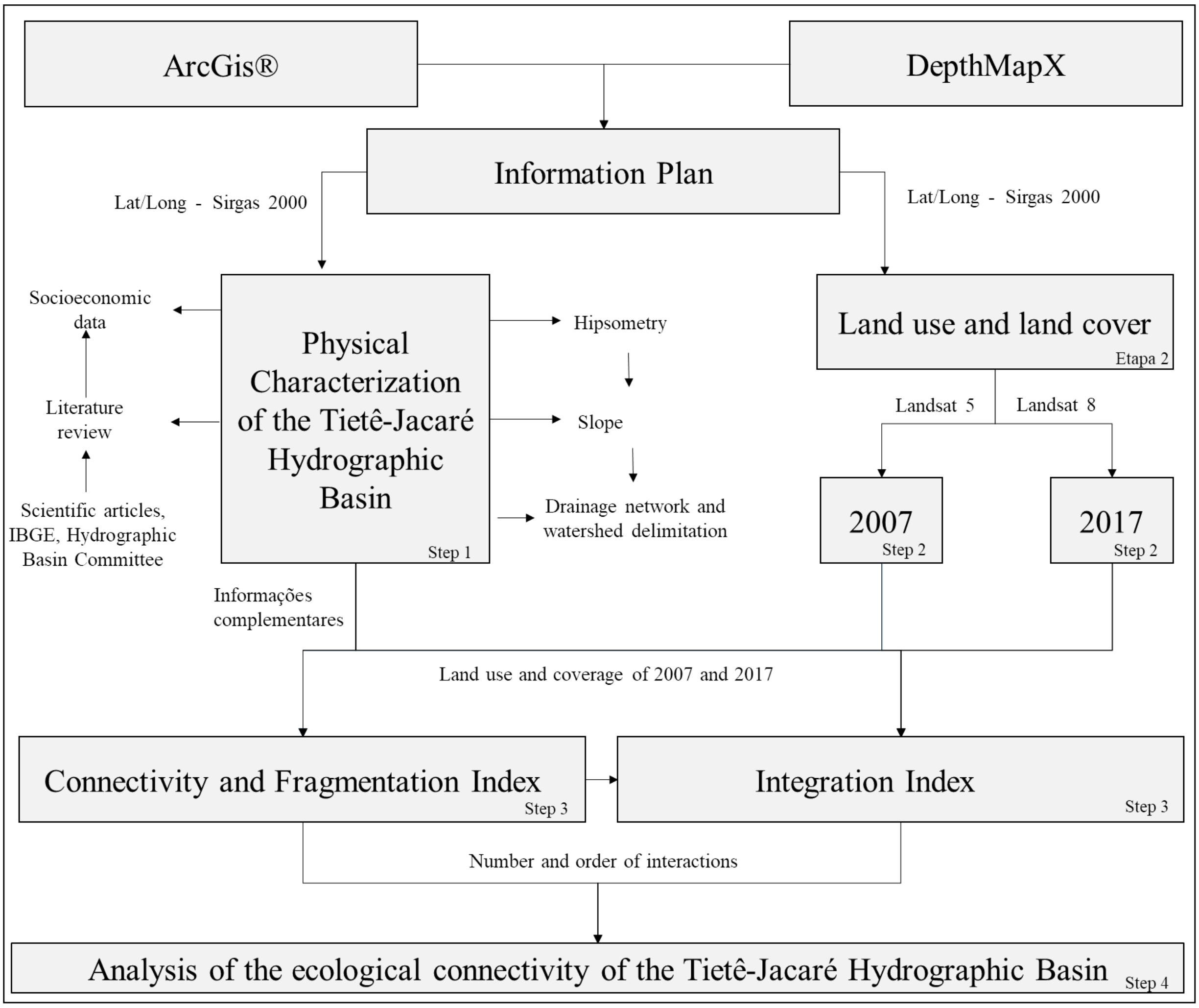

Figure 2: Work chart

The files were imported into the Geographic Information System, which enabled the analysis and digital processing of the vector file, using the IBGE planialtimetric charts, acquired in an analog form on the 1:50,000 scale[25]. Through the digitalization on-screen, drainage lines were obtained, and the delineation of hydrographic sub-basins was obtained, acquired through the digitalization of territorial limits, determined and directed by the elevations of the land, present in the hypsometric classes.

By visual on-screen digitizing the land use and land cover were based on the multi-level classification system proposed by the Land Use Technical Manual from IBGE[26]. In the primary level, four classes were included that indicate the principal land use categories. The secondary level analyzed the types of land uses that were included in the first level and the tertiary level explained the land uses themselves (Table 1).

[25] IBGE. Brazilian Institute of Geography and Statistics. Planialtimetric charts. 1971. Available in <ftp://geoftp.ibge.gov.br/cartas_e_mapas/folhas_topograficas/editoradas/escala_50mil> Accessed on March 27, 2019.

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Tabela 1. Description of land use and land cover classes.

Class (I)	Type (II)	Description (III)
Anthropogenic and not agricultural areas	Urban areas	Dense urban area and areas with rural developments (industrial and household)
Anthropogenic-agricultural areas	Sugarcane	Cultivation area of *Saccharum officinarum L.*
	Citrus	Cultivation area of *Citrus sinensis*.
	Pastures	An area with a predominance of herbaceous vegetation (native or exotic), used for extensive livestock farming.
	Silviculture	Cultivation area of Eucalyptus *spp* or *Pinus spp*.
	Soil exposed	Soil fallow area for *Saccharum officinarum L.* cultivation
Vegetation	Natural vegetation	An area with a predominance of tree vegetation, with vegetation types of semi-deciduous forest and *Cerrado*.
Water	Water	Large rivers, lakes, ponds, and reservoirs.

The time dynamics of land use and coverage was performed based on the visual classification of LandSat images available on the United States Geological Survey platform[27], dated April 21, 2007, and March 11, 2017. Through the digitalization on screen, a "pixel" was assigned to each class of use. For analysis of land use and land cover in 2017, images from the LandSat 8 satellite - OLI / TIRS sensor, bands 6/5/4, were used, and for 2007, images from the LandSat 5 satellite - TM sensor, bands 5/4/3 were used, referring to the orbits/points 220/75, 220/76, and 221/75, 221/76.

The use of different satellite scenes[28] occurred due to the unavailability of images by a single satellite during the study period, where the images used for this study had the same spatial resolution of 30 meters. The dates were selected according to the work schedule to be carried out, where the periods of March and April, due to the seasonality of the agricultural practices prevalent in the region. The 10-year difference between the

[27] USGS. Scientific agency for natural sciences, 2017. LandSat 5 and LandSat 8. Available in < https://earthexplorer.usgs.gov> Accessed on March 27, 2019.

[28] USGS. Scientific agency for natural sciences, 2017. LandSat 5 and LandSat 8. Available in < https://earthexplorer.usgs.gov> Accessed on March 27, 2019.

images made it possible to study the temporal patterns of the landscape, essential in directing regional planning, which considered the current growth and development aspects.

2.3 Analysis of fragments connectivity and fragmentation of the Tietê-Jacaré Hydrographic Basin

To analyze the fragments connectivity and fragmentation, the Metric Connectivity and Fragmentation Indexes were adapted from McGarigal et al., (1995)[29]; Volotão (1998)[30], Goerl et al., (2011)[31] and Rempel et al., (2012)[32]. It was considered the territorial ordering analyzed from the information present in the characterization of land use and land cover by images from the LandSat 5 and 8 satellites from 2007 and 2017.

Several authors have been developing works related to landscape connectivity and fragmentation[33][34][35][36][37][38][39][40], mainly related to the creation of ecological corridors and displacement of species. The study by Madureira (2012)[41] addressed the concept of green infrastructure in the contemporary urban landscape and the challenge of connectivity and the opportunity for multifunctionality, with the aim of presenting, developing and

[29] MCGARIGAL, K.; CUSHMAN, S. A.; NEEL, M.C.; ENE, E. FRAGSTATS: Spatial pattern analysis program for categorical maps: user manual v. 2.0, 1995, 141p.

[30] VOLOTÃO, C. F. S. Spatial analysis work: Fragstats metrics. INPE, São José dos Campos, 1998, 48p.

[31] GOERL, R. F.; SIEFERT, C. A. C.; SCHULTZ, G. B.; DOS SANTOS, C. S.; DOS SANTOS, I. Elaboration and application of fragmentation and connectivity indexes for watershed analysis. Brazilian Journal of Physical Geography, v.5, p.1000-1012, 2011. https://periodicos.ufpe.br/revistas/rbgfe/article/download/232678/26690

[32] REMPEL, R.S.; KAUKINEN; CARR, A. P. Patch analyst and patch grid. Ontario Ministry of Natural Resources. Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, 2012. https://www.umass.edu/landeco/research/fragstats/links/fragstats_links.html

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[36] GOERL, R. F.; SIEFERT, C. A. C.; SCHULTZ, G. B.; DOS SANTOS, C. S.; DOS SANTOS, I. Elaboration and application of fragmentation and connectivity indexes for watershed analysis. Brazilian Journal of Physical Geography, v.5, p.1000-1012, 2011. https://periodicos.ufpe.br/revistas/rbgfe/article/download/232678/26690

[37] MADUREIRA, H. Green infrastructure in the contemporary urban landscape: the challenge of connectivity and the opportunity for multifunctionality. Journal of the Faculty of Arts – University of Porto, v.1, p.33 - 43, 2012. http://ojs.letras.up.pt/index.php/geografia/article/download/10/10

[38] LORONI, M. L. Connectivity and ecological networks in fragmented landscapes: applications in biodiversity conservation and ecological restoration. 2015. Available in < https://www.criandoelo.com.br/wp-content/uploads/2015/10/Maria-Lucia-Lorini.pdf> Accessed on January 11, 2019.

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[40] ADAMCZYK, J.; TIEDE, D. Zonal Metrics: A Python toolbox for zonal landscape structure analysis. Computers & Geosciences, v.99, p.91-99, 2017. https://doi.org/10.1016/j.cageo.2016.11.005

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discussing the concept of green infrastructure and connectivity, discussing the challenge connectivity of urban green areas as an ecological, social and urban composition value.

To analyze the number of connections from the ecological network in the analyzed periods, the tool "Groups" and "Region Group" was used to identify the existing connections, considering all the fragments, through the "pixel" analysis of the generated images by the “Overlay” tool, allowing the quantification and ordering of connectivity in the hydrographic basin[42][43].

This classification was performed using the “Eight” functions that define the connectivity between cells of the same value if they are within the immediate vicinity of each other (including right, left, above or diagonal) and “Within” that tests the connectivity between equal input values in the same zone, where the only cells that can be grouped are cells of the same value that meet the specified spatial connectivity requirements).

The study of fragments connectivity and fragmentation of the Tietê-Jacaré Hydrographic Basin was complemented by the metric indexes of Connectivity and Landscape Fragmentation, considering that the more fragmented the landscape, the lower the connectivity between its elements[44]. Land use and land cover are one of the most used indicators to determine the degree of fragmentation of a study area or a watershed. In this way, indexes (Table 2) were elaborated based on attributes of land use and coverage, calculated using the “Raster Calculator” function and the “Patch Analyst” plugin in ArcGis 10.5.

Table 2. Indexes for assessing the degree of connectivity and fragmentation of the landscape

Index	**Equation**	**Unity**	**Description**
Average fragment area per class	$F_{cx} = \frac{A_c}{N_{fc}}$	ha	Average size of fragments by class
Total area	$At = \sum Af$	ha	Total size of fragments
Average fragment area	$F_{ax} = \sum \frac{A_f}{N_f}$	ha	Average fragment area
Total area of fragments	$Ac = \sum Afc$	ha	Total size of fragments by class

[42] CASERI, A. N.; FERRAZ, S. F. B.; DE PAULA, F. R. Assessment of hydrological connectivity in the Corumbataí River basin, SP. Annals. II Seminar on water resources in the Paraíba do Sul Hydrographic Basin: recovery of degraded areas, environmental services and sustainability, Taubaté, p.223-232, 2009.

[43] WEIS, C. V. C.; HASENACK, H.; BECKER, F. G.; LIMA, L. T.; TERCEIRO, A. M. Geoprocessing tools applied in the temporal analysis of connectivity between lagoons on the north coast of Rio Grande do Sul, Brazil. Annals. XVI Simpósio Brasileiro de Sensoriamento Remoto – SBSR. INPE, p.5523 – 5528, 2013.

[44] GOERL, R. F.; SIEFERT, C. A. C.; SCHULTZ, G. B.; DOS SANTOS, C. S.; DOS SANTOS, I. Elaboration and application of fragmentation and connectivity indexes for watershed analysis. Brazilian Journal of Physical Geography, v.5, p.1000-1012, 2011. https://periodicos.ufpe.br/revistas/rbgfe/article/download/232678/26690

by class			
Occupied relative area	$ARO = \frac{\frac{A_c}{N_{fc}}}{\frac{A_t}{N_f}}$	-	Value refers to how much each class occupies in relation to the total area
Average declivity	$S = \sum \frac{S_{xt}}{N_{ft}}$	o	Mean slope value
Average declivity by class	$S = \sum \frac{S_{xc}}{N_{fc}}$	o	Average slope value by class
Fragmentation density	$F_d = \frac{N_f}{A_t}$	Nf/ha	Number of fragments in relation to the area
Fragmentation density by class	$F_{dc} = \sum \frac{N_{fc}}{A_c}$	Nf/ha	Number of fragments in relation to area by class
Perimeter density (edge)	$DP = \frac{P}{At}$	m/m^2	Relationship of the perimeter to the total area
Perimeter density (edge) by class	$DPc = \frac{Pc}{Atc}$	m/m^2	Relationship of the perimeter to the total area by class
Standard deviation of mean fragment area	$DesvP_{Fax} = \frac{\sqrt{Af - Fax^2}}{Nfc}$	ha	Variation in the size of the spots under the average value
Standard deviation of the average fragment area per class	$DesvP_{Fax} = \frac{\sqrt{Afc - Faxc^2}}{Nfc}$	ha	Variation in spot size under average value per class
Average shape indicator	$IF = \frac{P}{At^2}$	m/m^2	Express how close the spot is to a circle. The closer the value is to 1, the shape of the stain is more like a circle.
Average shape indicator by class	$IFc = \frac{P}{Ac^2}$	m/m^2	
Largest fragment index	$F_m = \frac{F\,max}{A_t} x100$	%	Relationship of the largest fragment to the total area
Largest fragment index by class	$F_m = \frac{F\,max\,c}{A_t c} x100$	%	Relationship of the largest fragment to the total area by class
Average of fragments	$F_x = \frac{N_f}{N_c}$	-	Average number of fragments
Total number of fragments	$N_f = \sum N_{fc}$	-	Total number of fragments
Average perimeter	$P = \sum \frac{Cf}{Nf}$	m	Average perimeter length

(edge			
Average perimeter (edge) per class	$P = \sum \frac{Cfc}{Nf}$	m	Average perimeter length per class

Source: McGarigal et al., (1995)[45]; Volotão (1998)[46], GOERL et al., (2011)[47] e Rempel et al., (2012)[48]

Ac = area of each class; Af = fragment area; Afc = area of the class fragment; At = total area; Cf = Length of the fragment; Cfc = Length of fragments by class; SD = perimeter density; DPc = perimeter density by class; DevP = Standard deviation; Fax = average area of fragments; Faxc = average fragment area per class; Fmax = largest fragment of the basin; Fmaxc = largest fragment of the class; nc = number of classes; IF = Form index; IFc = Form index by class Nf = total fragments; Nfc = fragments of each class; P = perimeter; Pc = class perimeter; Sxc = mean slope of the class; Sxt = average slope.

The connectivity and landscape fragmentation indices calculated for the study area were separated into two main groups, the general indicators, and the relative fragmentation indicators. Thus, the general indicators were the indices calculated considering the hydrographic basin entirely as a unit of analysis, allowing the comparison and evaluation of the fragmentation and connectivity conditions between different basins and sub-basins[49][50]. The relative indicators were the metrics established for the classes of uses and land cover found in the hydrographic basin, allowing the elaboration of a comparative analysis between the classes of use and allowing an evaluation of the behavior of the basin in face of impacts caused by the occurrence of processes of any nature[51][52], as for example, through the analysis of the Average Declivity indicator by Class of use and

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land cover it was possible to determine the potential capacity of the fragments of each class to connect with the fragments downstream[53].

3. RESULTS AND DISCUSSION

3.1 Land use and land cover

The uses of sugarcane, water, citrus, diverse cultures (by satellite image resolution, some regions such as corn, coffee, and rice were grouped in the same use), pastures, silviculture, and vegetation (Figure 2) were classified. The interval of 10 years showed an expansion of agricultural activities with an increase of 24,507.53ha (2.05% of the total area) of cultivated areas, mainly by sugar cane cultivation.

The 10-year time interval is small considering the total size of the region. However, this change between the landscape land uses explains the consolidation state of the anthropic activities, where regions whose agricultural activities occur are already predefined and delimited. In 2007, approximately 72% of the area showed a predominance of agricultural activities, being 542,114ha occupied by sugarcane, 49,272.60ha by silviculture, 76,817.59ha by pasture, 62,121.90ha by citrus cultivation and 1,315.71ha by diverse cultures (Table 3).

The exposed soil areas are associated with crops (122,046ha), as they refer to the fallow period and soil preparation for the next harvest. Pasture areas arise in small territorial portions, becoming a subsistence or small-scale production activity. Sugar cane is predominant in all municipalities, but in some regions, other types of agricultural cultures are predominant, such as citrus cultivation in the Araraquara, Nova Europa, and Gavião Peixoto region, and forestry in the Agudos and Pederneiras and Brotas and Itirapina region. In 2017, approximately 74% of the area presented the predominance of agricultural activities, being 607,455ha occupied by sugarcane, 58,258ha by silviculture, 51,564.9ha by pastures, 38,198.80ha by citriculture, 1,382.63ha by diverse cultures and 121,346ha by exposed soil. It was observed the growth of 65,331ha of sugarcane crops, where areas of other agricultural uses or soil exposed were converted contributing to the predominance of this crop in the region.

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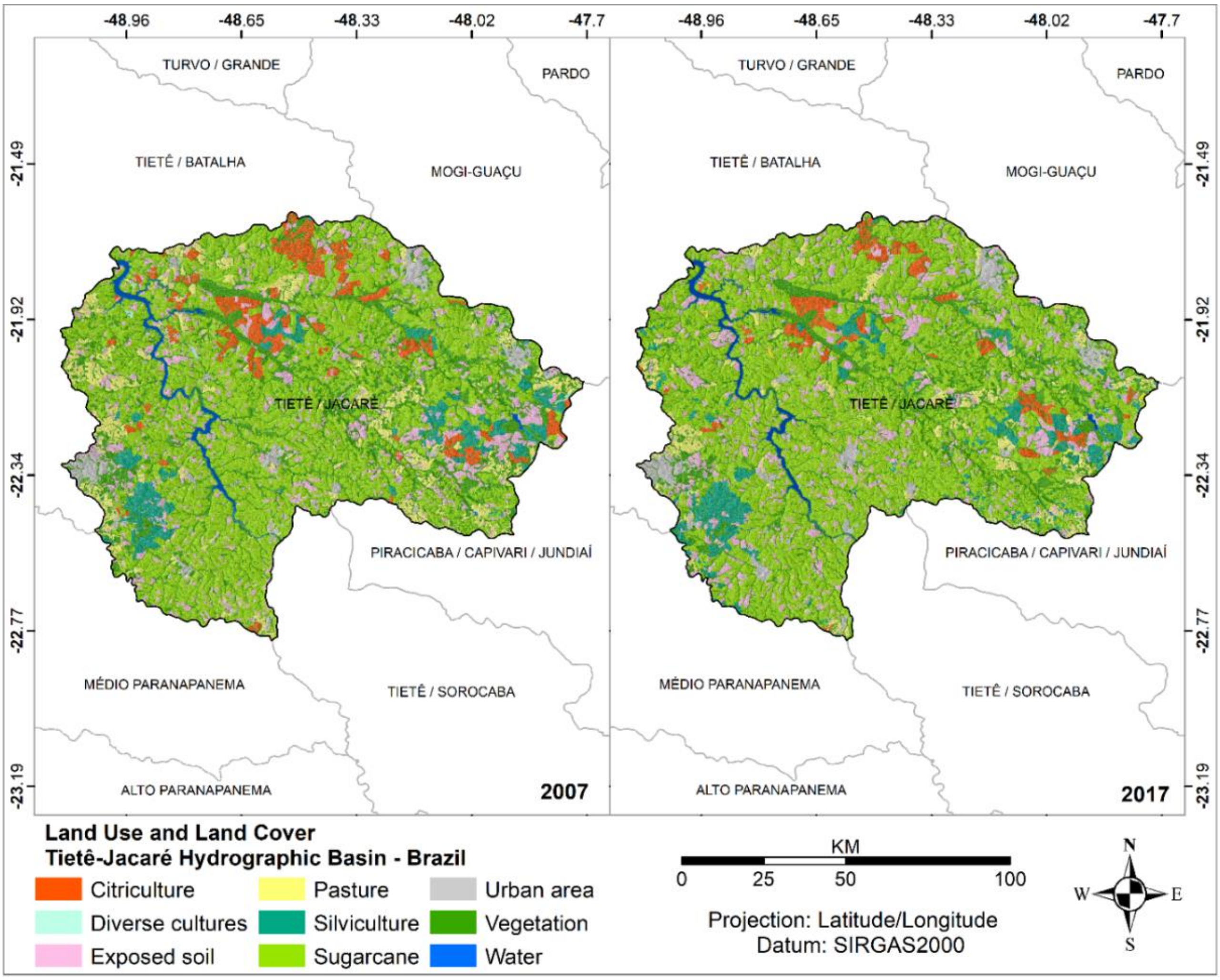

1. **Figure 2**: Land use and land cover of the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

Urban areas had increased 7,832.67ha (36,148.40ha in 2007 and 43,981.07ha in 2017) and this growth was more noticeable in medium to large municipalities, such as Jaú, Bauru, São Carlos and Araraquara, where small municipalities such as Torrinha, Ibaté, and Brotas, still maintain their structures mainly focused on activities related to the agricultural and industrial sector with industrial support from the larger municipalities.

Table 3. Distribution of land use and land cover classes of the Tietê-Jacaré Hydrographic Basin for 2007 and 2017.

Classes	Land use 2007		Land use 2017	
	Area (ha)	%	Area (ha)	%
Sugarcane	542,124.00	45.90	607,455.00	51.43
Water	16,955.80	1.44	16,764.60	1.42
Citriculture	62,121.90	5.26	38,198.80	3.23
Diverse cultures	13,15.71	0.11	13,82.63	0.12
Pastures	76,817.59	6.50	51,564.90	4.37

Silviculture	49,272.60	4.17	58,258.00	4.93
Exposed soil	122,046.00	10.33	121,346.00	10.27
Urban area	36,148.40	3.06	43,981.07	3.72
Vegetation	274,288.00	23.22	242,139.00	20.50
Total	**1,181,090.00**	**100.00**	**1,181,090.00**	**100,00**

This predominance of crops and mainly of sugarcane coincides with the characteristics of the São Paulo state, mainly in the interior, which is the largest producer of sugarcane in Brazil. This, as well as in the Tietê-Jacaré Hydrographic Basin, is due to the conditions favorable to its cultivation, such as the existence of fertile soils that allow the average productivity higher than in other regions[54][55]. In the case of the Tietê-Jacaré Hydrographic Basin, with the expansion of sugarcane cultivation areas, it is similar to studies carried out with this theme and different regions[56][57].

The vegetation is fragmented along the study area, presenting a loss of approximately 2.7% in ten years (32,149ha) and these fragments are immersed in the agricultural matrix and mostly associated with water. A fact that correlates with the reduction of the region's main water masses, with a loss of 191,20ha. The natural remnants are located near the Tietê-Jacaré River, in the municipalities of Itajú, Bariri, Ibitinga, and Bocaina, near the Jacaré-Guaçu River in the municipalities of Ribeirão Bonito, São Carlos, Ibaté and Itirapina, near the Jacaré-Pepira River in the municipalities of Dourado and Brotas and Rio Jaú, in the municipalities of Jaú and Mineiros do Tietê.

The studies conducted by Moraes (2013)[58] and Mello (2014)[59] also evidenced the process of fragmentation in the landscape due to anthropic action, which analysed the vegetation types of Cerrado (Brazilian Savanna) and Seasonal Semideciduous Forest (vegetation types present in the study area). The Atlantic Forest and the Cerrado are two

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hotspots of biodiversity and it is necessary to plan to avoid the fragmentation process of the landscape due to the advancement of anthropic activities[60]. These impacts compromise all environmental structures and services, such as impacts on soils that support vegetation cover and the major sources of energy for terrestrial life[61][62].

The uncontrolled land occupation and inadequate soil management have led to several environmental problems, such as soil compaction, decreases infiltration of rainwater, and increased runoff. This set of factors favors the intensification of the water erosion process, which can evolve to the laminar, groove, or ravine form[63][64]. In the case of water resources management, the issue of water quality impairment for domestic supply is due to the pollution caused by different sources such as household, industrial, urban, and agricultural effluents. The contamination by industrial effluents is due to the raw materials and industrial processes used and may be complex concerning the nature, concentration, and volume of the waste produced. The degradation of the water sources occurs because of the increase of the primary activity of the plants and algae caused by the nitrogen and phosphorus from the farms and confined animal production[65][66].

The overgrowth of algae and plants reduces the availability of dissolved oxygen in the water, adversely affecting the aquatic ecosystem and sometimes causing fish mortalities. In addition to the impacts to aquatic ecosystems, increasing nutrient levels in water may jeopardize their use for domestic supply on account of changes in the taste and odor of water or the presence of toxins released by the flowering of some types of algae[67][68].

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The transition matrix (Table 4) showed an alteration of 34.70% in the Tietê-Jacaré Hydrographic Basin's landscape between 2007 and 2017. The exposed soil areas were the ones that suffered the most changes (85.10%), due to their fallow characteristics for other uses. The transition characteristics were similar in all regions of the river basin, due to the predominance of activities related to sugarcane, which in turn directed the other fragments of the landscape to be converted to such cultivation.

Table 4. The transition of land use of the Tietê-Jacaré Hydrographic Basin for 2007 and 2017.

Transition matrix	**Hectares in 2007**	**Hectares kept 2017**	**Hectares converted**	**% Hectares converted**
Sugarcane	542,124.00	421,977.14	120,146.86	22.20
Water	16,955.80	16,764.60	191.20	1.10
Citriculture	62,121.90	23,037.40	39,084.50	62.90
Diverse cultures	1,315.71	1,315.71	0.00	0.00
Pastures	76,817.59	24,744.32	52,073.27	67.80
Silviculture	49,272.60	29,396.77	19,875.83	40.30
Exposed soil	122,046.00	18,230.60	103,815.40	85.10
Urban area	36,148.40	36,148.40	0.00	0.00
Vegetation	274,288.00	199,764.83	74,523.17	27.20
Total	**1,181,090.00**	**771,379.77**	**409,710.23**	**34.70**
		1,181,090.00		

Agricultural uses also changed, such as citrus (62.90%), pasture (67%), forestry (40.30%), and sugarcane (22.20%). Some of these areas have either become fallow or no-till areas for sugarcane cultivation. The natural areas changed 36.4%, which were converted between the other uses, although some areas were recovered (**Table 5**).

Table 5. Distribution of land use and land cover transition of the Tietê-Jacaré Hydrographic Basin for 2007 and 2017.

Transition (2007 - 2017)		**Area (ha)**	**Transition (2007 - 2017)**		**Area (ha)**
Sugarcane	Sugarcane	421,977.14	Pasture	Urban	1,921.98
Sugarcane	Citriculture	5,944.67	Pasture	Vegetation	7,765.59
Sugarcane	Pasture	9,834.27	Silviculture	Sugarcane	5,935.15
Sugarcane	Silviculture	10,181.10	Silviculture	Citriculture	904.11
Sugarcane	Exposed soil	72,449.10	Silviculture	Pasture	1,020.50

Sugarcane	Urban	2,373.09	Silviculture	Silviculture	29,396.77
Sugarcane	Vegetation	19,364.63	Silviculture	Exposed soil	7,152.34
Water	Sugarcane	67.22	Silviculture	Urban	48.23
Water	Water	16,764.60	Silviculture	Vegetation	4,815.50
Water	Citriculture	0.51	Exposed soil	Sugarcane	77,737.30
Water	Pasture	40.19	Exposed soil	Citriculture	5,868.57
Water	Silviculture	21.00	Exposed soil	Pasture	6,110.23
Water	Exposed soil	0.61	Exposed soil	Silviculture	6,929.36
Water	Urban	16.71	Exposed soil	Exposed soil	18,230.60
Water	Vegetation	44.97	Exposed soil	Urban	557.08
Citriculture	Sugarcane	25,698.81	Exposed soil	Vegetation	6,612.87
Citriculture	Citriculture	23,037.40	Urban	Urban	36,148.40
Citriculture	Pasture	541.94	Uses	Uses	1,315.71
Citriculture	Silviculture	1,386.02	Vegetation	Sugarcane	43,881.30
Citriculture	Exposed soil	7,847.92	Vegetation	Citriculture	2,098.69
Citriculture	Urban	289.77	Vegetation	Pasture	9,198.46
Citriculture	Vegetation	3,311.06	Vegetation	Silviculture	6,953.22
Pasture	Sugarcane	32,197.40	Vegetation	Exposed soil	9,302.40
Pasture	Citriculture	350.02	Vegetation	Urban	3,022.18
Pasture	Pasture	24,744.32	Vegetation	Uses	66.92
Pasture	Silviculture	3,347.49	Vegetation	Vegetation	199,764.83
Pasture	Exposed soil	6,490.80			

The most significant transitions in the watershed region are related to the conversion of areas with natural vegetation to the cultivation of sugarcane (in all the municipalities), totaling 43.881ha in 10 years. However, in the various regions, the recovery of agricultural areas to vegetation occurred, although despite being significant. During this period, the restoration or recovery of large areas did not occur, but rather small fragments throughout the landscape.

The predominance of sugarcane in the region also meant that other agricultural uses were converted to this crop, such as pasture (32,197.40ha), citriculture (25,698.81ha), and silviculture (5,935.15ha). Although this activity is consolidated in the region, moving a large part of the economic sector of the region, some caveats are necessary related to the monopolization of the sugarcane and the conservation of natural ecosystems. Various authors discuss the impacts of the transition from natural or even agricultural fragments to sugar cane or other crops[69][70][71] monocultures. As Zimmermann (2009)[72] says, "the simplification of ecosystems, an indispensable process for the development of extensive monoculture, is extremely dangerous for the maintenance of those that are, in general, complex."

3.2 Analysis of the fragment's connectivity and fragmentation of the Tietê-Jacaré Hydrographic Basin

The vegetation structure was observed by the Ecological Connectivity Index (Figure 4), which demonstrated that the vegetation configuration of the Tietê-Jacaré Hydrographic Basin between 2007 and 2017 suffered little structural changes, with the main connections being related to the executory each sub-basin and consequently the hydrographic basin.

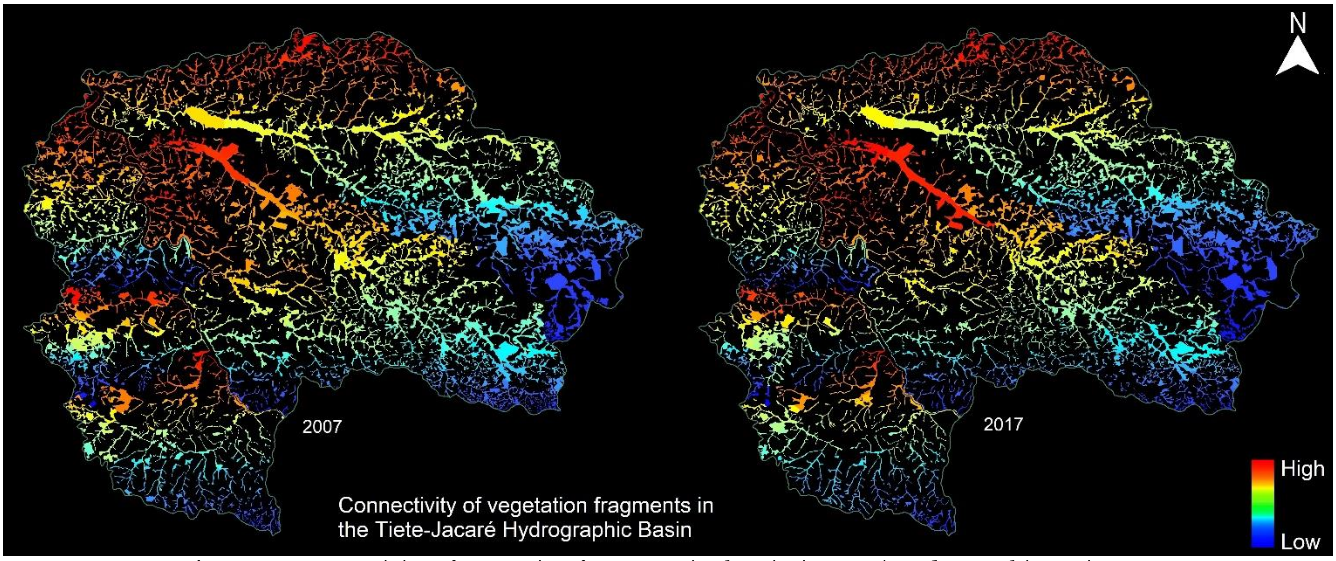

Figure 4: Connectivity of vegetation fragments in the Tietê-Jacaré Hydrographic Basin.

Between 2007, about 19% of the fragments (417) had low or no connectivity and in 2017 that number increased to 23% (515), related to the growth of fragmentation, with a decrease in areas with high connections from 17.53% (384) to 14.12% (315). In both periods, the main connection fragments of the landscape are in the regions of the Jacaré-

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Guaçu and Jacaré Pepira sub-basin, however, they are also the areas that most present fragments with low connectivity in 2007 and 2017 (90 and 149 and 102 and 135 respectively).

The growth of vegetation fragmentation contributed to the decrease in the number of interactions between the fragments of the hydrographic basin, which showed an average decrease of 18% (Table 6 and Figure 5). In 2007, the total number of connections was 2,648, falling to 2,158 in 2017, totaling a decrease of 490 interactions (18.50%). The region has five orders of connections, with secondary connections as predominant, with 462 (21.10%) in 2007 and 549 (24.61%) in 2017.

Table 6. Distribution of the number of interactions of vegetation fragments in the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Sub-basin	Interactions (2007)	%	Interactions (2017)	%	% Decrease
Bauru River	246	9.29	157	7.28	36.18
Claro River	323	12.20	300	13.90	7.12
Jacaré-Guaçu River	807	30.48	598	27.71	25.90
Jacaré-Pepira River	553	20.88	523	24.24	5.42
Jaú River	408	15.41	290	13.44	28.92
Lençóis River	311	11.74	290	13.44	6.75
Total	**2,648**	**100.00**	**2,158**	**100.00**	**18.50**

This decrease was similar in all regions of the hydrographic basin (Figure 6), with the sub-basin of the Jacaré-Guaçu River, where the municipalities of São Carlos, Araraquara, Ibaté, Matão, among others are located, presented the largest number of interactions, totaling 27% of all vegetation fragments in the region. The sub-basins of the Rio Bauru and Rio Lençóis showed the highest losses of fragments in the studied period, with a decrease of 90 and 94 fragments, also showing a decrease in the number of isolated fragments, which indicates their disappearance in the conversion to other types of fragments. land uses.

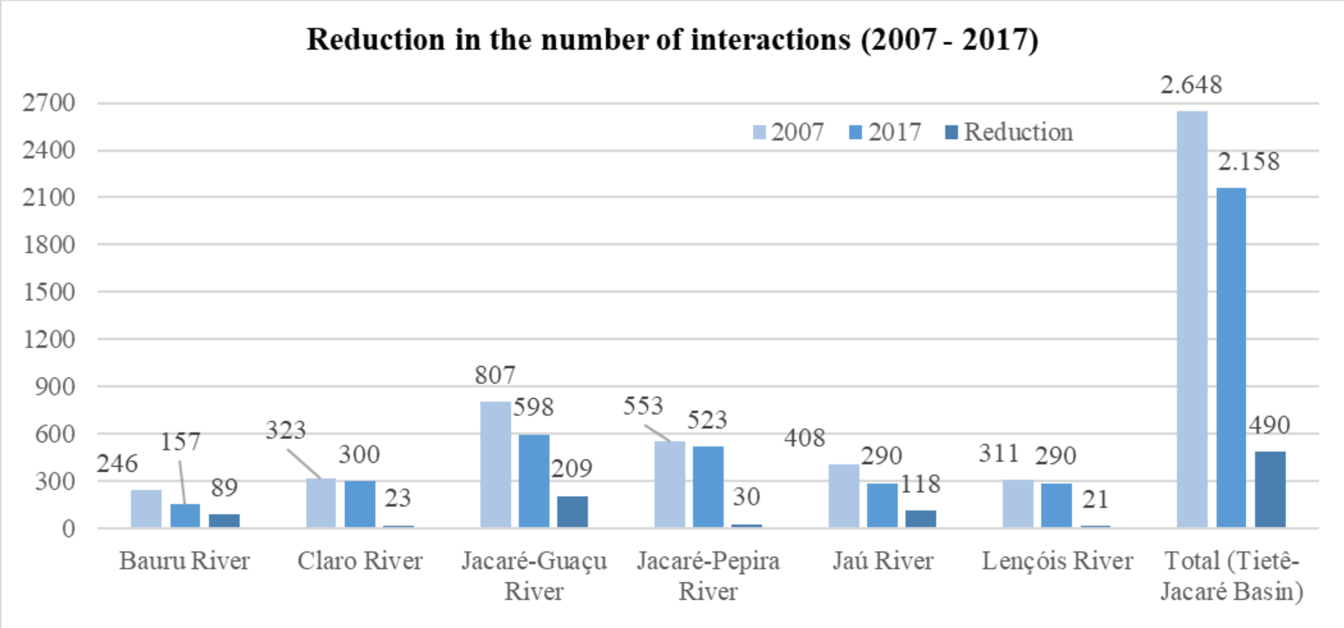

Figure 5: Number of interactions of vegetation fragments in the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Table 7 presents the general fragmentation indicators for the hydrographic basin in 2007 and 2017, with 5,866 and 5,521 fragments being identified respectively, which have a density of 0.0050 and 0.0047 fragments per hectare and an average size of 201.17 and 213.18ha, however with a standard deviation of approximately 375 and 405ha. There was an average of 655 and 613 fragments per class of use and land cover with the area of the largest fragment occupying approximately 0.78 and 0.77% of the total area of the basin.

Table 7. Connectivity and fragmentation rates of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Index	2007	2017
Total area of fragments (ha)	1,181,090,00	1,181,090.00
Average fragment area (ha)	201.35	213.93
Average declivity	6.37	6.37
Fragmentation density (nf / ha)	0.0050	0.0047
Perimeter density	39.73	38.38
The standard deviation of mean fragment area	375.60	405.09
Average shape indicator	1.81	1.82
Largest fragment index (%)	0.78	0.77
Average fragments per class	655.33	613.88
Total number of fragments	5,866.00	5,521.00
Average perimeter (edge)	7,999.73	8,574.47

The structural indicators of the fragments, such as perimeter density and shape index, are similar between the periods analyzed as long as 39.73 and 38.38 and 1.81 and 1.82 in 2007 and 2017 respectively, which is related the consolidation of the activities developed in the region as well as the organization and distribution of fragments in the landscape. The decrease in the number of fragments, as well as the increase in their average size, are mainly due to the growth of agricultural matrices with a consequent decrease in the diversification of fragments of the classes of use and land cover in the region of the study area, as was evidenced in the analysis of temporal dynamics. In contrast, the degree of fragmentation of the vegetation class increased, totaling 2,190 and 2,231 fragments, an average area of 125.25 and 108.53ha, and standard deviation from 250.87 to 256.16 in 2007 and 2017 respectively (Table 8 and Figure 6).

Table 8. Connectivity and fragmentation rates by class of land use and land cover in the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Usage classes / Index	**AT**		**AM**		**DF**	
	2007	**2017**	**2007**	**2017**	**2007**	**2017**
Urban area	36,148.40	43,981.07	187.30	193.75	0.00534	0.00516
Water	16,955.80	16,764.60	66.49	70.14	0.015	0.014
Vegetation	274,288.00	242,139.00	125.25	108.53	0.0080	0.0092
Exposed soil	122,046.00	121,346.00	88.38	125.49	0.0011	0.0080
Citriculture	38,198.80	62,121.90	381.99	913.56	0.0016	0.0018
Diverse cultures	1,315.71	1,382.63	263.14	276.53	0.0038	0.0036
Pasture	76,817.59	51,564.90	250.22	261.75	0.0040	0.0038
Forestry	49,272.60	58,258.00	473.78	257.78	0.0021	0.0039
Sugar cane	542,124.00	607,455.00	407.31	446.33	0.00075	0.00074

Usage classes / Index	**NTF**		**ARO**		**DMC**		**IMF**	
	2007	**2017**	**2007**	**2017**	**2007**	**2017**	**2007**	**2017**
Urban area	193	227	0.93	0.91	5.80	5.87	10.82	9.60
Water	255	239	0.33	0.33	3.85	3.65	53.77	54.39
Vegetation	2,190	2,231	0.62	0.51	7.69	7.76	1.33	2.94
Exposed soil	1,381	967	0.44	0.59	6.56	6.63	0.11	1.83
Citriculture	100	68	1.90	4.27	6.63	6.66	7.33	16.19

Diverse cultures	5	5	1.31	1.29	6.44	6.40	30.69	32.47
Pasture	307	197	1.24	1.22	6.84	6.91	3.36	6.32
Forestry	104	226	2.35	1.20	6.53	7.06	6.81	5.50
Sugar cane	1,331	1,361	2.02	2.09	6.70	6.80	0.73	0.68
Usage classes / Index	**DP**		**DesvP**		**IF**		**PM**	
	2007	**2017**	**2007**	**2017**	**2007**	**2017**	**2007**	**2017**
Urban area	1.02	1.14	523.30	522.03	1.48	1.47	6,287	5,934
Water	0.69	0.67	678.52	667.86	1.42	1.76	3,229	3,323
Vegetation	14.50	14.29	250.87	256.16	2.06	2.07	7,821	7,568
Exposed soil	4.97	4.29	144.85	183.25	1.58	1.50	4,255	5,240
Citriculture	1.22	0.72	723.50	814.20	1.81	1.59	14,454	12,527
Diverse cultures	0.038	0.037	149.57	160.10	1.65	1.60	9,075	8,930
Pasture	2.55	1.58	339.04	353.11	1.88	1.83	9,806	9,445
Forestry	1.01	1.42	564.57	469.64	1.83	1.48	11,339	7,392
Sugar cane	13.68	14.21	444.07	484.17	1.84	1.76	12,137	12,.338

At = total area; Am = average area; DF = fragmentation density; NTF; Total number of fragments; ARO = Occupied relative area; DMC = Average declivity by class; IMF = Index of the largest fragment; SD = perimeter density; DevP = Standard deviation; form index; PM = Average perimeter

Regarding the analysis of the number of fragments and the average area by the class of use, there was also a predominance of agricultural areas, with sugarcane again as the main activity, totaling 1,331 and 1,361 fragments with averages of 407.31 and 446, 33ha and standard deviation 444.07 and 484.17 in 2007 and 2017 respectively. This fact also occurs with the Occupied Relative Area, which indicated how much the fragments of each class occupy in relation to the area and the total number of fragments, which predominated in the forestry regions with 2.35 and 1.20 and cane sugar of 2.02 and 2.09.

The relationship between the relative area occupied and the total number of fragments made it possible to estimate the degree of fragmentation of each class of land use and cover. Urban areas, with few fragments and low relative occupied area, are characteristic examples of fragments that congregate in different conglomerates throughout the study area, differently from the behavior of sugarcane areas that have a high quantity of fragments with the high relative occupied aerial area, which is observed with the dissolution and predominance of such activity throughout the entire hydrographic basin.

As for the hydrographic basin as a whole, land use and land cover classes showed high Form index values between 1.5 and 2 (according to Rempel et al., 2012[73], the closer to 1, the lower the effect of edge). The Fragmentation Density by Class indicated the number of fragments in relation to the area by class of use and land cover, in which, the greater its value, the greater the number of fragments in relation to the area, and the greater the area and the smaller the number of fragments, the lower the fragmentation density. The entire hydrographic basin showed low fragmentation density, due to its territorial extension, with 0.0050 and 0.0047 in 2007 and 2017. Such fragmentation density may be related to the predominance of agricultural matrices with large fragments and the classification resolution land use and coverage, carried out on a 1: 50,000 scale, which may have inhibited the real fragmentation within the division of the analyzed regions.

Through the analysis of the indicator "Average Declivity by Class of Use and land cover" it was possible to determine the potential capacity of the fragments of each class to connect with the fragments downstream. According to Goerl et al., (2011)[74] this connection can occur mainly through the propagation of surface flow via flow generation mechanisms, as well as the type of matter produced by the upstream fragments, such as the diffuse transport of pollutants, acid resins and sediments generated via erosive processes.

The Tietê-Jacaré hydrographic basin showed a homogeneous average slope over the classes of land use and coverage, having, as expected, the areas of water bodies with the lowest rates, which indicates an interconnection between the classes of use and coverage of the land. land, which implies the different possibilities of impacts or influences of the regions, with each other. The landscape alteration process as analyzed in the Tietê-Jacaré Hydrographic Basin, was also noticed in studies from other regions[75][76][77] which observed

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the fragmentation process natural areas, as well as the impacts caused by human activities. OLIVEIRA et al., (2014)[78] aimed to map the land cover and analyze the fragmentation metrics of the landscape of the upper São Bartolomeu watershed - Federal District of Brazil, which showed that most of the remaining fragments of vegetation were under pressure by the agricultural matrix due to the accelerated process of land occupation in its surroundings, not always planned and organized.

The disordered occupation of the land and the inadequate management of the soil have caused several environmental problems, such as: soil compaction, decrease in the amount of rainwater infiltrated and increased runoff. This set of factors propitiates the intensification of the water erosion process, which can evolve in the laminar form, in the groove, ravine or gullet[79][80].

In the case of hydrographic basin management, the issue of compromising water quality for domestic supply purposes is due to pollution from different sources, such as domestic effluents, industrial effluents and urban and agricultural surface runoff. The degradation of springs, resulting from the superficial agricultural defluvium, occurs mainly due to the increase in the primary activity of plants and algae due to the supply of nitrogen and phosphorus from crops and animal production in a confined regime[81][82].

4. FINAL CONSIDERATIONS

The Tietê-Jacaré Hydrographic Basin region has a high potential for the development of agricultural activities, which were confirmed by the classification of land use and coverage that demonstrated the predominance of such activities in all regions of

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the basin. It is essential to be concerned not only with the current condition of the region, but with the trends that have solidified over the years, such as the loss of natural areas and changes in the pattern and organization of the landscape due to the expansion of human activities. Ecosystems, with their environmental goods and services, support various anthropic and socioeconomic activities, and when overloaded beyond their support capacity, they can compromise the fulfillment of human needs.

The hydrographic basin showed a reduction in environmental quality and an increase in the predominance of anthropic activities that consequently culminated in changes in the patterns of connectivity and fragmentation, where urban areas and sugarcane are predominant in these interconnections. This preponderance must be observed in more detail regarding the planning of the hydrographic basin, mainly related to the possible impacts caused by them.

The temporal dynamics of land use and coverage, associated with connectivity and fragmentation rates, when expressing the state of landscape configuration, presented themselves as important tools in the diagnosis aimed at the conservation of ecosystems, enabling a precise analysis of the elements that compose them. Such indexes also allowed the comparison not only of natural fragments, but of all classes of land use and coverage, which is essential in regional planning, such as the case of river basins. However, it is emphasized that the analysis of fragmentation and connectivity must always be contextualized and its discussions based on the scale of analysis used, as this can imply changes in the observation of studies.

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