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LAND USE AND COVER IN THE MUNICIPALITY OF CAMAÇARI, NORTH COAST OF BAHIA, BRAZIL: 1990 TO 2022

Uso e cobertura da terra no municipio de Camaçari, Litoral Norte da Bahia, Brasil: 1990 a 2022

Uso y cobertura del suelo en el municipio de Camaçari, Costa Norte de Bahia, Brasil: 1990 a 2022

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ABSTRACT

Changes in land use and land cover often result in habitat loss, which has been identified as a major threat to biodiversity conservation and ecosystem maintenance, essential for human health, quality of life, and economic development. This quantitative study of the rural area of the municipality of Camaçari, with 429.12 km², used the Land Cover Change tool of the QGIS program and land cover and use mapping from the MapBiomas Project. The objective was to analyze the spatiotemporal behavior of the landscape, focusing on forest habitats and the anthropic matrix, including the understanding of the socioeconomic dynamics of the area, using the area metric, between 1990 and 2022. In 1990, there was 132.39 km² of forest, while in 2022 the total was 144.45 km². Of this total, approximately 65% corresponded to preserved forests, and 35% to regenerated forests. During this period, 41.84 km² of forest were deforested and an increase in urban areas was observed. Recent research indicates that 40% of the landscape should be covered by forests, with 10% in a single or few larger fragments. With 33% of forest and the largest fragment occupying only 5.7% of the landscape, the rural landscape of Camaçari is below this fragmentation threshold, where the effects of the configuration aggravate the loss of forest habitat. Furthermore, the small increase in forest area does not reflect qualitative improvements in habitats, as revealed by significant changes in the configuration of the landscape. To ensure a landscape favorable to biodiversity, it is essential to conserve all forests in the landscape.

Keywords: Spatiotemporal analysis; Mapbiomes; Fragmentation threshold.

ABSTRACT

As mudanças no uso e cobertura da terra frequentemente resultam na perda de habitat, o que tem sido apontado como grande ameaça para conservação da biodiversidade e manutenção dos ecossistemas, essencias para a saúde humana, qualidade de vida e desenvolvimento econômico. Este estudo quantitativo na área rural do município de Camaçari, com 429,12 km², utilizou a ferramenta *Land Cover Change* do programa QGIS e o mapeamento de cobertura e uso da terra do Projeto MapBiomas. O objetivo foi analisar o comportamento espaço-temporal da paisagem, com foco nos habitats florestais e na matriz antrópica, incluindo a compreensão da dinâmica socioeconômica da área, utilizando a métrica de área, entre os anos 1990 e 2022. Em 1990, havia 132,39 km² de floresta, enquanto em 2022 o total era de 144,45 km². Desse total, aproximadamente 65% correspondiam a florestas preservadas, e 35%, a florestas regeneradas. No período, 41,84 km² de floresta foram desmatados e observou-se um aumento da área urbanizada. Pesquisas recentes indicam que 40% da paisagem deve ser coberta por florestas, sendo 10% em um único ou poucos fragmentos maiores. Com 33% de floresta e com maior fragmento ocupando apenas 5,7% da paisagem, a paisagem rural de Camaçari encontra-se abaixo desse limiar de fragmentação, onde os efeitos da configuração agravam a perda de habitat florestal. Além disso, o pequeno aumento na área florestal não reflete melhorias qualitativas nos habitats, revelado por significativas alterações na configuração da paisagem. Para garantir uma paisagem favorável à biodiversidade é essencial conservar todas as florestas da paisagem.

Palavras-chave: Análise espaço-temporal*;* Mapbiomas; Limiar de fragmentação.

RESUMEN

Los cambios en el uso y la cobertura del suelo a menudo resultan en la pérdida de hábitat, lo que ha sido identificado como una amenaza importante para la conservación de la biodiversidad y el mantenimiento de los ecosistemas, esenciales para la salud humana, la calidad de vida y el desarrollo económico. Este estudio cuantitativo del área rural del municipio de Camaçari, con 429,12 km², utilizó la herramienta Land Cover Change del programa QGIS y el mapeo de cobertura y uso del suelo del Proyecto MapBiomas. El objetivo fue analizar el comportamiento espacio-temporal del paisaje, centrándose en los hábitats forestales y la matriz antrópica, incluyendo la comprensión de la dinámica socioeconómica de la zona, utilizando la métrica de área, entre los años 1990 y 2022. En 1990, existían 132,39 km² de bosque, mientras que en 2022 el total era de 144,45 km². De este total, aproximadamente el 65% correspondió a bosques preservados, y el 35% a bosques regenerados. Durante el período se deforestaron 41,84 km² de bosque y hubo un aumento del área urbanizada. Investigaciones recientes indican que el 40% del paisaje debería estar cubierto de bosques, y el 10% en uno solo o en unos pocos fragmentos más grandes. Con un 33% de bosque y el fragmento más grande ocupando apenas el 5,7% del paisaje, el paisaje rural de Camaçari está por debajo de ese umbral de fragmentación, donde los efectos de la configuración agravan la pérdida de hábitat forestal. Además, el pequeño aumento de la superficie forestal no refleja mejoras cualitativas en los hábitats, reveladas por cambios significativos en la configuración del paisaje. Para garantizar un paisaje favorable a la biodiversidad, es esencial conservar todos los bosques del paisaje.

Palabras clave: Análisis espacio-temporal; Mapbiomas; Umbral de fragmentación.

1 INTRODUCTION

The landscape, understood as a dynamic system made up of different physical and biological elements that interact at different levels and are influenced by human action, can be analyzed from the perspective of their structure and changes over time, considering their markedly spatial dimension (Pinto-Correia, 2021). In this study, landscape analysis focused on the dynamics of forest habitats and the anthropic matrix, defined as the set of non-habitat units for a given community or species (Metzger, 2001a).

Changes in land use and land cover have a direct effect on the structure of the landscape and the consequences of the changes can be identified in long-term processes (Guiomar *et al.*, 2021). Among these changes, habitat loss and fragmentation have been identified as a major threat to biodiversity conservation (Fahrig, 2003; Hooper *et al.*, 2005; Plagia *et al.*, 2006; Haddad *et al.,* 2015; Intergovernmental Platform on Biodiversity and Ecosystem Services - IPBES, 2019) and the maintenance of ecosystem services (Hooper *et al.*, 2005; IPBES, 2019; Assis *et al.*, 2023), which are fundamental to health, quality of life and human well-being and economic development. Reducing habitat loss has been considered a priority for biodiversity conservation (Villard; Metzger, 2014; Arroyo-Rodríguez *et al.*, 2020).

Knowing the interaction between structure and processes in the landscape allows us to assess possibilities for planning, building or developing sustainable landscapes. Arroyo-Rodríguez *et al.* (2020) cited these landscapes as favorable landscapes for biodiversity, arguing that relevant benefits for biological communities are directly related to the amount of forest cover in the landscape, supporting larger populations, genetic diversity and the persistence of forest species, which influences the provision of goods and services to humans on a local and landscape level. Therefore, they considered maintaining forest cover as a top priority, especially in humid tropics.

Landscape pattern quantification has received considerable attention since the early 1980s, both in terms of development and application (Gergel; Tunner, 2017). One of the ways of quantifying changes in the pattern of land use and cover is through the area indicator. This metric is presented by Botequilha-Leitão and Ribeiro (2021) as the easiest to read and most widespread measure of landscape structure and, therefore, perhaps the most important, being a compositional metric that is very simple to interpret and useful for describing the spatial pattern of different landscapes.

The area of habitats in the landscape is a key indicator for the United Nations'

Sustainable Development Goal (SDG) No. 15 (United Nations, 2015). This is Indicator 15.1.1, referring to forest area as a proportion of total land area, with the goal of ensuring the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, especially forests, wetlands, mountains and dry lands, in accordance with obligations arising from international agreements.

Though simple, area metrics are crucial as they are related to most, if not all, landscape configuration metrics (Volotão, 1998; Fahrig, 2003; Villard; Metzger, 2014). Area metrics make it possible to quantify the available habitat (McGarigal; Marks, 1995), which is positively related to the wealth of species and the number of individuals that a landscape can support (Volotão, 1998; Fahrig, 2003; McGarigal; Marks, 1995; Pardini *et al.*, 2010).

Considering "habitat" as the conditions and resources necessary for species to survive, several authors (Pardini *et. al.* 2010; Andrén, 1994; Fahrig, 2003; Metzger, 2010) have dealt with the relationship between the amount of habitat and the persistence of species, pointing out percentages of habitat in landscapes that can mean sudden changes in ecological systems, thus affecting biodiversity and the provision of ecosystem services. These are known as ecological thresholds, such as fragmentation, extinction and percolation thresholds.

The thresholds mainly depend on the characteristics of the landscape and the tolerance or sensitivity of the species to habitat loss (Volotão, 1998; Villard; Metzger, 2014). The changes that occur in ecological processes at ecological thresholds lead to a reduction in the landscape's capacity to sustain biological diversity (Metzger, 2010).

Pardini *et al.* (2010) indicate that the total amount of remaining native vegetation may be the most important property in anthropogenic landscapes capable of causing irreversible changes in ecological systems, and is considered the main aspect of landscape management, impacting on other variables that affect its resilience (Andrén, 1994).

At thresholds, there is a sudden change in the landscape structure, with a reduction in patch size, an increase in the number and isolation of patches (Metzger, 2010), species composition (Andrén, 1994) and loss of connectivity.

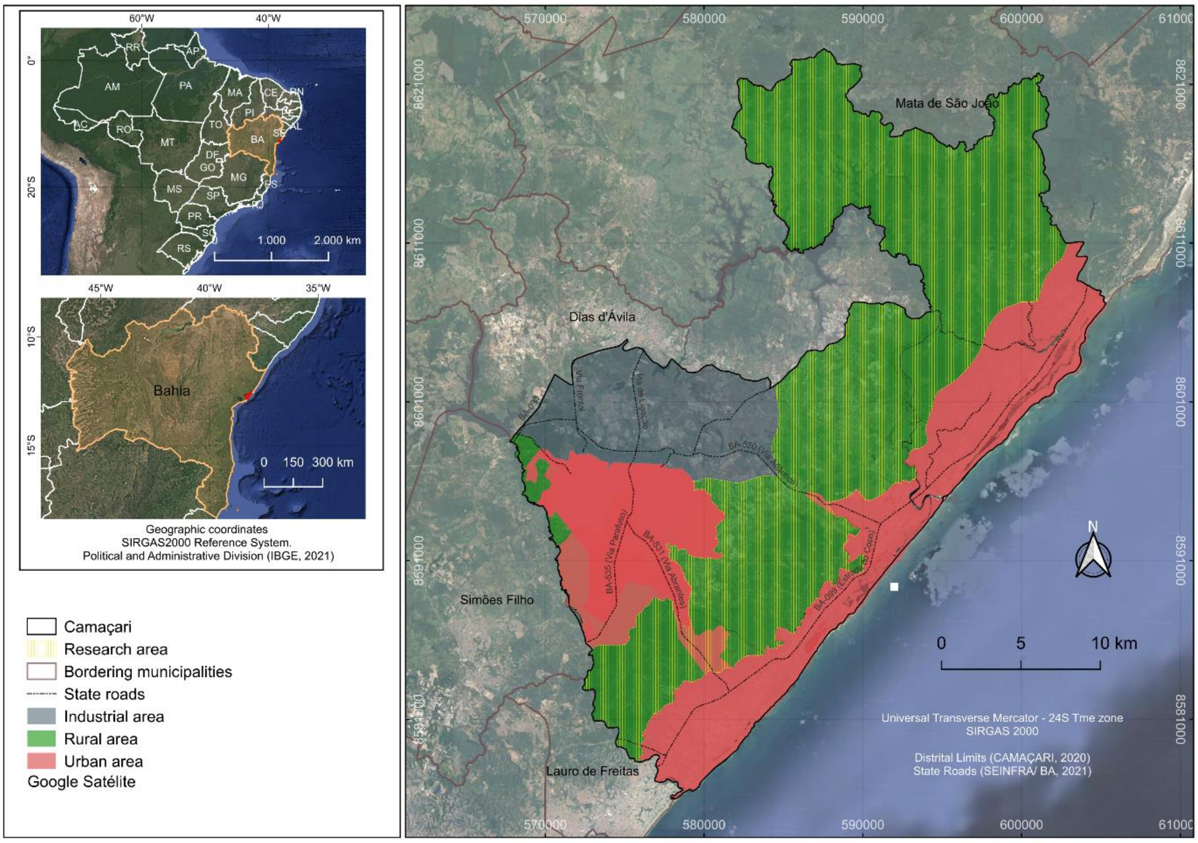
There is a need for studies on landscape dynamics, using metrics to assess the availability, fragmentation and loss of forest habitat, given the importance of maintaining minimum quantities for biodiversity conservation. With this in mind, the purpose of this article is to analyze the spatio-temporal behavior of Camaçari's rural landscape, with a focus on forest habitats, using the area metric from 1990 to 2022, and considering the influence of socio-economic dynamics.

2 METHODOLOGY

2.1 Study area

Camaçari is a municipality on the north coast of Bahia, in the metropolitan region of Salvador. It covers 785,421 ^{km2} (Instituto Brasileiro de Geografia e Estatística - IBGE, 2022), including urban, rural and industrial areas (Camaçari, 2008) (Figure 01), areas of great ecological importance due to being home to various phytophysiognomies and associated ecosystems, such as Sandbank Vegetations, Mangroves, Dense Ombrophilous Forests and Cerrado Enclave (Brazilian Savannah), as well as Bogs and Wetlands (IBGE, 2018).

Figure 01 – Location and macro-zoning of Camaçari and the study area



Source: Prepared by the authors (2024).

The research was carried out in the rural area to the east of the municipality of Camaçari, covering 429.12 km^2 (Figure 01). This area was selected after analyzing data sources (IBGE, 2018; Instituto do Meio Ambiente e Recursos Hídricos - INEMA, 2019; Fundação SOS Mata Atlântica; Instituto Nacional de Pesquisas Espaciais - INPE, 2023; Projeto MapBiomas, 2023), as it has Dense Ombrophilous Forest vegetation, given its importance in the Atlantic Forest biome. There was an overlap in two sites with the urban area, which is not yet consolidated, with rural characteristics or slums and urban communities. The rural area has been the target of anthropic interventions, under pressure from the adjacent urban areas on the edge of the municipality, marked by an intense process of occupation through the deployment of regularized soil plots and spontaneous occupations, resulting in the reduction of natural areas and threatening the conservation of local fauna and flora.

2.2 Methodological steps

To assess changes in the landscape, we used data from the Mapbiomas land cover and land use mapping, collection 8, for the years 1990, 2000, 2010 and 2022 (MapBiomas Project, 2023), produced on the basis of Landsat images with 30 m spatial resolution, with a spatial generalization that eliminates isolated areas smaller than 0.5 ha.

MapBiomas is a collaborative network that produces annual maps of land cover, land use and other products in Brazil. It has a platform that makes data available for free. It uses cloud processing and automated classifiers developed and operated from the Google Earth Engine platform to generate a historical series of annual land cover and land use maps of Brazil. Annual mapping from 1985 to 2023 is available, allowing changes in land use and vegetation cover to be monitored over time.

The methodology uses all the available images from each year, as well as spectral indices, texture indices and relief information so that the machine learning classifier can differentiate between the mapped classes.

The areas of the classes were quantified using the *r.report* tool in the GRASS GIS 7.8.7 add-on to the QGIS 3.22.14 - Białowieza program, allowing us to understand the spatial behavior of each class over the period analyzed.

The analysis of landscape evolution in the period 1990 to 2022 was carried out using the *Land cover change* - LCC post-processing tool from the *Semi-Automatic Classification Plugin* 7.10.11 add-on, also from QGIS 3.22.14 - Białowieza. This tool made it possible to evaluate the transitions in land use and cover in the period indicated and to point out the changes that occurred in that time range. A reclassification was made based on the transition of use and cover between the classes, using the *reclass* processing tool, also from the GRASS GIS 7.8.7 add-on.

The results obtained for the rural landscape of Camaçari were compared with the parameters proposed by Arroyo-Rodríguez *et al.* (2020) on fragmentation thresholds and the configuration of landscapes favorable to biodiversity conservation. These authors recommend maintaining at least 40% of the landscape area as forest, 25% of which should be in a single patch. In order to quantify the area occupied by the largest patch (McGarigal and Marks, 1995), the Largest Patch Index (LPI) was calculated using the Fragstats 4.2 program. The LPI is calculated by dividing the area of the largest patch in square meters by the total area of the landscape, multiplied by 100 (to convert into a percentage).

In order to understand the local socio-economic dynamics, a bibliographic survey was carried out on the Google Scholar platform using the term "Camaçari development". Three studies were selected for the discussion: Souza (2006), Andrade (2008) and Gileá *et al.* (2020), which presented a comprehensive view of the socio-economic changes that have taken place in the municipality in recent decades. In addition, complementary data on land use and cover was analyzed, such as the mapping of certified rural properties and those with environmental records, settlements (National Institute for Colonization and Agrarian Reform - INCRA, 2023) and mining areas (National Mining Agency - ANM, 2023). This data was important for assessing additional influences not captured by Mapbiomas, such as mining and occupation of rural properties, on the changes noticed in the landscape.

3 RESULTS AND DISCUSSION

The structure of Camaçari's 429.12 km^2 rural landscape (Figure 01) has undergone few quantitative changes in its composition over the analyzed decades (1990, 2000, 2010 and 2022).

The classes with the greatest representation in the landscape were: Forest formation and Mosaic of Uses, occupying 129.74 km² (30%) and 191.70 km² (44%) of the landscape in 1990, and 141.81 km² (33%) and 152.46 km² (35%) in 2022, respectively (Table 01). Other classes that are representative of the landscape are: marshland and pasture, occupying 30 km² (7%) and 63.3 km² (14%) of the landscape in 1990, and 31.97 km² (7%) and 78.02 km² (18%) in 2022, respectively (Table 01).

In 1990, 255.79 km² (60%) of the rural area was already anthropized (Urban area, Other non-vegetated areas and Agriculture), and by 2022 it would occupy 239.69 km² (54.6%) of the landscape. The Forest Plantation class, which was present on just 0.01 km² in 1990, now occupies 4.04 km² (1%) in 2020 (Table 01). And despite being a rural area, there was also an increase in the Urban Area class from approximately 1.9 km² to 2.02 km² (less than 1%) of the landscape (Table 01), which is still very incipient.

Table 01 – Quantity, in km² and %, of land use and land cover classes in the landscape in the analyzed decades

Classes - Level 1	Classes - Level 2	Area (%)							
		1990		2000		2010		2022	
		km²	%	km²	%	km²	%	km²	%
Non-forest Natural Formation	Wetlands	30.07	7%	32.86	8%	31.14	7%	31.97	7%
	Hypersaline Tidal Flat					0.04			
	Herbaceous Sandbank Vegetation	0.01		0.02		0.04		0.01	
Subtotal		30.08	7%	32.88	8%	31.22	7%	31.97	7%
Non-vegetated area	Beach, Dune and Sand Spot	0.07		0.04		0.07		0.06	
Forest	Forest Formation	129.74	30%	119.30	28%	129.09	30%	141.81	33%
	Mangrove	2.42	1%	2.53	1%	2.64	1%	2.56	1%
	Wooded Sandbank Vegetation	0.13		0.18		0.18		0.08	
Subtotal		132.29	31%	122.01	28%	131.91	31%	144.45	34%
Body of water	River, Lake and Ocean	10.89	3%	6.44	1%	12.53	3%	12.94	3%
Non-vegetated area	Urban Area	0.14		0.39		0.92		2.02	
	Other non-vegetated areas	0.64		0.93		0.44		3.11	1%
Agriculture	Forest Plantation	0.01		0.18		1.33		4.04	1%
	Pasture	63.30	15%	80.90	19%	81.94	19%	78.02	18%
	Mosaic of Uses	191.70	45%	185.34	43%	168.75	39%	152.46	36%
	Agriculture					-		0.05	
Subtotal - Anthropized area		255.79	60%	267.75	62%	253.38	59%	239.69	56%
Total		429.12		429.12		429.12		429.12	

Source: Prepared by the authors based on data from the MapBiomas Project, collection 8 (2024).

In this anthropogenic matrix, the Mosaic of Uses class shows the greatest transition over the period, with a loss of 39.24 km² (20%) (Table 01). This is where areas of agricultural or livestock use predominate, with or without remnants of native vegetation, in which it is not possible to distinguish a predominant use between agriculture, livestock, mixed use or remnants of native vegetation (Parente *et al*., 2020), making the landscape complex. This calls for more detailed research into the landscape matrix, given the importance of having a high-quality matrix, i.e., a permeable one that favors ecological processes between habitats (Haddad *et al.*, 2015; Arroyo-Rodríguez *et al.*, 2020). According to Fischer *et al.* (2006), it is important to maintain a structurally complex matrix, where the proportion of land occupied by the matrix is large and the areas of native vegetation are small or poorly connected, including structurally characteristic stretches of native vegetation, corridors and stepping stones between them and buffers around sensitive areas.

Table 01 – Quantification of the transition, in km², between land use and land cover classes in the 1990 and 2022 landscape

1990 \ 2022	Forest Formation	Mangrove	Forest Plantation	Flooded Grassland	Pasture	Mosaic of Uses	Beach, Dune and Sand Spot	Urban Area	Other non-vegetated areas	River, Lake and Ocean	Temporary Crops	Wooded Sandbank Vegetation	Herbaceous Sandbank Vegetation
Forest Formation	**92.23**	0.18	1.19	0.02	9.81	**25.71**		0.23	0.13	0.25			
Mangrove	0.02	2.26								0.13			
Forest Plantation						0.01							
Flooded Grassland	0.01		0.01	**24.61**	1.61	2.29	0.00	0.59	0.15	0.79			
Pasture	6.42		1.58	0.28	**29.32**	**23.55**		0.08	0.43	1.65			
Mosaic of Uses	**42.22**	0.03	1.25	4.30	**36.96**	**98.44**	0.03	0.98	2.08	5.31	0.01	0.03	0.07
Beach, Dune and Sand Spot						0.03	0.03						
Urban Area								0.14					
Other non-vegetated areas				0.03	0.05	0.24			0.28	0.04			
River, Lake and Ocean	0.91	0.09	0.02	2.72	0.25	2.09			0.04	4.78			
Wooded Sandbank Vegetation					0.01	0.09						0.03	
Herbaceous Sandbank Vegetation													0.01

Source: Prepared by the authors based on data from the MapBiomas Project, collection 8 (2024).

The matrix is also made up of the non-forest natural formation class, within which the flooded grassland class stands out, as well as the Hypersaline Tidal Flat and Herbaceous Sandbank Vegetation classes, which are almost non-existent in the landscape (Table 01). The Flooded grassland class is characterized by the presence of predominantly herbaceous vegetation with adaptations to permanent or temporary flooding (MapBiomas Project, 2023).

The remnants of native vegetation in the Mosaic of Uses class and the Non-forest natural formation are classified in other vegetation mappings (IBGE, 2012; INEMA, 2014) as areas with original Cerrado vegetation, which could contribute to a more permeable matrix. A matrix with a vegetation structure similar to patches of native vegetation (with low contrast) will bring numerous benefits to the functioning of the ecosystem, in particular the provision of habitat for some native species, enhanced landscape connectivity and reduced edge effects (Fischer *et al.*, 2006).

The Forest class, comprising the Forest Formation (represented in this landscape by the Dense Ombrophilous Forest), Wooded Sandbank Vegetation and Mangrove classes, considered as habitat in this research, occupied 132.29 km^2 (30.8%) of the landscape in 1990 and 144.45 km² (33.7%) in 2022 (Table 01). Between 1990 and 2000, there was a downward trend in dense ombrophilous forest. Since 2010, there has been a trend towards an increase in area (Table 01), which is responsible for the increase in the amount of forest in the landscape, since 0.5 km² of Wooded Sandbank Vegetation area was lost and only 0.14 km² of Mangrove area were added (Table 01).

Authors such as Fahrig (2003), Villard and Metzger (2014), Arroyo-Rodríguez *et al*. (2020), positively relate the greater amount of habitat to the availability of resources, the increase in population size, the greater genetic and taxon diversity and the persistence of specialist species.

Considering the area metric, Arroyo-Rodríguez *et al.* (2020) state that landscapes of appropriate size should contain 40% or more forest cover, to ensure the persistence and preservation of most wildlife, in the case of landscapes with a low-quality matrix or in the tropics. Of these 40%, 10% are in a single or a few patches and the other 30% are evenly distributed in scattered smaller patches. Even with the 3% increase in forest area in the rural landscape of Camaçari, the amount of habitat is below the value proposed by Arroyo-Rodríguez *et al.* (2020).

The fragmentation threshold, according to Andrén (1994), is the minimum habitat cover above which the population size is influenced only by habitat loss and not by the configuration, and below which the negative effects of the configuration (patch size and isolation) will reinforce the effect of habitat loss with a faster decline in population size. Thus, in landscapes with an amount of habitat above the fragmentation threshold, the occurrence and abundance of species will be regulated only by the loss of habitat, while below it, the configuration of the habitat is very significant, with the potential to reduce or mitigate the effects of habitat loss (Villard; Metzger, 2014).

For Andrén (1994) and Fahrig (1998), this threshold can be between 10 and 30% of the suitable habitat remaining in the landscape for birds and mammals, highlighting, in the results of their analyses, that in landscapes with around 20% of the original habitat, the effects of the configuration began to appear. More recent research (Fahrig, 2001; Pardini *et al.,* 2010; Metzger, 2010) points to a fragmentation threshold of 30% and, under this proposal, the amount of habitat in the rural landscape of Camaçari is very close to this threshold.

The rural landscape of Camaçari, when compared to the thresholds proposed by Fahrig (2003), Pardini *et al.* (2010), Metzger (2010) and Arroyo-Rodríguez *et al.* (2020), it showed an amount of habitat very near (30%) or below (40%) the fragmentation threshold, which was not favorable for biodiversity conservation in any of the years analyzed, even with the increase in forest area over the period. In these landscapes, it is important to predict configurations that result in greater functional connectivity and therefore a greater likelihood of species persistence (Villard; Metzger, 2014).

Spatial analysis has helped to identify portions of the landscape where forest loss has been significant and the effects of habitat configuration can reinforce the effects of habitat loss. Figure 02 shows that the loss of Dense Ombrophilous Forest was greatest in the central-southern part of the landscape, while the increase in this class occurred in the southern and central-northern parts of the landscape.

Of the total forests in 2022, i.e., 144.45 km², just over 65% are preserved forests, represented by those that existed in 1990 and in 2022, and 35% are regenerated forests (Table 02). This scenario confirms the importance of forest regeneration in the composition of the landscape studied, which occurred in 49.76 km^2 of the landscape, very close to the deforestation area of 41.84 km^2 (Table 02). Figure 03 shows the changes related to the Forest class in the landscape configuration, indicating the preserved forest, regenerated forest and deforestation areas.

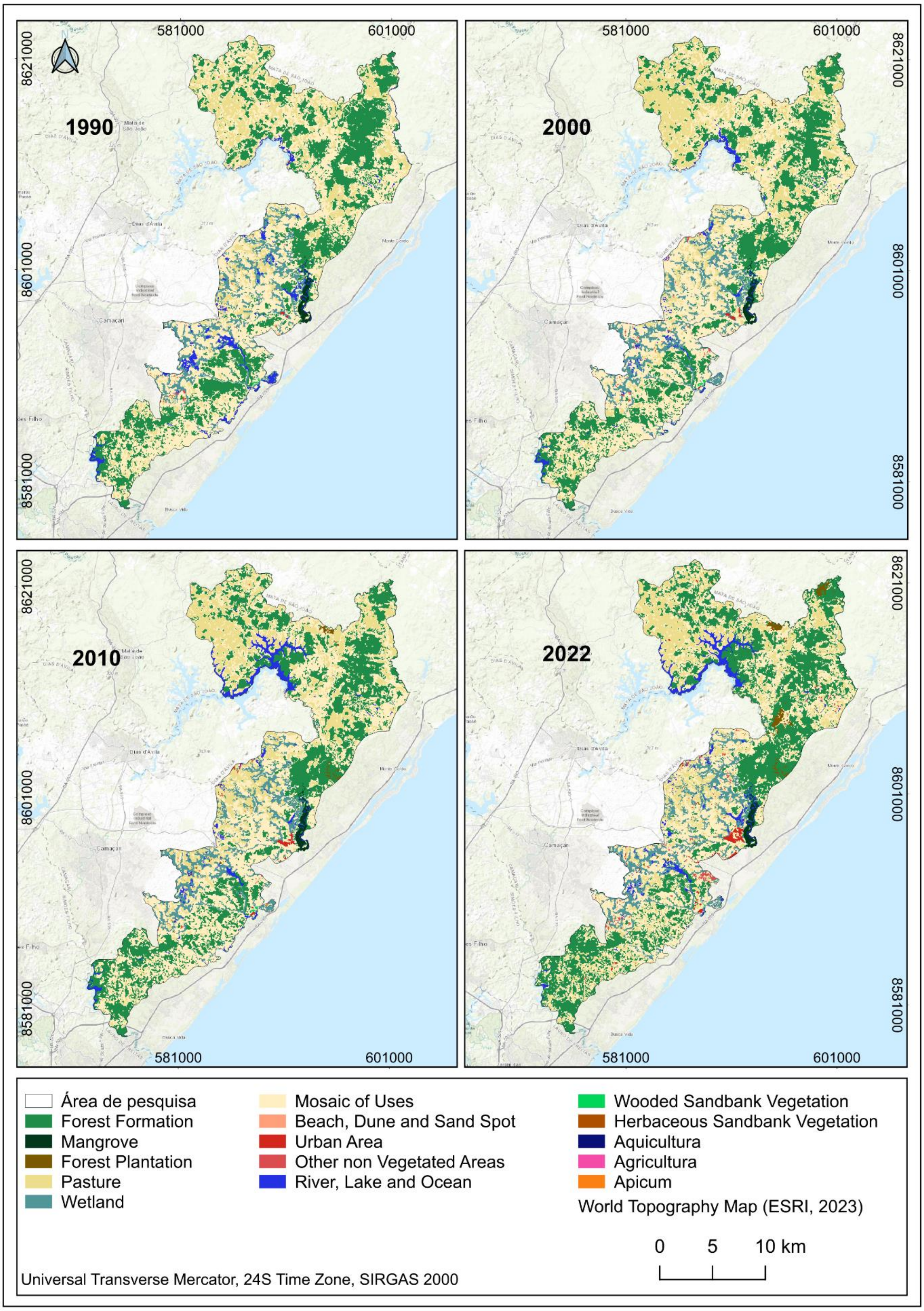
Arroyo-Rodríguez *et al.* (2020) highlight the caution in considering young forests as part of the 40% forest cover they suggested, since late-successional secondary forests are more suitable habitats for many specialized forest species, ratifying that early successional forests work best when considered in order to increase matrix permeability, ecological connectivity and decrease negative edge effects.

Table 02 – Quantification of the transition in land use and cover in the landscape between 1990 and 2022

Class	km^2	%
Preserved forest	94.69	**22%**
Regenerated forest	49.76	**12%**
Deforestation	41.84	**10%**
Anthropization	197.82	**46%**
Body of water	12.94	**3%**
Other transitions	32.06	**7%**
Total	**429.12**	

Source: Prepared by the authors (2024).

Figure 02 – Space-time analysis of changes in land use and land cover in the landscape



Source: Prepared by the authors based on data from the MapBiomas Project, collection 8 (2024).

Analyzing the changes between land use and land cover classes (Table 01), 42.21 km² of the Mosaic of Uses class will be occupied by Dense Ombrophilous Forest in 2022. And 25.71 km² of Dense Ombrophilous Forest were cleared and transformed into a Mosaic of Uses in 2022 (Table 01), resulting in a forest gain of 16.5 km² between these classes. Both the loss and regeneration (the process in which forest or habitat is re-established) of native habitats occur concurrently in landscapes. Thus, the amount of habitat can remain stable in two different periods, which can generate significant changes in the structure of landscapes, making the scenario quite complex (Martensen *et al*., 2017).

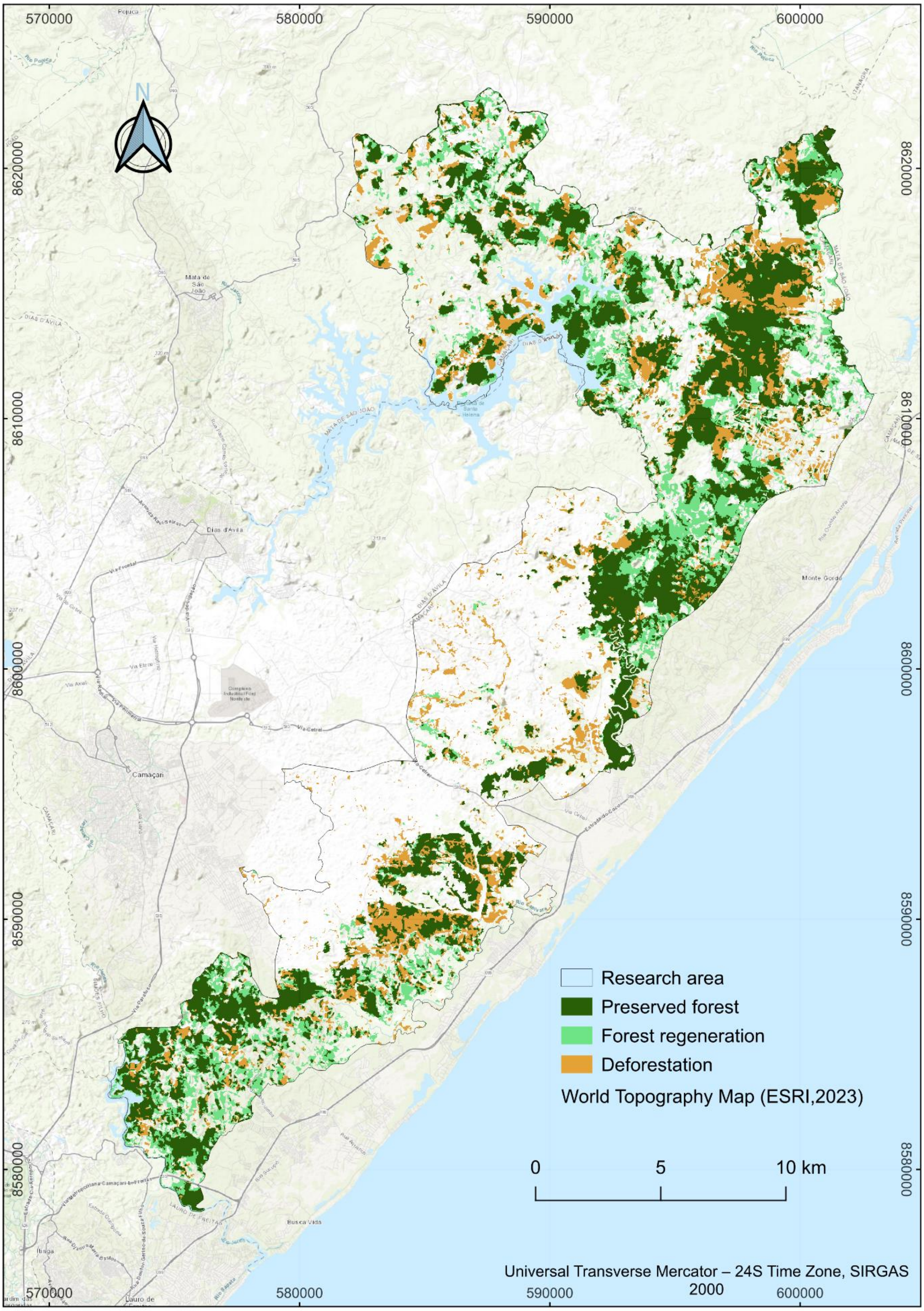
Preserved forests, considered to be more advanced stages of ecological succession, represent 94.69 km^2 (22.07%) of Camaçari's rural landscape in 2022 (Table 02 and Figure 03). Regenerated forests, considered to be early successional stages, occupy 49.76 km^2 (11.6%) (Table 02 and Figure 03). However, these statements need to be analyzed and verified in the field, since, as Martensen (2021) states, habitat regeneration is poorly studied and depends on multiple biotic factors (e.g., distance from seed sources and propagules), abiotic factors (e.g., soil) and anthropogenic factors (e.g., time since last disturbance, land use).

The southern part of the landscape has extensive regenerated forest, as well as preserved forest, and the most deforested parts of the landscape were the central and northeastern parts (Figure 03).

Considering only regenerated forest as habitat (22%) means that the landscape fragmentation threshold is well below the 40% level proposed by Arroyo-Rodríguez *et al.* (2020) and below the 30% level proposed by Fahrig (2003), Pardini *et al.* (2010) and Metzger (2010).

Andrén (1994) points out that once there is a certain reduction in the amount of habitat, mass extinctions of various species are triggered, causing the destruction of entire ecosystems. This process is known as extinction thresholds, which Fahrig (2003) describes as the limit level of habitat, below which the population cannot sustain itself. According to Villard and Metzger (2014) "below the extinction threshold, the species will not persist" and between the fragmentation and extinction thresholds, the regulation of species occurrence and abundance will depend on the quantity and configuration of habitat. The configuration of patches is very important for the persistence of species (Andrén, 1994; Fahrig, 1998; Villard; Metzger, 2014; Püttker *et al*., 2020).

Figure 03 – Transition of land use and cover in the rural landscape of Camaçari, between 1990 and 2022



Source: Prepared by the authors based on data from the MapBiomas Project, collection 8 (2024).

Thus, for the rural landscape of Camaçari, in addition to prioritizing the conservation of forests, especially those considered in this research as preserved forests, it is necessary to propose a favorable configuration that guarantees the persistence of key species.

The high dynamism of landscapes, with rapid losses and gains of habitats, have joint effects that can be divided into two types: spatio-temporal legacy and spatio-temporal pathway (Martensen *et al.*, 2017; Martensen, 2021). The possibility of an individual moving from a given location with habitat at time 1 (t1) to a location with habitat at time 2 (t2) is presented by Martensen *et al.* (2017) and is related to the dynamism of landscapes. Studies that consider this dynamism can contribute to a better understanding of the relationship between landscape structure and the ecological processes that occur in habitats over time.

Changes in the configuration of the landscape, with the loss of key patches, shown in the central area of the landscape (Figure 03), which could be serving as *stepping stones*, show changes in percolation and functional connectivity for forest species. Landscape percolation is the possibility for an organism unable to leave its habitat to cross the landscape (Metzger, 2010).

The percolation threshold is the minimum amount of habitat needed in a given landscape for this to happen (Metzger, 2001b). This threshold is related to the composition and configuration of the landscape and key patches are important in this regard. The effects of habitat loss in the central part of the landscape are enhanced by the new landscape configuration.

Another important area metric, related to the total remaining habitat in the landscape (Fahrig, 2003), is the Largest Patch Index - LPI, which quantifies the percentage of the total landscape area occupied by the largest patch of the class (McGarigal; Marks, 1995). For certain species, the largest patch of the landscape can be related to the other patches from the perspective of the "*source-silk systems*" metapopulation model (Plagia *et al.,* 2006), with the largest patch being a source habitat, which produces overpopulation, and the other smaller patches being sink habitats, which receive immigrants from the source habitat to ensure the persistence of the species.

Arroyo-Rodríguez *et al.* (2020) suggest that it is appropriate to keep 10% of the landscape as a single or few habitat patches and the other 30% of the landscape in smaller habitat patches dispersed evenly in the matrix. The LPI of Camaçari's rural landscape remained stable at 5.7% in 1990 and 2022 (Table 03), fluctuating between the periods analyzed, but always below the authors' recommendations.

Table 03 – Index of the largest patch of the forest class in the years analyzed

Metric	%			
	1990	**2000**	**2010**	**2022**
LPI	5.74	4.06	4.54	5.70

Source: Prepared by the authors (2024).

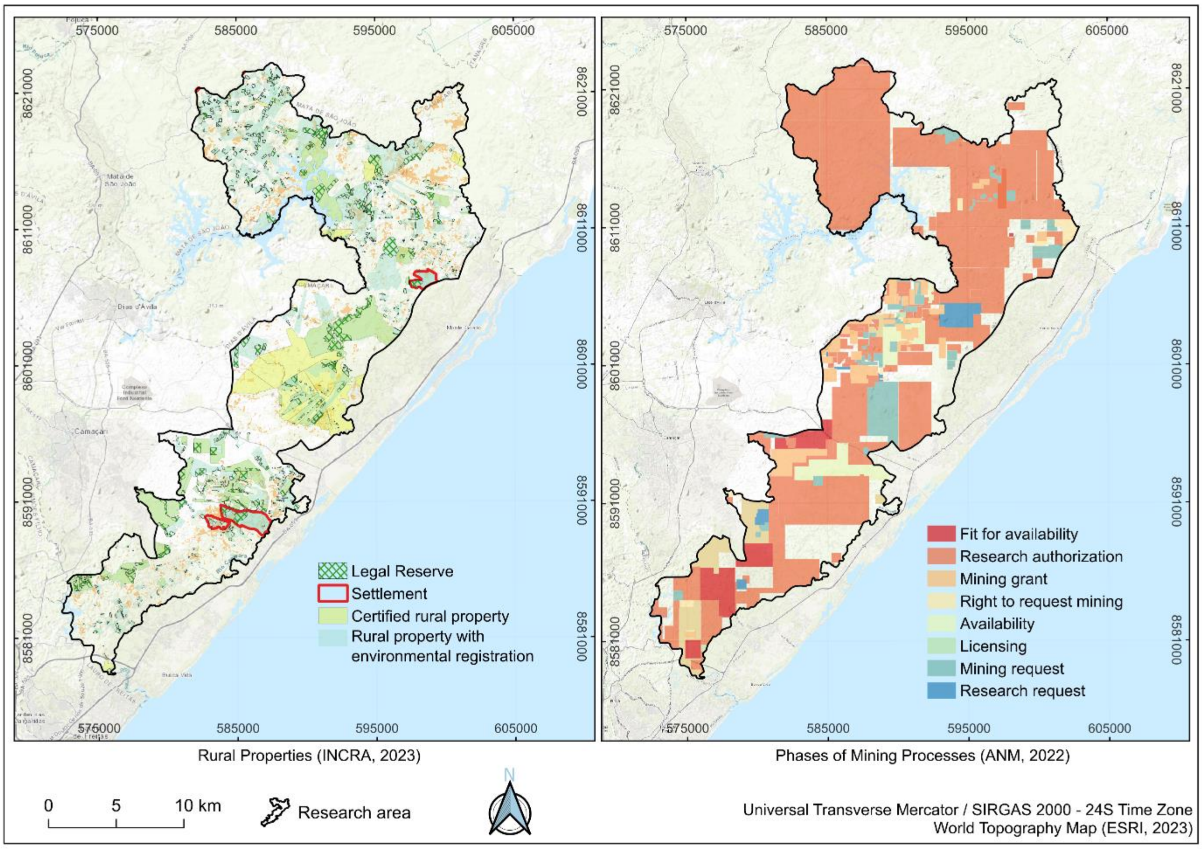
The use and coverage of the land in the rural area of Camaçari during the period in question was certainly influenced by the socio-economic dynamics of the municipality. Studies by Souza (2006), Andrade (2008) and Gileá *et al.* (2020) have shown that this dynamic resulted from a process of regional development with exogenous planning, which culminated in the establishment of the Camaçari Industrial Complex in 1978. According to the authors, despite its long history of occupation, the municipality only underwent profound changes from the 1970s onwards, which changed the municipality's agro-tourism tradition into an economic area with a predominantly secondary, industrial base. For Souza (2006, pg. 22), in the period from 1970 to 2005, the municipality of Camaçari was "a poorly developed agrarian region, like many regions in the Northeast of Brazil" and underwent a "transformation of the bucolic landscape and the quiet life led within the municipality" (Souza, 2006, pg. 84).

Andrade (2008) points out that this productive restructuring demanded changes in the municipality's social structure. One of the biggest problems revealed was the rapid rise in population, which brings with it many other intrinsic problems, especially related to the demand for infrastructure, inputs and services, as well as land use and land cover, and their consequences.

The Master Plan for the Camaçari Petrochemical Complex - Copec (Bahia, 1974), presented the municipality's potential for mining as far back as the 1970s, since it has clay, kaolin, sand and sandstone within its territorial space. Souza (2006) highlighted, among the various environmental problems that occur in Camaçari, the degradation of areas due to mineral activity, occurring mainly on the outskirts of the city and in the rural area of the municipality.

The mapping of data on mining polygons and rural properties and settlements (Figure 04) showed that mining is a highly demanded and developed activity in the area, contributing to deforestation; likewise, the rural settlements in the south-central part of the landscape are in the area where there was significant deforestation in the landscape during the period analyzed (Figures 03 and 04).

Figure 04 – Mapping of rural properties and settlements and the polygons required for mining activities in the rural landscape of Camaçari



Source: Prepared by the authors (2024).

Socio-economic dynamics are related to the use and occupation of land in the rural landscape of Camaçari, with an increase in the occupation of urban areas even in rural areas, given the demographic increase to keep up with municipal development, which resulted in the deforestation of areas, particularly in settlement areas. On the other hand, the analysis showed that agricultural areas were abandoned, favoring forest regeneration during the period analyzed.

The complexity of the landscape matrix, the Mosaic of Uses class, makes it difficult to establish more consistent relationships between changes in land use and occupation and socio-economic aspects, since this class is a mixed use of areas in which it is not possible to distinguish between agricultural or livestock use, with or without remnants of native vegetation. Even so, it is possible to establish a relationship between the increase in inputs, such as water, increasing the area of water bodies; food, increasing the area of pasture; cellulose, with an increase in the area of forest plantation; and mining, which although not mapped in the MapBiomas Project, has generated changes in the landscape revealed by the increase in the non-vegetated area.

4 FINAL CONSIDERATIONS

The results of the multi-temporal analysis (1990-2022) of Camaçari's rural landscape indicate that the Mosaic of Uses class was predominant in all the years analyzed, followed by the Dense Ombrophilous Forest. Although there was an increase in the Agriculture, Pasture and Urban Area classes, the overall anthropization rate fell. Despite deforestation of 41.84 km^2 over the studied period, the Forest class recorded an increase of 3%. However, this quantitative increase does not reflect an improvement in the quality of the forest habitat, since in 2022, 65% of forest areas are considered preserved, while the other 35% correspond to regenerated forests, which are often not considered suitable habitats for many specialized forest species.

By relating land use and land cover metrics to the socio-economic dynamics of the landscape, the research enabled a detailed analysis of the spatio-temporal behavior of Camaçari's rural landscape, with a focus on the conservation of forest habitats.

The anthropogenic matrix, represented predominantly by the Mosaic of uses class, limited the analysis of changes in land use and cover and their relationship with socio-economic aspects, due to its mixed nature that includes both anthropized and natural areas. Even so, socio-spatial transformations, driven by rapid population growth and the phenomena associated with it, have had an impact on economic activities, which have modified the municipality's agricultural and tourist base, generating effects on the configuration of the landscape.

With regard to ecological thresholds, the percentages of forest cover and the Largest Patch Index (LPI) in 2022 indicate that the landscape does not have an adequate amount and configuration of forest habitat to ensure the preservation of most forest species, as well as the delivery of ecosystem goods and services.

In order to contribute to conservation actions in the landscape, it is advisable to explore other configuration metrics, such as patch size, perimeter, shape, proximity, fragmentation, isolation and aggregation. These metrics can assess the permeability and resistance of the matrix, helping to establish priorities for conservation actions that increase connectivity and improve habitat quality.

Finally, this research makes an important contribution to understanding aspects of land use and land cover, as well as the socio-economic dynamics of Camaçari's rural landscape. The results have the potential to guide land use and environmental planning by identifying preserved and regenerated forest areas. In addition, the findings can inform future research into the urban sprawl, helping to identify priority areas for biodiversity conservation, including the creation of protected areas and the promotion of connectivity between habitats. The data reinforces the urgent need to prioritize forest conservation, since the current landscape is already below critical fragmentation thresholds.

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