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FOREST FRAGMENTATION IN AN UNREGULATED PROTECTED AREA ON THE ATLANTIC COAST OF BRAZIL

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Abstract

Brazilian protected areas are subjected to an intense process of fragmentation due to the lack of environmental regularization and anthropic activities inside them. This study evaluates the forest fragmentation of the Alto Cariri National Park inside the Atlantic Forest of northeastern Brazil. The mapping of forest fragments was performed with the visual interpretation of a satellite image, analyzed based on landscape metrics and physical and topographic conditions. The results show a high forest fragmentation, which is responsible for the segmentation of the forest patch into 120 fragments, predominantly smaller than 5 ha, with an irregular shape and incident edge effect. The obstacles to the preservation of the Atlantic Forest are due to the irregular use of these areas for the production of cattle in pastures and the lack of agility of the public power to implement the expropriation of the population, the drafting of a management plan and decision make.

Keywords: national park, edge effect, landscape management, remote sensing.

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Introduction

Brazil has serious problems with the implementation of protected areas. Although Brazil sanctioned the National System of Conservation Units (SNUC), which creates conservation units (CUs) as territorial spaces with protected environmental resources for the purpose of conservation and preservation, divided into Integral Protection, without human alterations, and Sustainable Use, with sustainable exploitation of resources (Brasil, 2000).

To Brito (2010) the management plan and zoning are mandatory documents for all CUs. They guide decision-making and environmental management processes, but the lack of guidelines, associated with the situation of land tenure irregularity, indiscriminate use, and lack of integration of the public power with the population generate conflicts in protected areas and in buffer zones that hinder an effective management.

The interaction with the community that is part of a CU must be considered since its creation, preventing models of management of protected areas from being authoritarian activities and promoting environmental conflicts in the creation and management of protected areas (Conti and Carvalho Antunes, 2012). Also, created protected areas, but with installed social dynamics, need to ensure an effective maintenance of cultural and socioeconomic conditions until the land expropriation process. This factor creates an obstacle in achieving the objectives of the protected area. It creates an environmental bottleneck in most CUs of integral protection.

National parks are integral protection units with the objective of preserving biodiversity, ecosystems of great ecological relevance, and scenic beauty, enabling scientific research, environmental education, recreation, and ecological tourism activities (Brasil, 2000). All private properties inside the limits of national parks must be expropriated and regulated by rules of the agency responsible for their administration.

In the south of Bahia, an area fully inserted in the Atlantic Forest, parks account for 638.67 km² of protected areas. They form the Central Corridor of the Atlantic Forest (MMA, 2020). Although the Descobrimento, Pau Brasil, Monte Pascoal, and Alto do Cariri parks cooperate for environmental maintenance in the region, it is necessary to highlight difficulties the historical process of forest fragmentation faces associated with the exploitation of wood, pastures, agricultural cycles of coffee and cocoa, and more recently the expansion of forestry.

Studies on forest fragmentation in areas of national parks, regularized or not, allow understanding landscape structures and support strategies for preserving the ecosystems in these protected areas (Oliveira *et al.*, 2019), as the dynamics of forest patches is an important factor to ensure the richness and abundance of species that depend on structural traits of habitats for survival (Rodrigues and Nascimento, 2006; Laurance and Vasconcelos, 2009; Matos *et al.* 2018).

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The Alto Cariri National Park (PNAC) has a regional importance, as it is responsible for protecting remnants of the Atlantic Forest, springs, water sources, streams, and rock formations, and preserving a great diversity of species of mammals and birds threatened with extinction, including the woolly spider monkey (Brachyteles hypoxanthus), which is endemic to the region and threatened with extinction (Brito *et al.* 2008; Brasil, 2010). In addition, this park has important ecological functions and is of great value due to the rich hydrographic network that contributes to the formation of the Buranhém River, the main water resource in the region (MMA, 2020).

The PNAC is in a region with rural communities, where agricultural and livestock activities are the main forms of land use. Therefore, performing these activities inside the CU is the main issue for landscape change and natural fragmentation throughout the ten years of its existence. Therefore, evaluating the fragments and understanding their relationship with socioeconomic development allows understanding the structure of forest remnants and inducing scientific dissemination towards creating effective policies for the restoration and maintenance of biodiversity.

In this context, studies on forest fragmentation and its relationship with socioeconomic dynamics are relevant, as they seek management and strategies to mitigate disturbances in order to conserve natural resources. Thus, this study aims to assess the forest fragmentation of the Alto Cariri National Park and establish relationships with the socioeconomic development of the city of Guaratinga, in the south of Bahia.

Research metodology

Área de estudo

The Alto Cariri National Park was created by the Decree w/no. of June 11, 2010, in the municipality of Guaratinga, south of Bahia. It has an area of 19,264 hectares, as Fig. 1 shows (Brasil, 2010). It borders the state of Minas Gerais, with a territorial junction to the Cariri State Park in that state and in Bahia. It is located in the Identity Territory of the Costa do Descobrimento, a region with a vocation for tourism and of historical and cultural importance to Brazil.

The municipality of Guaratinga has a territorial extension of 2,189,404 km² and an estimated population of 20,700 inhabitants, which means a low urban density and extensive rural areas focused on agriculture, especially the production of cocoa, coffee, papaya, beef cattle breeding, and milk. This economic development creates a diversity of conflicts inside the PNAC, since it has a diversity of local producers in its interior and surroundings, evidenced by the non-regulation of land ownership and the expropriation of residents (IBGE, 2017; 2019; 2020).

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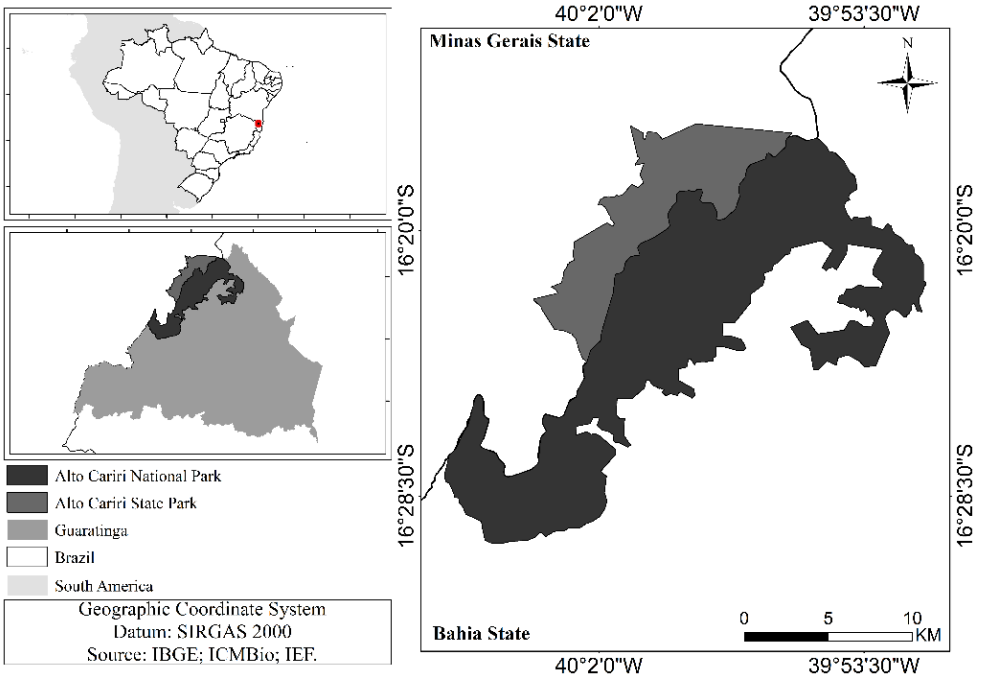

Figure 1. Location of the Alto Cariri National Park, Guaratinga, Bahia.

Analysis of fragmentation metric

The mapping of forest fragments was performed using a Sentinel satellite image, SAR and MSI sensors, of March 2019, acquired free of charge from the United States Geological Survey (USGS) website. The image was processed and redesigned in the Southern Hemisphere for the DATUM SIRGAS 2000 24S plane coordinate system.

Subsequently, a colored composition of red, green, and blue spectral bands was processed, with a spatial resolution of ten meters, superimposing it on the vector file containing data on the park boundary. The mapping was performed by visual interpretation of the image and vector editing according to criteria established by Panizza and Fonseca (2011). Shape, size, location of the object in the landscape, texture, tone, and structure of the forest fragment were analyzed using the software ArcGIS 10.8 (ESRI, 2020).

The fragments were classified into size as < 5 ha (small fragments), 5-50 ha (medium fragments), and > 50 ha (large fragments), according to Pirovani *et al.* (2014). The metrics for each fragment were calculated using the V-LATE extension (Vector-based Landscape Analysis Tools Extension) together with the software ArcGIS 10.8 and Microsoft Excel 365. For the analysis, metrics for fragments were selected according to Table 1.

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Table 1. Landscape metrics for forest fragments.

Level	Metric	Unit	Value
Patch	Patch Area (CA)	ha	[0 - ∞[
	Number of Class (NP) Fragments	adm.	[0 - ∞[
	Border density (ED)	m/ha	[0 - ∞[
	Total borders (TE)	m	
	Average patch size (MPS)	ha	[0 - CA[
	Mean fragment borders (MPE)	m	
Fragment	Area	ha	[0 - ∞[
	Perimeter	m	[0 - ∞[
	Perimeter/Area Ratio (PARA)	adm.	[0 - ∞[
	Fractal Dimension (FRAC_DIM)	adm.	
	Shape (SHAPA INDEX)	adm.	

Analysis of physical and topographic characteristics of the terrain

The PNAC pedological, geological, and geomorphological maps was plotted, in addition to determining the hypsometric and slope characteristics of the terrain. Pedology and geomorphology derived from the pedological and geomorphological mapping of the state of Bahia at a scale of 1:1.250000, prepared by the State Water Resources Plan (PERH). The geology data were acquired from the Brazilian Environmental Information Database (BDIA) at a scale of 1:250,000 (IBGE, 2020). Both files were manipulated and segmented for the region of interest, composing the information associated with forest fragments.

Hypsometry and slope were generated using the Digital Elevation Model (DEM) acquired from the database of EarthData on the platform ASF Data Search with a spatial resolution of 12.5 meters. The DEM was redesigned for the Southern Hemisphere using the flat coordinate system and DATUM SIRGAS 2000 spindle 24S. For the slope, the DEM was processed in terrain analysis modules, thus obtaining the percentage of slope in the terrain classified according to the definition of the Brazilian Agricultural Research Corporation (EMBRAPA) as varying from flat to steep relief (Embrapa, 2006).

The topographic characteristics were superimposed on the forest fragments and the means of the values corresponding to altitude and slope. The pedological, geological, and geomorphological occurrences were extracted for each class of forest fragment size using the zonal statistics command.

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Results and discussion

The PNAC forest fragments total 9,862.13 ha, corresponding to 51.2% of its total area. The distribution of the patch is intertwined with the dynamics of life of rural communities, which have lived inside the CU before its creation and whose anthropic uses of land are a means of subsistence.

Figure 2 shows the distribution of fragments and their respective sizes. There are 120 forest fragments distributed into 56 small fragments (46.67%), 46 medium fragments (38.33%), and 18 large fragments (15%). The existence of numerous fragments does not result in a greater conservation, but in an intensive segmentation of the protected area that suffers the effects of non-regularization and agro-forestry-pasture expansion.

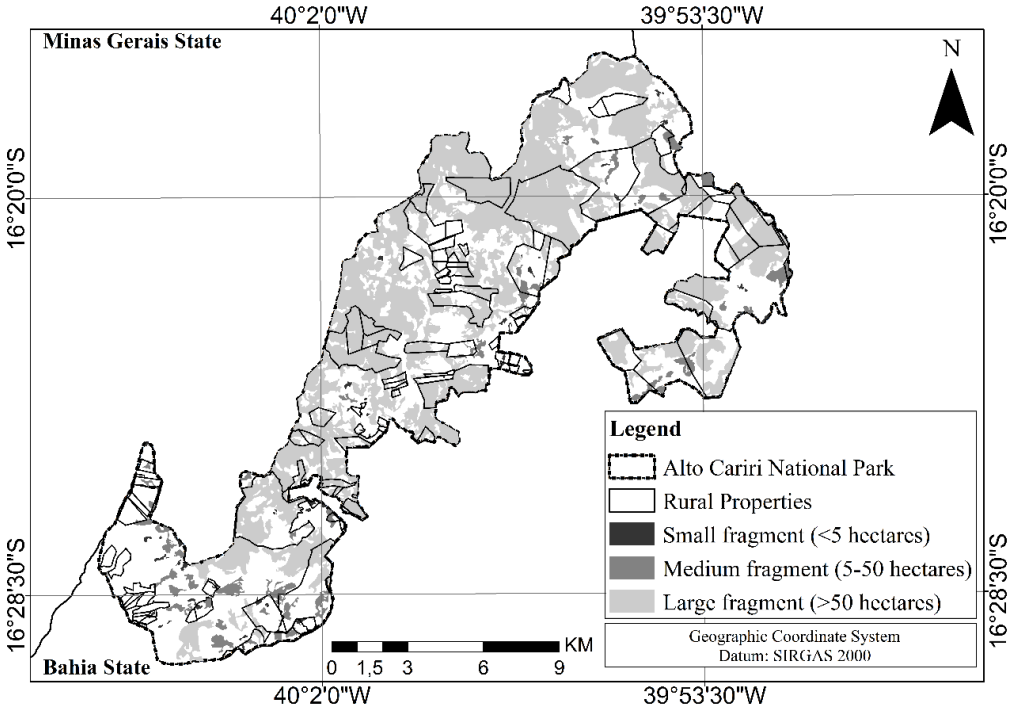

Figure 2. Fragment distribution by size classes in the Alto Cariri National Park.

The distribution of smaller and more elongated fragments of the PNAC is in intensely anthropized areas, close to nuclei of rural communities, which are concentrated within rural properties, specifically to the south. Most large fragments are concentrated in the north and west. They connect to the Alto Cariri State Park in Minas Gerais, creating a wide continuum of forest area between the states.

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Inside the park it is common to find agricultural crops of bananas, coffee, pepper, olericulture, eucalyptus and intensive livestock. The breeding of beef cattle and the production of milk is an obstacle for the entire municipality, contributing to the conversion of natural areas, mostly due to illegal deforestation.

The PNAC is a UC in the category of integral protection with ten years of existence, but its creation rights are not guaranteed by the public power, given that it did not regulate the expropriation of the population. Therefore, that the residents who have lived there before the park was created have already an established rural cultural and conventional ways of living. In addition to the not yet existent area management plan, management finds in conflict mediation the palliative solution to make the park functional and, at the same time, ensure that the impacts of the population's are minimized.

Table 2 shows the landscape metrics identified in the forest area. The area of the forest patch is equivalent to more than half the area of the park, but that does not provide it with a guarantee of preservation since investment in agribusiness and forestry is the greatest incentive in the region (Santos and Machado, 2015). According to the Guaratinga Atlantic Forest Conservation and Recovery Plan, the municipality has 64.39% of its soil occupied by pastures, 3.51% by eucalyptus, and 0.33% by agriculture (Gambá, 2016). The different types of land use stimulate the environmental degradation of the fragments either due to a lack of technical knowledge or due to the socioeconomic vocations implanted in the region.

Table 2. Forest fragment metrics.

Level	Group	Metric	Result
Patch	Area	Total area of fragments	9,862.13 ha
		Number of Fragments	120
	Border	Border density	75.78 m/ha
		Total borders	747,315.65 m
		Mean fragment borders	6,227.63 m
	Size	Average patch size	82.18 m

The density and total of borders are high, as well as the mean of fragment borders. The values found indicate that the fragments are in high contact with local anthropic uses, exposing the local biodiversity to endogenous and exogenous factors for their existence. According to Murcia (1995), Primak and Rodrigues (2001), Cunha *et al.* (2021) and forest fragmentation encourages the abrupt contact of one ecosystem to the other, generating border effects. The border effect contributes to

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the interference in wind intensity, excessive sunlight, microclimate production, noise, and the entry of invaders that increase disturbances in the forest fragment (Volotão, 1998, Zuñe-da-Silva, 2022).

There is an indication of an intense anthropic pressure on the remnants of the region and, above all, on the forest fragments of the park, which has a fragmented landscape. Resilience and new conditions for the maintenance of local biodiversity are thus needed. It is worth mentioning that, according to Winagraski *et al.* (2018), the composition of forest patches in the landscape influences the species richness in fragments through genetic diversity, dispersion, and available habitat. Thus, larger patches tend to be more effective for certain species instead of large amounts of small fragments, as habitat fragmentation reduces connectivity and gene flow between fragments and impedes the conservation of the local biodiversity.

For Liu *et al.* (2018), fragmentation affects the functioning of the ecosystem, considerably changing the biotic community and the regularity of provision of ecosystem services of habitat, food, gene flow, and reproduction of fauna and flora. Its effects affect considerably the native fauna and flora and protection of water resources, promote the regularization of areas of permanent preservation, in addition to having consequences for humans, considering that the effects can affect the provision of ecosystem services that depend on biodiversity and habitat quality (Mea, 2005, Lima *et al.*, 2020).

Table 3 shows the quantitative metrics of the class of each fragment, confirming the high forest fragmentation of the protected area. The findings of this study are not associated with the conditions found by Primak and Rodrigues (2001), who indicate that the negative effects of border effect is only possible with connected and more circular fragments, improving the quality of the matrix at the center.

Table 3. Metrics of forest fragment class.

Level	Group	Metric	Minimum	Mean	Maximum	Standard deviation
Fragment	Area	Area (ha)	0.20	82.18	5422.06	501.29
		Perimeter (m)	183.43	6,227.63	321,176.72	29,731.60
		Perimeter/Area Ratio (adm.)	0.00	0.03	0.104	0.02
	Shape	Fractal Dimension (adm.)	1.23	1.32	1.42	0.04
		Shape Index (adm.)	1.05	1.91	12.30	1.24

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The perimeter and size of the fragments indicate a high variability and are between 0.2 and 5,422.05 ha. Although larger fragments are less frequent, their territorial area is greater than the sum of small and medium fragments. Lopes *et al.* (2020) observed this process. The authors reported smaller fragments at a greater quantity and with a smaller area and intense agricultural use in southeastern Brazil. Indicated that intensive fragmentation reduces the ability to maintain biodiversity, including support services for agriculture.

The variation of fragments, confirmed by the standard deviation of the size, perimeter, and shape index, also strengthens the intensive fragmentation in the PNAC area. The size and shape of the fragments may influence many ecological processes between habitats and the relationship with the border effect (Costa *et al.*, 2019; Laurence and Vasconcelos, 2009).

The larger the border of the fragment, the more irregular its shape, and thus the greater the proportion of borders. Regularly shaped fragments, on the other hand, have a smaller border/area ratio. The central area of the fragment moves away from the borders and therefore from external environmental factors (Pirovani *et al.,* 2014). The perimeter/area ratio and the fractal dimension had non-dimensional mean values of 0.02 and 1.32, respectively. There was an inversely proportional trend of the fragments, confirming their relationship with size and total area between small, medium, and large fragments (Herrmann *et al.,* 2005).

The large fragments showed a lower border density, revealing a better conservation condition despite the fact that large fragments concentrated in the central and western regions have an evident border and a sinuous effect justified by the intense conversion of areas into pastures, which means smaller areas with reduced biodiversity. Silva *et al.* (2020) and Lisboa *et al.* (2019) studied forest fragmentation and observed significant temporal changes in native forest. It can be converted into other types of land use and occupation, affecting the support capacity for biodiversity.

Table 4 shows physical and topographic characteristics (slope, geology, geomorphology, pedology, and hypsometry) associated with forest fragments. Both sizes of fragments are located in heavily undulating reliefs at an average altitude between 365 meters and 525 meters.

In PNAC, steeper reliefs do not prevent the fragmentation of areas; on the contrary, can be submeter of the increase in the loss of natural areas and more conversions for human use in case the environmental regularization of the Park does not occur. This hypothesis is also reinforced by the indication that there are large fragments at lower altitudes than small and already segmented fragments. These indications are opposed to the claim of Silva *et al.* (2020) that elevated regions with rugged or mountainous terrains act as a mitigating force for the conversion of natural areas into agricultural systems.

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Table 4. Prevalence of physical characteristics of the land for classes of forest fragments. Caption: *Predominance among fragments. **Mean of values.

Fragment	Slope (%)	Hypsometry (altitude)	Pedology (soil type)	Geology (geological unit)	Geomorphology
Small	Strongly undulate**	558 meters**	Dystrophic Yellow Latosol Dystrophic Red-Yellow Latosol* Dystrophic Red-Yellow Argisol	Jequitinhonha Type S granitoids*	Coastal Plateau Pre-Coastal Plateau
Medium	Strongly undulate**	525 meters**	Dystrophic Yellow Latosol Dystrophic Red-Yellow Latosol* Dystrophic Red-Yellow Argisol	Jequitinhonha Type S granitoids*	Coastal Plateau Pre-Coastal Plateau*
Large	Strongly undulate**	365 meters**	Dystrophic Yellow Latosol* Dystrophic Red-Yellow Latosol	Jequitinhonha* Type S granitoids	Coastal Plateau* Pre-Coastal Plateau

For Tabarelli *et al.* (2010), there is an important relationship between altitude and the forest cover in the Atlantic Forest. The first is the larger original extension of the vegetation cover of the forest, which is concentrated at altitudes between 200 m and 1,200 m, with peaks between 400 and 800 meters. The second is in the highest concentration of protected areas and fragments over 30 ha at altitudes higher than 1,200 m; therefore, at these altitudes, there is the highest concentration of habitats. In the case of PNAC the smaller fragments are at higher altitudes than larger fragments, refforcing that the topographic features of steeper slope and hypsometry do not prevent the advancement of fragmentation

All fragments are on the Jequitinhonha geological unit and type S granitoids, the geomorphology of coastal plateau, and the pre-coastal plateau, in addition to soils predominantly converted to agricultural use. The geological composition of the park is a local natural attraction. It is formed by igneous and metamorphic rocks from the Paleozoic that extend along the Brazilian Atlantic coast.

The existing coastal plateaus have relief features of tabular tops covered by sediments from the Barreiras group. The average altitude is 60 m, and they contribute to the type of soil found in the region, as well to in the development of local hygrophilous vegetation. The Pre-Coastal Plateau, on the other hand, is recognized for its mountainous reliefs at altitudes between 400 m and 800 m and notches that form a rich drainage. The latosol and Argisol soils are porous, deep, and drained with strong weathering and facilitate rooting and thus the installation of agricultural crops and the expansion of tropical forest regions.

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It is worth mentioning that these conditions also favor urbanization pressures, which are intensified in less elevated areas with less sloping terrain, increasing the degradation of the Atlantic Forest. These activities also use fire as a management practice and, in the long run, nutrients and local biodiversity are lost.

There is a need to implement environmental awareness mechanisms for communities and sustainable landscape management practices, reinforcing the monitoring of forest fragmentation in intensely anthropized areas inside the Park. It is also necessary to strengthen dialogue and conflict mediation with local communities. In this analysis, there are two major obstacles for the Park. The first is management practices developed by communities, although part of it reflects the population's subsistence and only source of income, but which transform the forest into agricultural crops and pastures and change the quantity and quality of forest remnants.

The second obstacle is the lack of regularization by public authorities, which encourages conflicts with environmental legislation and the implementation of protection guidelines for protected areas established in Brazil. Although individuals, cultures and ways of life that exist there before the creation of the Park must be taken into account, the restrictions to preserve the area are essential.

Conclusion

The Alto Cariri National Park has more than half of its area covered with a forest patch with forest fragments predominantly smaller than 5 ha. Local fragmentation is high. It is estimated that it will be further fragmented if regularization mechanisms are not put into force. Although large fragments have greater extensions, the topographic characteristics of soils, the low altitude and the relief reinforce the dangerousness of conversion of these areas.

The regional socioeconomic vocation for agriculture and the absence of environmental regularization of the protected area are the greatest bottlenecks to the high forest fragmentation in the park, preventing the maintenance of local biodiversity and biological diversity, which are objectives of its creation in the south of Bahia.

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