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Scientific Article

CONTRASTS IN LANDSCAPE STRUCTURE AND THEIR EFFECTS ON CONSERVATION IN AGRICULTURAL SUB-REGIONS OF BAHIA

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ABSTRACT

Landscape fragmentation, driven by diverse agricultural practices, represents one of the significant challenges for biodiversity conservation. Although some sub-regions in Bahia are considered better preserved due to their traditional land-use patterns, comparative assessments with less preserved areas remain scarce. This study aimed to evaluate the landscape structure in two rural communities in Bahia, Brazil: Rio do Engenho (Ilhéus) and Riacho da Guia (Alagoinhas), characterized respectively by agroforestry systems (cabruca) and monocultures (citrus and eucalyptus). The methodology was based on the analysis of CBERS-04A satellite images (2024) with an 8-meter spatial resolution, processed using QGIS 3.34. Land-use and land-cover mapping was conducted through manual visual interpretation, identifying up to nine thematic classes. To assess landscape structure, nine ecological metrics were calculated using the LecoS plugin, encompassing composition, shape, connectivity, and diversity. The results indicated that Rio do Engenho has a larger proportion of native vegetation, greater cohesion, and lower edge density, revealing a configuration more favorable to biodiversity conservation. In contrast, Riacho da Guia exhibited higher fragmentation, a predominance of agricultural land uses, and reduced connectivity among forest remnants. Therefore, the findings demonstrate that adopting agroforestry systems enhances biodiversity maintenance and ecosystem resilience, whereas monoculture practices accelerate environmental degradation.

Keywords: Agroecology; Biodiversity conservation; Forest fragmentation

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CONTRASTES NA ESTRUTURA DA PAISAGEM E SEUS EFEITOS SOBRE A CONSERVAÇÃO EM SUB-REGIÕES AGRÍCOLAS DA BAHIA

RESUMO A fragmentação da paisagem, impulsionada por diferentes práticas agrícolas, representa um dos principais desafios à conservação da biodiversidade. Embora sub-regiões baianas sejam consideradas mais preservadas por causa do habitual uso da terra, avaliações estabelecendo comparações com outras consideradas menos preservadas são escassas. Este estudo teve como objetivo avaliar a estrutura da paisagem em duas comunidades baianas, Rio do Engenho (Ilhéus) e Riacho da Guia (Alagoinhas), submetidas, respectivamente, a sistemas agroflorestais (cabruca) e monoculturas (citrus e eucalipto). A metodologia baseou-se na análise de imagens do satélite CBERS-04A (2024), com resolução espacial de 8 m, processadas no software QGIS 3.34. O mapeamento do uso e cobertura da terra foi realizado por fotointerpretação manual e a classificação considerou até nove categorias temáticas. Para a avaliação da estrutura da paisagem foram utilizadas nove métricas ecológicas, calculadas com o plugin LecoS, abrangendo composição, forma, conectividade e diversidade. Os resultados indicaram que Rio do Engenho apresenta maior cobertura de vegetação nativa, elevada coesão e baixa densidade de borda, refletindo uma configuração mais favorável à conservação. Em contraste, Riacho da Guia exibiu alta fragmentação, predominância de uso agropecuário e valores reduzidos de conectividade entre fragmentos. Portanto, a análise revelou que a adoção de sistemas agroflorestais favorece a manutenção da biodiversidade e a resiliência ecossistêmica, ao passo que monoculturas intensificam a degradação ambiental.

Palavras-Chave: Agroecologia; Conservação da biodiversidade; Fragmentação Florestal

1. INTRODUCTION

Agriculture and livestock farming have formed the basis of global food production for approximately 10,000 years, playing a fundamental role in shaping human societies (Liu et al., 2019). However, the conversion of natural ecosystems into productive systems has resulted in severe environmental impacts, including vegetation fragmentation, habitat loss, and biodiversity decline (Gallindo et al., 2022).

Among the primary drivers of these impacts, extensive agricultural expansion and monoculture practices are notable. Such practices promote landscape homogenization, trigger microclimatic alterations, and contribute to the decline of native fauna and flora populations (Liu et al., 2019).

Within this context, the Atlantic Forest (Mata Atlântica) is recognized as one of Brazil's most biodiverse biomes and has been widely studied in global scientific literature. It is characterized by high ecological heterogeneity, harboring various forest formations and associated ecosystems (Marques et al., 2021). Its floristic structures and compositions vary significantly, influenced by geographic factors such as topography and altitude, as well as climatic conditions and soil types (Nettesheim et al., 2010; Silva et al., 2007).

Since the colonial period, the Atlantic Forest has been systematically degraded, primarily due to agricultural activities and urban expansion. Nevertheless, the state of Bahia still retains significant forest remnants with high ecological complexity and essential roles in sustaining ecosystem services (Myers et al., 2000).

The increasing fragmentation of the landscape, driven by anthropogenic pressures, has generated multiple impacts on Atlantic Forest ecosystems. These include genetic erosion, soil degradation, contamination of surface and groundwater, and substantial microclimatic changes (Parrotta, 1992; Dale & Polasky, 2007; Gallindo et al., 2022).

Even small-scale productive systems, such as family farming, can cause significant effects on native ecosystems. This highlights the need to understand better how agricultural activities influence forest remnants (Dale & Polasky, 2007).

Integrating environmental conservation with agricultural production is, therefore, crucial. Restoring degraded areas and valuing ecosystem services, such as water regulation, microclimatic stability and maintaining soil fertility, are key strategies for sustainable management (Ruiz-Agudelo et al., 2020).

Although agriculture and urbanization are central to local economies and livelihoods, they exert substantial pressure on ecosystems, especially in regions with intensive natural resource use (Quaresma & Silva, 2022).

The Rio do Engenho community, one of the areas analyzed in this study, stands out for its ecological, cultural, and historical value. The region features Atlantic Forest remnants and associated ecosystems, recognized for their scenic beauty and ecological significance (Noia et al., 2008). Its origins trace back to the colonial period with the establishment of sugar mills (Marcis, 2000). Today, the local economy is diversified, involving agroecological practices, tourism, and artisanal crustacean harvesting, although the surrounding areas remain strongly influenced by cacao cultivation (Noia et al., 2009). In contrast, the Riacho da Guia community, located in the municipality of Alagoinhas (Bahia), presents a mosaic landscape composed of Atlantic Forest and Caatinga fragments alongside with family farming plots, conventional citrus plantations and forestry (Alves et al., 2023).

In this scenario, geotechnologies have become essential tools for mapping forest fragments and analyzing landscape structure. These technologies support decision-making in conservation processes by identifying priority areas for ecological restoration. They also play a role in the identification of relationships between different forms of land use, allowing a comparative evaluation of the environmental advantages of each occupation model.

Given this context, the present study aims to map and characterize the effects of landscape fragmentation resulting from agricultural practices in the communities of Rio do Engenho, in the municipality of Ilhéus (Bahia), and Riacho da Guia, located in Alagoinhas (Bahia). The findings provide a scientific basis for supporting conservation strategies and promoting sustainable use of local ecosystems.

2. MATERIAL AND METHODS

2.1 Study area

The Rio do Engenho community, located in the municipality of Ilhéus, Bahia (-14.8527, -39.0669), is recognized for its historical, cultural, and ecological significance (Figure 1).

The vegetation in the region belongs to the Atlantic Forest biome, characterized by dense evergreen broadleaf shrub formations, with the presence of mangroves along brackish coastal zones (Franco et al., 2011).

In addition to native vegetation, the area includes cacao plantations integrated into shaded forests, locally known as cabruca. This agroforestry system plays a critical role in biodiversity conservation by enabling the coexistence of native and cultivated species (Delabie et al., 2007).

The climate is warm and predominantly humid, with an annual mean temperature above 24 °C and average temperatures in the coldest month (June) remaining above 21 °C. Annual precipitation exceeds 1,900 mm, with rainfall distributed throughout the year. The wettest period extends from December to March, while September and October record the lowest rainfall indices (Franco et al., 2011).

Alagoinhas, another municipality in Bahia, located in the Agreste region, lies 108 km from the state capital, Salvador, at coordinates -12.1336, -38.4236, and an average altitude of 130 m (Nunes & Matos, 2017). The municipality has approximately 140,000 inhabitants and covers an area of 1,179 km², comprising the districts of Boa União and Riacho da Guia.

The region's climate is predominantly semi-arid, and the territory is composed of approximately 86% Atlantic Forest and 14% Caatinga biome. The prevailing soil types are Yellow Argisol (65.7%) and Quartzarenic Neosol (16.1%). Dense ombrophilous forests in the region have been significantly degraded due to deforestation for agropastoral activities and, more recently, industrial expansion driven by large-scale eucalyptus monocultures (Nunes & Matos, 2017).

The Riacho da Guia district (Figure 2), located in Alagoinhas, covers an area of approximately 3,540 km² and has an estimated population of 1,066 inhabitants, according to the IBGE Census (2022).

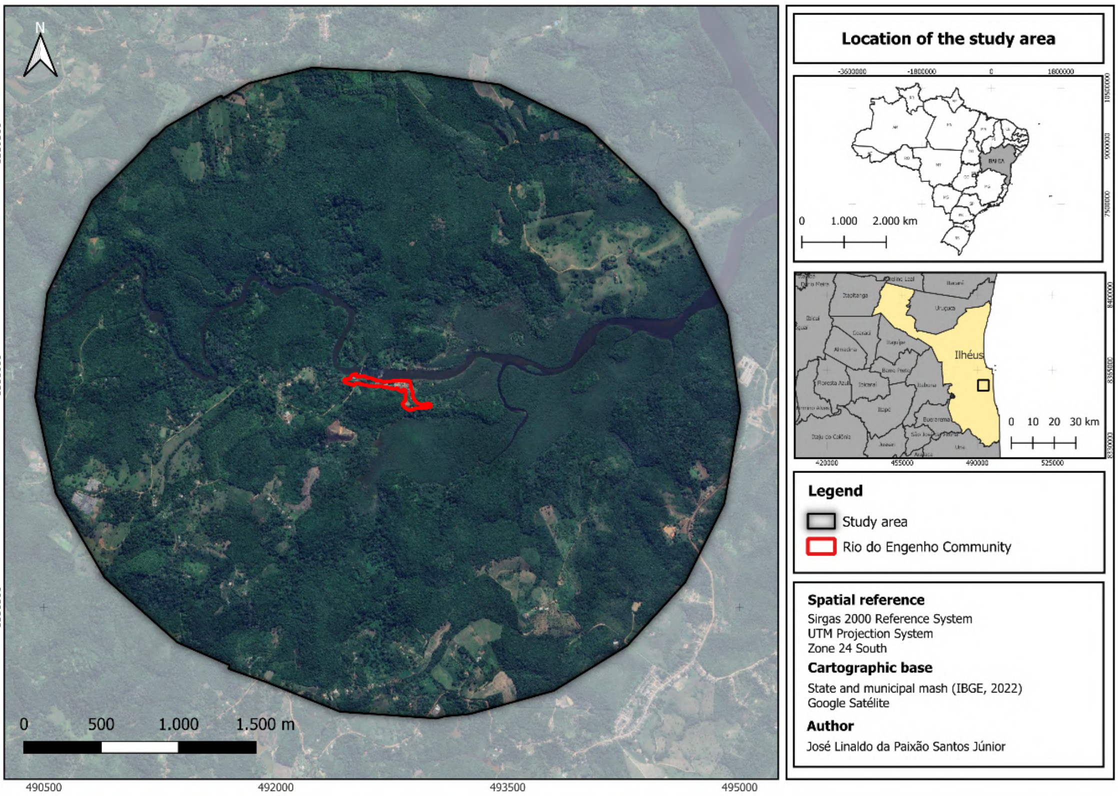

Figure 1. Location map of the Rio do Engenho community
Figura 1. Mapa de localização da comunidade do Rio do Engenho

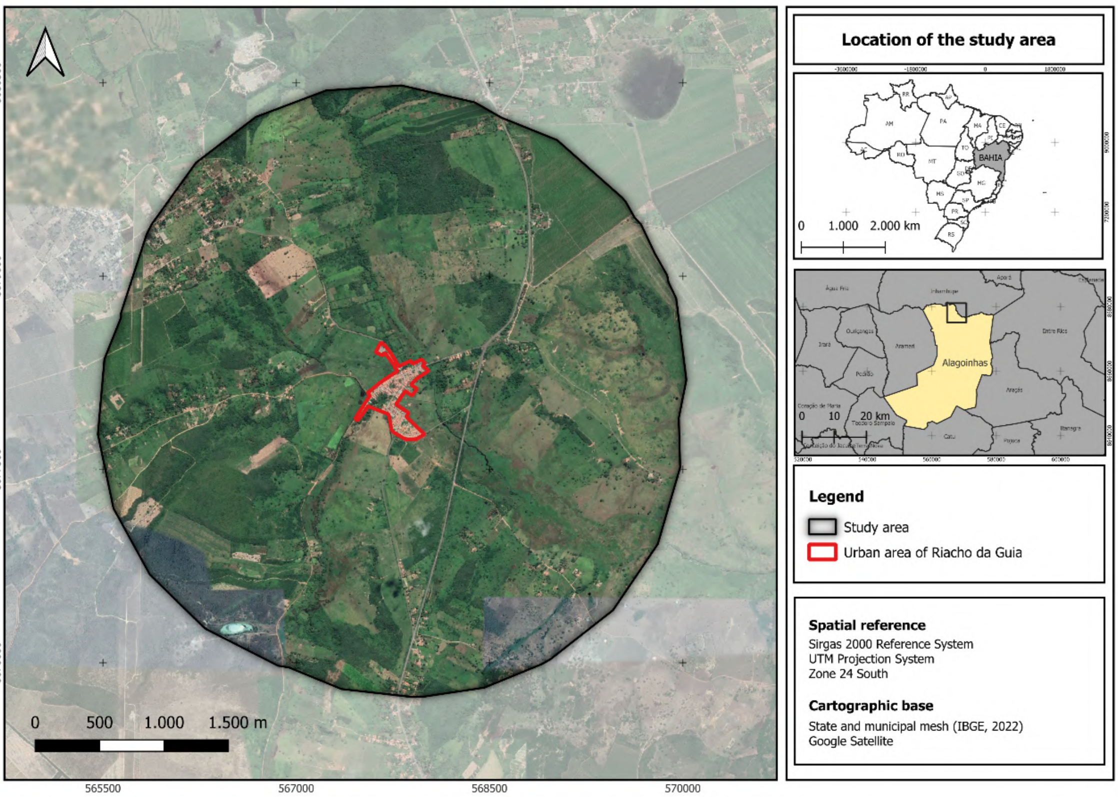

Figure 2. Location map of the Riacho da Guia district
Figura 2. Mapa de localização do distrito Riacho da Guia

Geologically, the region lies within the northern Recôncavo sedimentary basin, with deposits from the Quaternary period and sediments from the Barreiras, Marizal, and São Sebastião formations (Nunes & Matos, 2017).

2.2 Spatial data

To define the study areas, QGIS software (QGIS Development Team, 2024) was used to create a 2,000-meter buffer from the urban center of each community. This approach established an anthropogenic influence radius, enabling a detailed analysis of human impacts on landscape structure and local biodiversity.

The spatial dataset consisted of an 8-meter resolution mosaic generated from CBERS-04A satellite imagery acquired in June 2024. Two scenes were selected to fully cover the study area, prioritizing those with minimal cloud cover to ensure high-quality visual interpretation and classification accuracy.

Image processing was conducted using QGIS version 3.34, where the selected scenes, acquired at Instituto Nacional de Pesquisas Especiais (INPE), were mosaicked and clipped according to the study area boundaries. The spatial reference system was standardized to UTM Zone 24S, using the SIRGAS 2000 datum, with the Warp (Reproject) tool.

After obtaining the mosaic, the spectral bands were colored using the RGB combination (Band 4 = red, Band 3 = green, Band 2 = blue) and enhanced using linear stretching (minimum–maximum adjustment) of the the raster's symbology properties to improve the visual differentiation of land-cover features.

Land-use and land-cover mapping was performed through manual photointerpretation, as spectral similarities between cabruca plantations and native forest remnants prevented the reliable application of automatic classifiers. The interpretation considered visual attributes such as color, texture, shape, and spatial pattern. The features were delimited manually, creating digitized polygon-type vector layers and then filled into the attribute table with class identification.

Six similar in use and occupation thematic classes were identified, namely: agriculture, representing areas used for cultivation; water bodies, including rivers, lakes and streams; built-up areas, representing rural settlements and urban areas; Atlantic Forest, with a predominance of native trees and shrubs; grasslands, composed of natural herbaceous vegetation; and exposed soil, corresponding with areas without vegetation cover.

In the Rio do Engenho community territory, a distinct mangrove class was mapped, characterized by dense arboreal vegetation adapted to tidal influence and periodic flooding.

Otherwise, in Riacho da Guia, two additional classes were identified, namely pastures, used for forage cultivation, and roadways, representing paved rural access routes that influence territorial dynamics.

2.3 Landscape metrics

The analysis of landscape structure was conducted through the calculation of ecological metrics widely recognized in landscape ecology to quantify the effects of fragmentation and the alterations caused by anthropogenic activities on vegetation cover. The selection of metrics was based on their ecological relevance, sensitivity to spatial heterogeneity, and ability to represent different aspects of landscape organization, including composition, configuration, and structural connectivity.

Nine metrics were analyzed: total class area (CA), proportion of landscape (PLAND), most extensive patch index (LPI), number of patches (NP), fractal dimension index (FRAC), cohesion (COHESION), edge density (ED), mean patch area (MPA), and Simpson's diversity index (SIDI). These indicators were selected following the methodological framework proposed by McGarigal et al. (2012), which defines them as robust and sensitive to variations in spatial configuration (Table 1).

Each metric provides complementary information: CA represents the total area occupied by a specific land-cover class, while PLAND expresses its proportional representation relative to the total landscape

Table 1. Description of selected landscape metrics
Tabela 1. Descrição das métricas da paisagem selecionadas

Category	Metric	Equation	Range
Area and edge	CA	$\sum_{j=0}^{n} a_{ij}\left(\frac{1}{10000}\right)$	CA > 0, no limit
	PLAND	$\frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	0 < PLAND ≤ 100
	LPI	$\frac{(a_{ij})}{A}(100)$	0 < LPI ≤ 100
	ED	$\frac{\sum_{k=1}^{m} e_{ik}}{A}$	ED ≥ 0, no limit
	MPA	$\frac{\sum_{j=1}^{n} a_{ij}}{n_i}$	MPA > 0, no limit
Shape	FRAC	$\frac{2\,In\,(.25\,p_{ij})}{In\,a_{ij}}$	1 ≤ FRAC ≤ 2
Aggregation	NP	n_i	NP ≥ 1, no limit
	COH	$\left[1-\frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right] * \left[1-\frac{1}{\sqrt{A}}\right]^{-1} * 100$	0 ≤ COH ≤ 100
	SIDI	$1-\sum_{i=1}^{m} p_i^2$	0 ≤ SIDI ≤ 1

Note: A = total area of the landscape (m²); aij = area of fragment ij (m²); eik = total perimeter of the landscape between fragments of classes i and k; ni = number of fragments in the landscape of class i; pij = proportion of occupied landscape between classes p and j.
Nota: A = área total da paisagem (m²); aij = área do fragmento ij (m²); eik = perímetro total da paisagem entre fragmentos de classes i e k; ni = número de fragmentos na paisagem da classe i; pij = proporção de paisagem ocupada entre as classes p e j.

area. LPI identifies the spatial dominance of the largest fragment, whereas NP reflects the degree of fragmentation. FRAC indicates the geometric complexity of patch shapes, and COHESION evaluates the degree of physical connectivity among patches within the same class. ED highlights the influence of edge effects by relating perimeter and area, MPA indicates the average patch size, and SIDI measures the diversity of land-cover classes based on their proportional distribution.

Simpson's diversity index is a valuable measure of landscape heterogeneity, as it indirectly considers the spatial distribution of patches across different land-use classes. It provides essential information about the diversity and relative abundance of land-cover types, allowing for a better understanding of ecosystem complexity, such as soil cover and area distribution (Barwicka & Milecka, 2021).

All metrics were processed using QGIS version 3.34 through the LecoS (Landscape Ecology Statistics) plugin, as described by Jung (2016). This tool allows obtaining the automated extraction of spatial metrics from classified raster data. It organizes the results at two levels: class-level, which describes the specific patterns of each land-use category, and landscape-level, which synthesizes the overall structural configuration of the study area.

3. RESULTS

The total area analyzed in this study corresponds to 3,191 hectares. The land-use and land-cover analysis revealed contrasting patterns between the Rio do Engenho and Riacho da Guia communities, both in terms of landscape composition and structural configuration. To allow a more accurate comparative assessment, the results are presented separately for each area.

3.1 Rio do Engenho community

In the Rio do Engenho community, the land-use and land-cover map (Figure 3) reveals a predominance of native vegetation, including remnants of the Atlantic Forest and mangroves areas, which collectively represent 75.54% of the local landscape. Pasture and agricultural areas account for only 6.6%, and no extensive livestock farming areas were identified.

Atlantic Forest is the dominant land-cover class, occupying 65.67% of the total community area. This vegetation is concentrated in two large fragments of 580.33 hectares and 385.78 hectares, which together comprise 98.33% of the total forest cover. The remaining thirteen fragments, each smaller than three hectares, represent only 1.67% of this class. This spatial concentration of vegetation in a few large patches surrounded by smaller, isolated fragments reflects a structural pattern commonly observed in regions experiencing significant anthropogenic pressure on native vegetation.

The most extensive patch index (LPI) confirms this configuration by indicating the dominance of extensive, continuous blocks of native forest. Edge density values are relatively low (Table 2), which can be attributed to the predominance of compact, large patches and the reduced occurrence of small, irregular fragments.

Regarding patch morphology, fractal dimension values (Table 3) indicate relatively simple regular shapes, which contribute to maintaining landscape connectivity among forest remnants and support a structurally more integrated configuration. The low edge density reinforces this interpretation, as large contiguous patches are less exposed to edge-related disturbances.

In the case of mangroves, although average fragment size is smaller, their regular shapes and high spatial cohesion indicate stable and well-defined patches. The low edge density observed for this class further supports the characterization of a landscape composed of compact and relatively well-preserved units (Table 3).

3.2 Riacho da Guia community

The Riacho da Guia community exhibits a markedly different structural configuration. Native vegetation covers only 14.47% of the

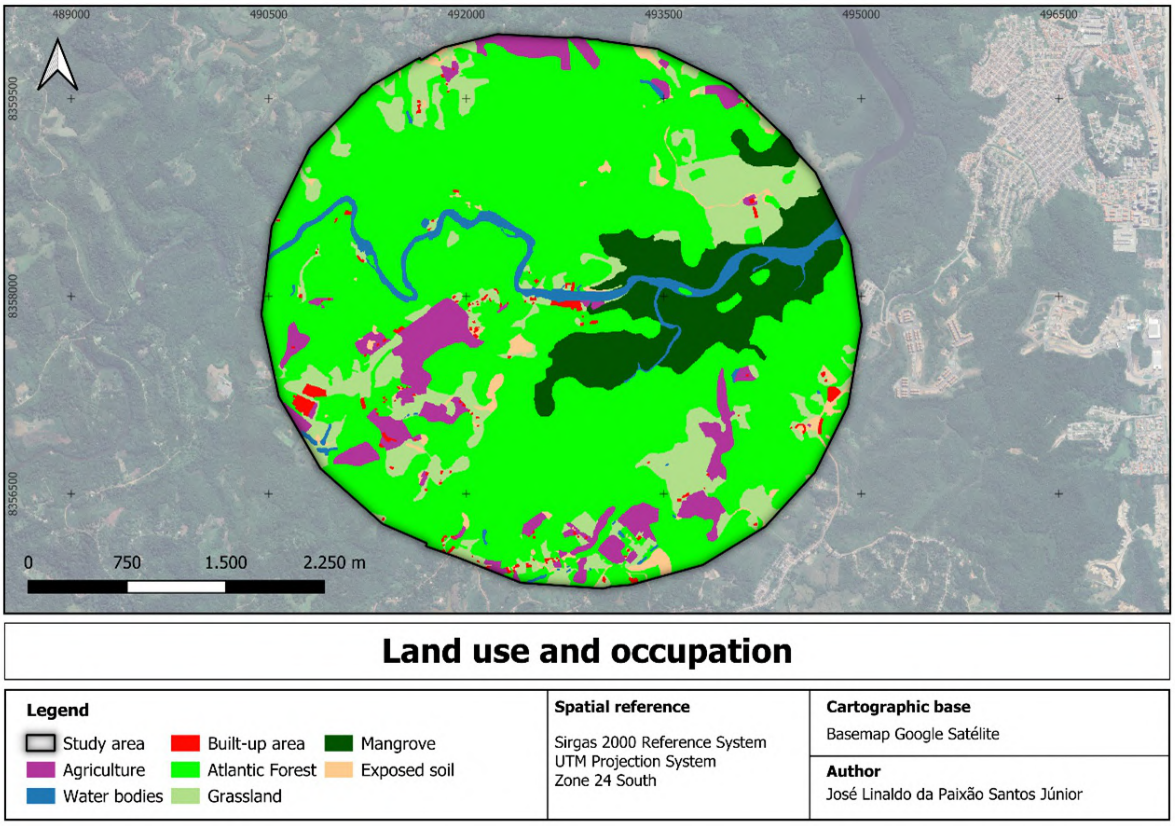

Figure 3. Land use and occupation map of the Rio do Engenho community
Figura 3. Mapa de uso e ocupação do solo da comunidade do Rio do Engenho

Table 2. Total area (CA), Area in percentage (PLAND), large fragment index (LPI) and number of fragments (NP) by land use class for the community of Rio do Engenho
Tabela 2. Área total (CA), Área em porcentagem (PLAND), índice de fragmentos grandes (LPI) e número de fragmentos (NP) por classe de uso do solo para a comunidade do Rio do Engenho

Class	CA (ha)	PLAND (%)	LPI	NP
Agriculture	98,8	6,6	2	35
Water bodies	45,7	3,1	3	26
Built-up areas	12,8	0,9	0,1	128
Exposed soil	25,4	1,7	0,2	77
Grassland	183,3	12,3	3	82
Atlantic Forest	982,5	65,7	39	15
Mangrove	147,6	9,9	4	5

Table 3. Fractal dimension index (FRAC), Fragment cohesion index (COH), Edge density (ED), Average fragment area in hectares (MPA), of the Atlantic forest and mangrove of the community of Rio do Engenho
Tabela 3. Índice de dimensão fractal (FRAC), Índice de coesão dos fragmentos (COH), Densidade de borda (ED), Área média de fragmentos em hectares (MPA), da mata atlântica e mangue da comunidade do Rio do Engenho

Class	FDI	COH	ED	MPA
Atlantic Forest	1,12	9,85	0,0081	65,5
Mangrove	1,13	9,53	0,0016	29,53

total landscape, distributed among highly fragmented patches ranging from 1.08 to 46 hectares. The matrix is dominated by agricultural and pasture activities, which together account for 69.68% of total land cover (Figure 4).

The structural analysis reveals a high degree of fragmentation, as evidenced by the number of patches (NP) and significantly lower LPI values compared to Rio do Engenho. The absence of dominant forest patches and the abundance of small, isolated fragments compromise ecological connectivity, amplifying edge effects and reducing the potential for biodiversity conservation.

Edge density for Atlantic Forest remnants in Riacho da Guia is substantially higher than in Rio do Engenho (Table 4). This increase is associated with the predominance of small fragments whose disproportionately large perimeters relative to their areas exacerbate exposure to edge-related environmental impacts (Laurance et al., 2007).

As for fractal dimension (Table 5), values indicate mostly regular shapes, but structural cohesion among patches is moderate, suggesting only partial connectivity within a highly fragmented agricultural matrix.

Edge density also reflects a higher proportion of marginal areas relative to total patch size, reinforcing the vulnerability of these fragments (Table 4). Mean patch area values further confirm this trend, revealing a discontinuous landscape composed of small, spatially isolated units with reduced structural resilience.

4. DISCUSSION

The landscape characteristics observed in the Rio do Engenho region are closely linked to the historical development of local agricultural activities, particularly the establishment of cacao cultivation since the introduction of the first seeds in southern Bahia in 1746 (Aguiar & Pires, 2019). A key aspect of this process was the early adoption of the cabruca system (*Theobroma cacao*), characterized by cultivating cacao, under the shade of native trees (Sambuichi, 2006).

This agroforestry system integrates agricultural production with environmental conservation, proving essential for maintaining biodiversity and preserving

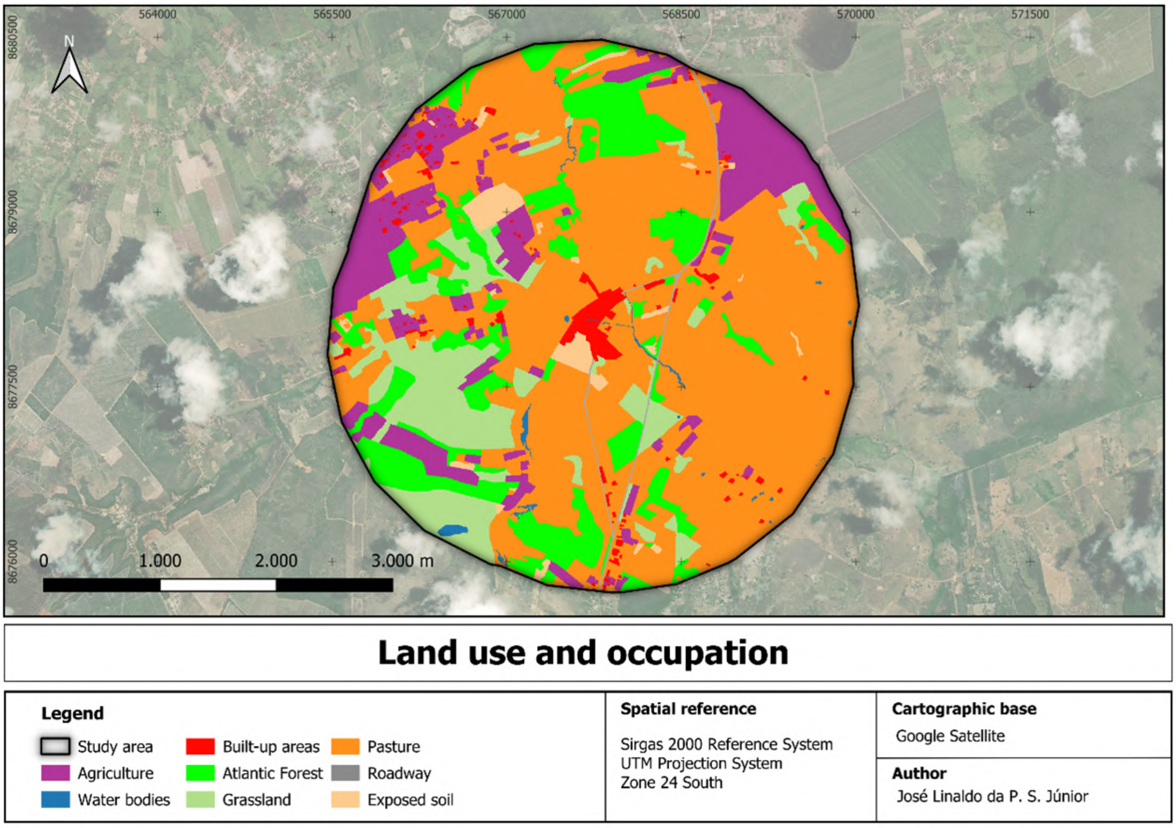

Figure 4. Land use and occupation map of the Riacho da Guia community
Figura 4. Mapa de uso e ocupação do solo da comunidade do Riacho da Guia

Table 4. Total area (CA), Area in percentage (PLAND), large fragment index (LPI) and number of fragments (NP) by land use class for the community of Riacho da Guia
Tabela 4. Área total (CA), Área em porcentagem (PLAND), índice de fragmentos grandes (LPI) e número de fragmentos (NP) por classe de uso do solo para a comunidade do Riacho da Guia

Class	CA (ha)	PLAND (%)	LPI	NP
Agriculture	223,8	13,2	4,1	48
Water body	7,6	0,45	0,1	29
Built-up areas	34	2	1	145
Exposed soil	33,9	2	0,7	28
Pasture	957,3	56,48	2,4	36
Roadway	8,2	0,49	0,5	3
Grassland	184,9	10,91	4,4	25
Atlantic Forest	245,3	14,47	2,7	38

Table 5. Fractal dimension index (FRAC), Fragment cohesion index (COH), Edge density (ED), Average fragment area in hectares (MPA), of the Atlantic forest of the community of Riacho da Guia
Tabela 5. Índice de dimensão fractal (FRAC), Índice de coesão dos fragmentos (COH), Densidade de borda (ED), Área média de fragmentos em hectares (MPA), da mata atlântica da comunidade do Riacho da Guia

Class	FDI	COH	ED	MPA
Atlantic Forest	1,13	9,87	0.028	6,46

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remnants of the Atlantic Forest (Pardini et al., 2009). Consequently, Rio do Engenho presents conditions more favorable to ecosystem conservation, despite the fact that anthropogenic influences remain significant.

Beyond supporting diverse native plant species, the cabruca system mitigates the negative impacts of conventional agricultural practices, which are often associated with monocultures and require high inputs of chemical fertilizers and pesticides (Gama-Rodrigues et al., 2021). By incorporating native tree species to provide shade, cabruca promotes soil moisture retention, which is critical for agricultural sustainability in tropical environments, while simultaneously reducing farmers' dependence on external inputs and lowering production costs (Bentes-Gama et al., 2008).

This agroforestry approach directly contributes to soil conservation and water resource protection, creating a more resilient environment under variable climatic conditions. Such resilience is essential for sustaining long-term agricultural productivity (Franco et al., 2011). Moreover, agroecological systems, such as cabruca, support local economies by decreasing dependency on high-cost agricultural inputs and fostering low-impact production strategies (Franco et al., 2011; Gama-Rodrigues et al., 2021).

Cabruca fragments also act as ecological corridors, connecting areas of primary and secondary forest, facilitating species dispersal, and contributing to the recovery of degraded landscapes (Faria et al., 2007). This function is particularly significant for large-bodied species with extensive habitat requirements, which benefit from the structural continuity provided by these integrated systems.

Therefore, maintaining cabruca landscapes offers both ecological and economic advantages, illustrating how sustainable practices can mitigate the effects of fragmentation while supporting the preservation of essential ecosystems in Rio do Engenho.

In contrast, the Riacho da Guia community relies predominantly on traditional monoculture practices. Citrus cultivation plays a central role in the local economy, being closely associated with smallholder farming, while agro-industrial enterprises manage large-scale eucalyptus plantations.

Although eucalyptus forestry can represent an economically viable alternative for producing timber and other forest products, particularly when managed sustainably, the dominance of monocultures presents considerable environmental challenges. Intensive citrus production often leads to biodiversity loss, soil compaction, and degradation due to mechanized farming, alongside increased reliance on fertilizers and pesticides, which can contaminate water bodies and negatively affect non-target organisms (Gomes et al., 2020). Similarly, eucalyptus monocultures exert significant ecological pressure by replacing native ecosystems with extensive, structurally homogeneous landscapes (Barbosa et al., 2019).

The spatial patterns observed in this study emphasize apparent differences between the two communities. In Rio do Engenho, the cabruca system supports the preservation of large, continuous forest patches with compact edges, reinforcing the integrity of native vegetation remnants. In Riacho da Guia, however, monoculture practices have led to highly fragmented vegetation, resulting in smaller and more isolated patches, as well as irregular edges, which intensify edge effects and reduce connectivity among forest remnants.

Eucalyptus plantations, in particular, are associated with high water consumption rates, which may compromise water availability in adjacent areas, while also providing limited habitat resources for native fauna compared to integrated systems, such as cabruca (Lemessa et al., 2022).

The accelerated expansion of so-called "planted forests" raises additional environmental challenges, including biodiversity loss, soil degradation, and reduced ecosystem resilience. Furthermore, it often restricts access to arable land, directly influencing subsistence farming practices and altering local cultural dynamics, with significant implications for the sustainability of rural communities (Guerino et al., 2022).

Considering these findings, agroforestry systems such as cabruca emerge as more effective alternatives for reconciling environmental conservation with sustainable rural development. This conclusion holds particular relevance when evaluated across large territorial scales, such as the state of Bahia.

Within Rio do Engenho, forest fragments vary considerably in size, ranging from extensive areas of the Atlantic Forest to small, isolated patches. Spatial configuration plays a crucial role in biodiversity conservation, particularly in terms of habitat connectivity and exposure to edge effects.

Larger fragments, such as those of 580.33 ha and 385.78 ha, are essential for sustaining species that require continuous habitats, as they maintain stable microclimatic conditions and are less susceptible to anthropogenic disturbances (Ribeiro et al., 2009). Their lower edge-to-area ratios reduce exposure to environmental fluctuations, favoring endemic and large-bodied species (Barbosa et al., 2017).

Conversely, smaller fragments exhibit structural limitations, as their increased edge exposure facilitates the colonization of invasive species and threatens sensitive, specialized organisms (Barbosa et al., 2017). However, when strategically preserved, these fragments can act as stepping stones, promoting connectivity between larger areas and facilitating gene flow (Araújo & Bastos, 2019).

In this study, the Simpson's Diversity Index (SIDI) reached 0.54 for Rio do Engenho and 0.63 for Riacho da Guia, indicating moderate diversity when compared to similar landscapes (Pereira et al., 2001; Rocha et al., 2019). These results confirm that, despite differences in structural configuration, both regions exhibit reasonable diversity in land-use classes, with Atlantic Forest dominating in Rio do Engenho and agriculture prevailing in Riacho da Guia.

Fractal dimension values revealed that native vegetation fragments exhibit predominantly regular shapes, which reduce edge effects and result in more compact and structurally stable remnants. This finding is critical for understanding biodiversity responses to landscape configuration, as edge-related impacts can influence species richness and ecosystem processes (David et al., 2017).

Edge effects involve microclimatic alterations and increased susceptibility to invasive species along the peripheries of fragments (Fahrig, 2017). Patches with irregular edges are especially vulnerable because a larger proportion of their area is influenced by boundary conditions, which accelerates habitat degradation and biodiversity loss (Fahrig, 2003).

Spatial cohesion analysis indicated that, in both communities, forest fragments maintain relatively high degrees of connectivity, forming landscapes that are structurally integrated to varying extents. This result is particularly noteworthy for Riacho da Guia, where, despite intensive agricultural occupation, native vegetation remnants are not entirely isolated.

The cohesion metric reflects not only the physical distances between fragments but also their structural continuity, indicating potential for functional species movement and gene flow, which are critical for sustaining biodiversity (Ramos et al., 2022; Gomes et al., 2023).

Ultimately, the conservation of native vegetation fragments, combined with the adoption of sustainable agricultural practices, offers significant socioeconomic opportunities, particularly in Rio do Engenho. Preserving natural environments enhances ecotourism potential, diversifying the local economy, increasing household income, and reducing pressure on natural resources.

Capacity-building initiatives in agroecological practices, along with incentive programs such as targeted credit lines and subsidies for sustainable agriculture, can enhance community resilience. By promoting farmer knowledge, improving environmental stewardship, and integrating low-impact production techniques, these strategies support a transition toward agricultural models that are simultaneously productive and ecologically regenerative.

5. CONCLUSION

The results of this study demonstrate how different land-use strategies shape landscape structure and influence the conservation of native vegetation. The Rio do Engenho community, characterized by the presence of the cabruca agroforestry system,

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exhibits greater landscape connectivity, lower fragmentation, and improved environmental conservation. In contrast, Riacho da Guia, dominated by monocultures, displays a highly fragmented and ecologically vulnerable configuration.

These findings highlight the importance of valuing agroforestry systems as sustainable land-use strategies that reconcile agricultural productivity with biodiversity conservation. Public policies designed to promote these practices—such as targeted credit lines, technical assistance, and payments for ecosystem services—are essential to expand their large-scale implementation.

Furthermore, incorporating landscape metrics into territorial planning is strongly recommended, particularly for guiding the establishment of ecological corridors, fostering productive reconversion, and prioritizing strategic restoration in critical areas. Such measures can help mitigate the negative impacts of fragmentation while strengthening the sustainability and resilience of rural communities.

Overall, this study provides relevant insights to support evidence-based decision-making for sustainable land management, particularly in regions facing increasing agricultural pressures and biodiversity conservation challenges.

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AUTHOR CONTRIBUTIONS

Santos Júnior, J. L. da P.: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – Original Draft, and Visualization; Souza, J. G. S. de: Conceptualization, Methodology, Investigation, and Writing – Original Draft; Franco, V. S. de O.: Conceptualization, Methodology, Investigation, and Writing – Original Draft. Conceição, E. S. da: Conceptualization, Methodology, Writing – Review & Editing, Supervision, and Project Administration.

DATA AVAILABILITY

The entire dataset supporting the findings of this study has been published within the article.

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