Ciência Florestal
ISSN 1980-5098
OPEN ACCESS
Ci. Fl., Santa Maria, v. 35, e68141, p. 1-24, 2025 • https://doi.org/10.5902/1980509868141
Submitted: 17th/10/2021 • Approved: 13th/11/2024 • Published: 30th/06/2025

**Articles**

# Spatiotemporal dynamics of land use and cover in the Atlantic Forest Biome: quantifying spatial patterns along Bahia's north coast and agreste region

Dinâmica espaço-temporal do uso e cobertura no Bioma Mata Atlântica: quantificação de padrões espaciais ao longo do litoral norte e da região do agreste na Bahia

**Silvana Oliveira Wenceslau Soares[I], Rodrigo Nogueira de Vasconcelos[I], Jocimara Souza Britto Lobão[I], Elaine Cristina Cambuí Barbosa[II], Mariana Martins Medeiros de Santana[III], Washington de Jesus Sant'Anna da Franca-Rocha[I], Deorgia Tayane Mendes Souza[I]**

[I]State University of Feira de Santana, Feira de Santana, BA, Brazil
[II]Federal University of Bahia, Salvador, BA, Brazil
[III]State University of Amapá, Macapá, AP, Brazil

## ABSTRACT

The different land uses and coverages can generate various environmental impacts, both positive and negative. In the Bahia's north coast and agreste region, the diversified land use has resulted in significant changes in the spatial structure over the years. In this study, we aimed to understand the spatiotemporal dynamics of these transformations by analyzing a multitemporal series from 2000 to 2016 to quantify spatial patterns using landscape ecology methods and geoprocessing techniques. Land use and coverage data were obtained from the Annual Mapping Project of Land Use and Cover in Brazil (MapBiomas), using collection 2.3 for the study area. The quantitative analysis of the classes was conducted through metrics such as CA (area), NP (number of patches), LPI (largest patch), and PLAND (percentage of coverage). After reclassifying the land use and cover maps into the classes Agropastoral, Forest Formations, Mangrove, Grasslands, Water Bodies, Beaches and Dunes, and Urban Infrastructure, the CA metric indicated a gradual loss of 20% in forest formation areas and a 29% reduction in agropastoral and urban infrastructure areas. The LPI metric revealed that the largest fragment of forest formations occupies 22.7% of the total area, equivalent to 12,318.6 km². These analyses may support conservation and maintenance actions for forest areas, guide managers in creating or expanding conservation units, and inform environmental policies focused on sustainability and the conservation of this region.

**Keywords**: Landscape ecology; Landscape metrics; Geoprocessing; MapBiomas

## RESUMO

Os diferentes usos e coberturas da terra podem gerar impactos ambientais variados, tanto positivos quanto negativos. No Litoral Norte e Agreste Baiano, o uso diversificado do solo resultou em mudanças significativas na estrutura espacial ao longo dos anos. No presente estudo procuramos compreender a dinâmica espaço-temporal dessas transformações, para tanto analisamos uma série multitemporal de 2000 a 2016, com o objetivo de quantificar os padrões espaciais utilizando métodos da ecologia de paisagem e técnicas de geoprocessamento. Os dados de uso e cobertura da terra foram obtidos do Projeto de Mapeamento Anual da Cobertura e Uso do Solo no Brasil (MapBiomas), utilizando a coleção 2.3 para área de estudo. A análise quantitativa das classes foi conduzida através de métricas como CA (área), NP (número de manchas), LPI (maior mancha) e PLAND (porcentagem de ocupação). Após a reclassificação dos mapas de uso e cobertura da terra nas classes Agropastoris, Formações Florestais, Mangue, Campos, Corpos d'água, Praia e Dunas, e Infraestrutura Urbana, observou-se que a métrica CA indicou uma perda gradual de 20% nas áreas de formações florestais e uma redução de 29% nas áreas agropastoris e de infraestrutura urbana. A métrica LPI revelou que o maior fragmento de formações florestais ocupa 22,7% da área total, equivalente a 12.318,6 km².Essas análises poderão subsidiar ações de preservação e manutenção de áreas florestais, oferecendo suporte a gestores na criação ou ampliação de unidades de conservação, além de embasar políticas ambientais voltadas para a sustentabilidade e conservação dessa região.


**Palavras-chave**: Ecologia da paisagem; Métricas de paisagem; Geoprocessamento; MapBiomas

## 1 INTRODUCTION

Conceptually, landscapes are understood as heterogeneous mosaics distributed across units that interact in time and space (Metzger, 2001). In these interactions, natural elements and human influence determine the spatial configuration. These landscape elements organize dynamically over time and space, resulting in distinct features and conditions that enable the classification or grouping of similar arrangements, forming a mosaic. The landscape is a complex and dynamic system interacting with various natural, social, and cultural factors, shaping a global structure that yields new configurations (Metzger, 2001). This paradigm shift promotes advances in studies on fragmentation and conservation of species and ecosystems, enhancing the applicability of research for addressing environmental issues by fostering a comprehensive understanding of landscapes and territorial planning.

The application of Landscape Ecology is related to land-use planning, encompassing both natural and cultural landscapes, natural resource management, and biodiversity conservation while also addressing spatial patterns of landscape organization (Fernandes *et al*., 2024; Pereira *et al*., 2024). It raises questions, theories, and tools to understand the structure and dynamics of landscapes across various temporal scales to inform decisions on landscape conservation and planning (Cemin, 2014; Longo *et al*., 2024).

Changes in spatial patterns within the landscape result from alterations in land use and cover (Metzger, 2001), driven by social, cultural, political, and economic processes (Goerl *et al*., 2011). Human actions, as the primary transformative agents of spatial structure over time, lead to habitat loss, fragmentation of natural landscape structure, and, consequently, a reduction in biodiversity (Santos, 2011, 2018). Landscape ecology employs remote sensing tools combined with geographic information systems in this spatial analysis approach.

Currently, the MapBiomas platform methodology generates annual maps of land use and cover for Brazilian biomes rapidly and reliably. MapBiomas is a multi-institutional initiative that utilizes cloud processing techniques and automated classifiers developed and operated within the Google Earth Engine platform to create an annual historical series of land cover and use maps for Brazil (Mapbiomas, 2019). Each year, MapBiomas produces a broad set of data on the historical land use and cover across various Brazilian biomes, achieved through cloud processing techniques associated with machine learning methods, using data from sensors aboard the Landsat platform via Google Earth Engine (GEE) (Souza *et al*., 2020). The complete project description is available at http://mapbiomas.org.

The study area in this research spans both the Atlantic Forest Biome and the Caatinga Biome, partially encompassing both within the scope of this study. The Atlantic Forest is considered a conservation priority due to its high species richness and essential ecosystem services, such as potable water source protection, erosion control, support of agricultural productivity, slope containment, and maintenance of favorable climatic conditions (IBGE, 2020). Concurrently, the Caatinga, a biome exclusive to Brazil and the Northeast region, holds most of its biological heritage within national territory. It covers the Brazilian semi-arid area and transition zones with other biomes, spanning approximately 850,000 km², representing 10% of the national territory (IBGE, 2020). Despite its ecological importance, about 47% of the Caatinga's vegetation area is in a mosaic of grassland occupations. It is Brazil's third most degraded biome, behind only the Atlantic Forest and the Cerrado (IBGE, 2020).

Given the importance of these biomes, this study analyzes the dynamics of land use and cover in both regions simultaneously. By quantifying spatial patterns over the 2000 to 2016 time series, we used landscape metrics to evaluate land use and cover in the Atlantic Forest Biome in the Bahia's north coast and agreste region and the Caatinga. This integrated approach aims to understand the observed changes and to support conservation strategies and sustainable management in these ecosystems.

## 2 MATERIALS AND METHODS

### 2.1 Study area

This study was conducted in the region encompassing the territories of Bahia's north coast and agreste region. This area includes municipalities located between the geographical coordinates 11°20'28.8" and 12°37'49" South latitude; 38°47'06" and 37°20'26" West longitude, DATUM–SIRGAS 2000 (Figure 1). The "Territory of Identity" refers to a territorial approach to promote balanced and participatory regional development, grouping municipalities with similar economic, cultural, and environmental characteristics.

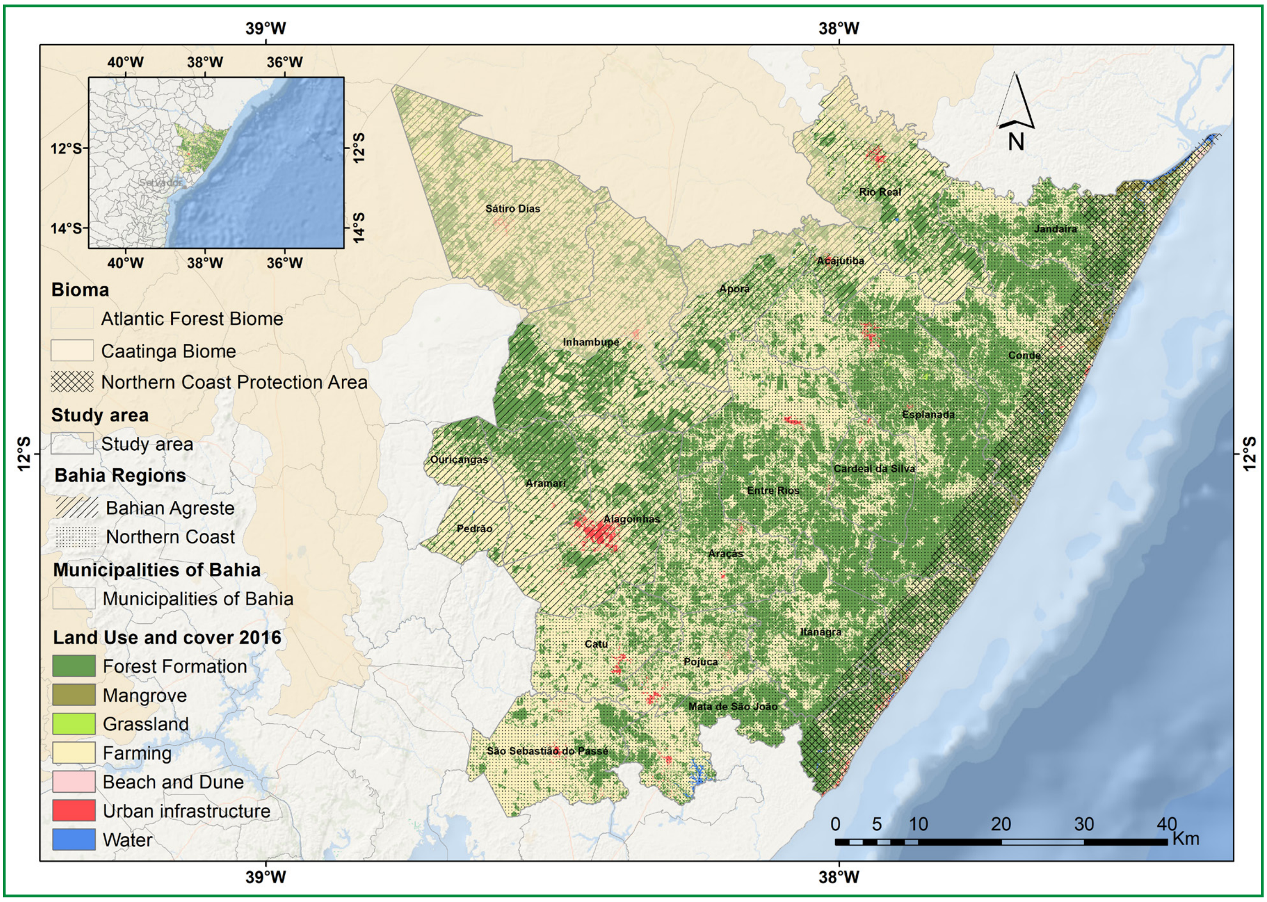
The Bahia's north coast and agreste region have a history of land use and occupation marked by natural resource exploitation, agricultural development, growth of livestock farming with cattle raising and subsistence crops, and, more recently, tourism and urban expansion. These regions harbor abundant biodiversity, providing habitats for endemic and endangered species. However, among the main types of land use, agricultural expansion, deforestation, and unregulated urban growth have led to habitat fragmentation and significant biodiversity loss, highlighting the urgency of implementing conservation strategies in these ecosystems (IBGE, 2020). Due to the lack of information associated with these regions and the pressing need for measures to improve land use management, the study area selection for this paper is justified.

## 2.2 Characterization of the study area

The study area encompasses 20 municipalities distributed across the identity territories of north coast (Araçás, Catu, Cardeal da Silva, Itanagra, Pojuca, São Sebastião do Passé, Conde, Entre Rios, Esplanada, Jandaíra, Mata de São João) and Agreste (Acajutiba, Alagoinhas, Aporá, Aramari, Inhambupe, Ouriçangas, Pedrão, Rio Real, Sátiro Dias) (Figure 1). In terms of area, the north coast and agreste identity territories cover approximately 12,318.6 km², including municipalities located within the Environmental Protection Area (APA) of Bahia north coast. This region comprises a coastal strip 144 km long and 10 km wide along the Linha Verde, encompassing the municipalities of Mata de São João, Entre Rios, Esplanada, Conde, and Jandaíra. The APA of North Coast of Bahia is known for its rich ecosystem diversity, featuring forest remnants, dunes, beaches, coral reefs, wetlands (marshes and lagoons), and mangroves.

The Bahia's north coast and agreste region identity territories have an estimated population of over 600,000 inhabitants, according to the 2010 Census by IBGE (SEI, 2019). The main economic activities in these regions include agriculture, with the cultivation of oranges, coconuts, and forest plantations of *Pinus spp.* and *Eucalyptus*. Livestock farming also plays a significant role, including poultry, beekeeping, cattle, and sheep-goat farming, as per the Ecological-Economic Zoning (ZEE) 2013. Additionally, there are oil exploitation, beverage, paper, and pulp industries, and, more recently, the expansion of the real estate and tourism infrastructure sectors, especially along the northern coast of Bahia.

Figure 1 – Geographical location of the Bahia's north coast and agreste region study area




Source: Authors (2019)

The municipalities of agreste region of Bahia cover the Cerrado region (Aporá, Acajutiba, Inhambupe, Jandaíra, Ouriçangas, Pedrão, Rio Real, Sátiro Dias), with a sub-humid to dry climate and semi-arid conditions, characterized by an average annual rainfall of less than 1,000 mm. There is a seasonal variation with 1 to 3 dry months, marked by two rainy periods: one in summer and another in winter (SEI, 2019).

According to data from the Agrarian Development Coordination, these territories are home to 12 quilombola communities in the municipalities of Alagoinhas, Araçás, and Mata de São João, as well as ten associations and artisanal fishing colonies across four municipalities. These communities significantly contribute to the region's cultural and economic diversity, strengthening traditional and sustainable activities.

Climatic characteristics vary between Bahia's north coast and agreste region, directly influencing economic activities and the availability of natural resources. In north coast, annual thermal amplitudes vary from south to north, with a predominantly Af climate type, according to Köppen and Geiger, and an average annual temperature between 23°C and 25°C (SEI, 2019). The coldest month records temperatures between 16°C and 18°C, while summers are long and warm, with averages above 22°C. The average annual rainfall ranges from approximately 900 mm to 1,200 mm, with abundant rainfall distributed throughout the year, most concentrated between March and August, characterizing a humid tropical climate without a defined dry season (SEI, 2019).

In contrast, the municipalities of agreste region of Bahia, including Aporá, Acajutiba, Inhambupe, Jandaíra, Ouriçangas, Pedrão, Rio Real, and Sátiro Dias, cover areas of the Cerrado. In this region, the climate varies from sub-humid to dry and semi-arid, with an average annual rainfall of less than 1,000 mm. There is a variation of 1 to 3 dry months, with two rainy seasons: one in summer and another in winter (SEI, 2019). These climatic characteristics directly influence the region's agricultural practices and water resource availability.

Geologically, Bahia's north coast and agreste region present three distinct features: the Domain of the Crystalline Plateaus, the Domain of Sedimentary Basins and Covers, and the Domain of Sedimentary Deposits (SEI, 2019). North coast consists of coastal terraces and plains, providing floodplains and mangroves, while agreste region of Bahia has geological formations that influence topography and soil fertility. Both regions fall within distinct river basins, such as the Itapicuru River, Recôncavo north, Inhambupe, and Rio Real (SEI, 2016), supporting a diversity of aquatic and terrestrial ecosystems.

The vegetation cover is diverse throughout the territory, characterized by phytogeographic regions of Dense Ombrophilous Forest, Semi-Deciduous Seasonal Forest, Gallery Forest, Caatinga, and Cerrado. Additionally, it includes areas with pioneer formations, such as restinga, marshes, lagoons, and mangroves, as well as zones of ecological tension between different floristic domains (SEI, 2016). These vegetative formations host a high richness and diversity of reptile and amphibian groups, especially in areas of the Atlantic Forest biome associated with Bahia's north coast and agreste region (Nunes; Matos, 2017).

However, anthropogenic activities such as reforestation with *Pinus spp.* and *Eucalyptus*, intensification of livestock, predatory fishing, mangrove degradation, and unregulated tourism in coastal districts have caused and contributed to significant environmental issues in both regions (INEMA, 2017). These actions result in habitat loss, forest fragmentation, and threats to local biodiversity. Therefore, it is essential to implement conservation and sustainable management strategies that consider the specific characteristics of Bahia's north coast and agreste region, aiming to mitigate environmental impacts and preserve these areas' rich and diverse ecosystems.

## 2.3 Data base

The land use and land cover maps used to quantify landscape spatial patterns were obtained from the MapBiomas Collection 2.3. Below, we summarize the main processing steps employed by MapBiomas in constructing the maps.

MapBiomas Collection 2.3 used a robust methodology to map land use and cover across Brazil from 2000 to 2016. Utilizing Landsat satellite images processed on the Google Earth Engine (GEE) platform, Collection 2.3 applied machine learning techniques, specifically the Random Forest algorithm, to classify land cover into 27 distinct classes (MAPBIOMAS, 2019). The central processing steps included data collection and pre-processing, attribute extraction, classification, post-processing, and validation (MAPBIOMAS, 2019).

Initially, images from the Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 (OLI) sensors were selected, ensuring minimal cloud cover and adequate seasonal representativeness. These images underwent pre-processing steps, including atmospheric correction and cloud and shadow masking using algorithms such as Fmask, enhancing data quality. Various spectral indices, such as NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index), were calculated to assist in distinguishing different cover types (MAPBIOMAS, 2019). A set of spectral bands and indices was compiled for attribute extraction as input variables for the classification process. Brazil's biomes were divided into smaller units based on watershed regions to improve classification accuracy. Stable training samples representing each land use and land cover class were collected with the help of experts familiar with local characteristics (MAPBIOMAS, 2019).

The Random Forest classifier was trained using these samples, leveraging its capacity to handle large datasets and multiple input variables effectively. Classification was conducted hierarchically, starting with broader classes and refining them into specific subclasses, which contributed to improved result accuracy (MAPBIOMAS, 2019).

In post-processing, spatial and temporal filters were applied to address classification inconsistencies and reduce noise. Techniques such as majority filters and temporal consistency checks were used to smooth abrupt changes and ensure logical transitions between classes over time. Integration with other land cover themes, such as agriculture and forestry, was achieved through hierarchical overlay and class prevalence rules.

In this study, we adopted the reclassification of land use and cover maps from Collection 2.3 for the time series from 2000 to 2016 into the following classes: Agro-pastoral, Forest Formations, Grasslands, Mangroves, Beaches and Dunes, Water Bodies, and urban infrastructure. The reclassification of classes for the selected time period is detailed in Table 1.

Table 1 – Land use and land cover classes used and their descriptions

| MapBiomas Classification | Reclassification | General description |
|---|---|---|
| Agriculture | Agropastoral | Agriculture – lands devoted to diverse farming practices, encompassing both annual and perennial crops;<br>Pasture – natural or planted grasslands managed for livestock;<br>Agro-pastoral areas where grazing and cropping cannot be reliably distinguished. |
| Pasture | | |
| Mosaic of Uses | | |
| Forest formation | Forest formation | Dense, open, and mixed evergreen (ombrophilous) forests; semi-deciduous and deciduous seasonal forests; arboreal pioneer formations; and planted forests consisting of commercially grown tree species (e.g., eucalyptus, pine). |
| Forest Plantation | | |
| Grassland | Grassland | Savanna and savanna–steppe formations – including park savannas, grassy-woody savannas, steppes, and early-successional shrubland and herbaceous communities. |
| Mangrove | Mangrove | Dense, evergreen forest stands that are regularly inundated by tides and form part of coastal mangrove ecosystems. |
| Beach and Dune | Beach and Dune | Non-vegetated area—bright-white sandy ridges entirely devoid of vegetation. |
| River, Lake and Ocean | Water | Permanent open-water features including lakes, ponds, reservoirs, coastal lagoons, and wetlands together with rivers and other natural or engineered water courses. This class also covers artificial ponds used primarily for aquaculture or salt-pond production. |
| Aquaculture | | |
| Urban infrastructure | Urban infrastructure | Urbanized areas dominated by impervious, non-vegetated surfaces – such as roads, streets, and buildings. |

Source: Authors (2019)

## 2.4 Landscape analysis

After reclassification, the temporal maps were quantified using the following metrics: Total Area of the landscape (CA), Number of Patches (NP), Percentage of area of the same class in the landscape (PLAND), and Percentage of the largest fragment of the class in the landscape (LPI) (Table 2).

To calculate these metrics, we used the software FRAGSTATS 4.0 (McGARIGAL *et al*., 2012) according to the descriptors indicated in Table 2. The graphs for the metrics were created using R-GUI and R-Studio, employing the R language.

Table 2 – Spatial metrics used to quantify the landscape structure

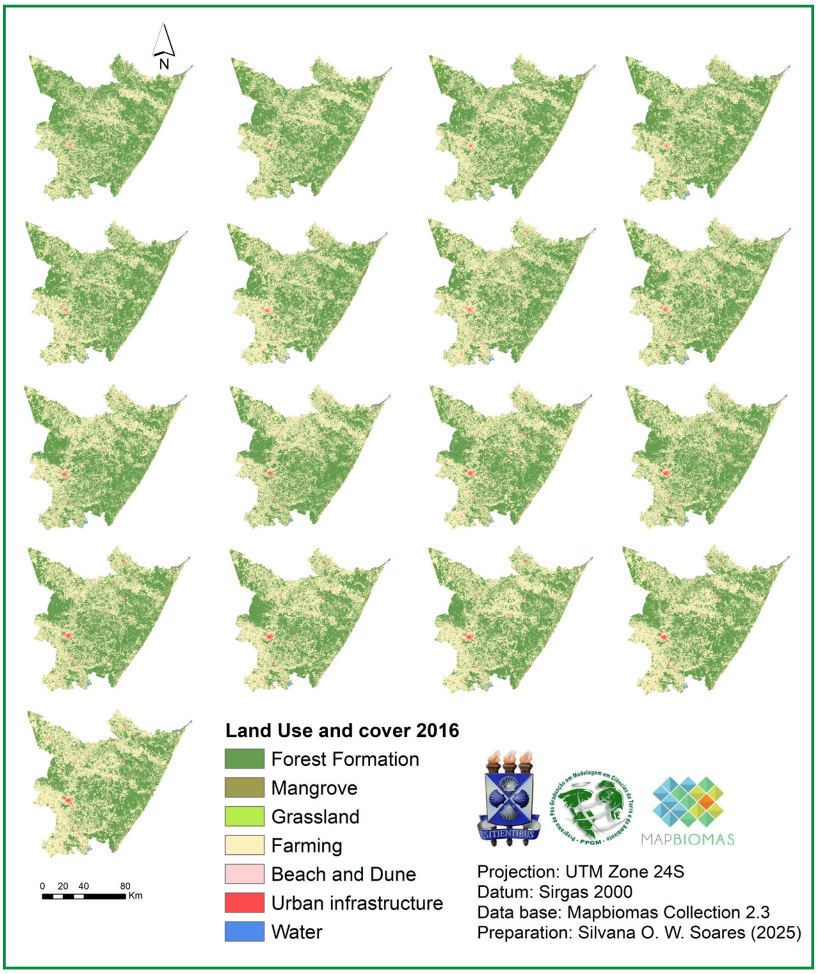
| Metric | Range | Unit | Description |
|---|---|---|---|
| CA | CA > 0 | Hectares (ha) | Total area of all patches belonging to a given class within the study region. |
| NP | NP≥1 | Dimensionless | Count of individual patches or fragments that occur in the thematic class. |
| PLAND | 0<PLAND≤100 | Percent (%) | Share of the landscape occupied by the same class, expressed as a percentage of the total study area. |
| LPI | 0 < LPI ≤ 100 | Percent (%) | Proportion of the landscape covered by the single largest patch of the class. |

Source: McGARIGAl, Cushman, Ene, (2012)

# 3 RESULTS

After inspecting the land use and land cover maps and the associated graphs of spatial structure metrics, perceptible changes were observed between natural cover classes and uses, such as agro-pastoral activities and urban infrastructure (Figure 2, Figure 3, Figure 4). By evaluating the area and percentage of cover metrics per class, it was possible to detect that the temporal series for forest formations, grasslands, mangroves, water bodies, and beaches and dunes showed a decrease in their landscape occupation values. Conversely, the agro-pastoral activities and urban infrastructure classes demonstrated an increase in occupation values (Figure 2, Figure 3, Figure 4).

Figure 2 – Dynamics of use and coverage of the Bahia's north coast and agreste region in the multitemporal series (2000-2016)




Source: Authors (2019)

The agro-pastoral class dominated throughout the period (2000-2016). In 2000, this class covered an area (CA) of 495,105.6 ha (4,951.06 km²), accounting for 40% of the area. By 2016, it had expanded to 638,771.13 ha (6,387.71 km²), representing 52% of the landscape. Table 3 displays the percentage variations for all classes.

Between 2000 and 2016, significant change patterns are observed across the different land use classes in terms of area (Table 3). The Agro-Pastoral class recorded a substantial increase, rising from 495,105.68 hectares in 2000 to 638,771.13 hectares in 2016, which corresponds to a percentage increase from 40.22% to 51.89%, with a positive variation of 29.02% (Table 3). Conversely, the grasslands class decreased from 4,095.01 hectares to 3,001.73 hectares, resulting in a percentage reduction from 0.33% to 0.24%, reflecting a negative variation of 26.7%. Water Bodies also saw a slight decrease, from 3,047.34 hectares to 2,961.87 hectares, remaining relatively stable in percentage terms, with a negative variation of 2.8% (Table 3). The Beaches and Dunes class experienced an area reduction from 1,879.76 hectares to 1,618.39 hectares, indicating a negative variation of 13.9%. The Mangrove class also declined, with the area decreasing from 6,056.69 hectares to 5,132.04 hectares, reflecting a negative variation of 15.27% (Table 3). In contrast, Urban Infrastructure registered a significant increase, growing from 1,893.22 hectares to 6,874.08 hectares, with an impressive positive variation of 263.09% (Table 3). Finally, Forest Formations experienced a considerable reduction, decreasing from 718,899.13 hectares to 572,617.58 hectares, resulting in a negative variation of 20.35% (Table 3).

Table 3 – Percentage variation between areas occupied in the 2000-2016 annual range

| Classes | Area (ha) | | Percent area (%) | | Percent Change (%) | Rate (slope coefficient) |
|---|---|---|---|---|---|---|
| | 2000 | 2016 | 2000 | 2016 | (2000-2016) | (2000-2016) |
| Agro-Pastoral | 495.105,68 | 638.771,13 | 40,22% | 51,89% | 29,02 | 5840 ha |
| Grassland | 4.095,01 | 3.001,73 | 0,33% | 0,24% | -26,7 | 149 ha |
| Water | 3.047,34 | 2.961,87 | 0,25% | 0,24% | -2,8 | 25,6 ha |
| Beach and Dune | 1.879,76 | 1.618,39 | 0,15% | 0,13% | -13,9 | -28.9 ha |
| Mangrove | 6.056,69 | 5.132,04 | 0,49% | 0,42% | -15,27 | -46.6 ha |
| Urban infrastructure | 1.893,22 | 6.874,08 | 0,15% | 0,56% | 263,09 | 348 ha |
| Forest Formation | 718.899,13 | 572.617,58 | 58,40% | 46,52% | -20,35 | -5930 Ha |

Source: Authors (2019)

When analyzing the classes with the highest landscape occupancy percentage (LPI) and number of patches (NP) distributed throughout the study area, the agro-pastoral class stands out with the largest coverage and growth trend in the landscape, indicating a decrease in the number of patches (Figure 5). This class occupies larger areas and tends to be less fragmented, showing significant occupancy. In 2000, this class had 29,686 patches (NP), and the percentage of the area of the largest patch in the landscape (LPI) was 11%. By 2016, the number of patches (NP) decreased to 19,852, and the LPI reached 42%, indicating a trend toward the continuity of agro-pastoral areas in the landscape.

The Forest Formations class (including both planted and natural forests) exhibited a negative percentage variation (20.35%) between 2000 and 2016, signifying a reduction in forested areas (Table 3, Figure 3, Figure 4). In 2000, it covered (CA) 718,899.13 ha (7,188.99 km²), corresponding to 58% of the total landscape area (PLAND), while by 2016, it had decreased to (CA) 572,617.58 ha (5,726.17 km²), representing (PLAND) of 46%.

In 2000, the number of patches (NP) was quantified at 2,934, with the largest patch in the landscape (LPI) covering 49%, indicating substantial continuous forest area. However, between 2000 and 2016, the NP increased to 26,875 patches, and the LPI value dropped to 22%.

The proportion of occupancy of the largest patch in the landscape showed a decline in the forest formations, beaches/dunes, and water bodies classes. In contrast, the mangrove, agro-pastoral activities, and urban infrastructure classes recorded an increase. The grasslands class, on the other hand, maintained consistent values (Figure 2, Figure 3, Figure 4). Regarding the number of patches, the forest formations and urban infrastructure classes were the only ones that showed an increase over the multitemporal series. The other classes exhibited a decline in values, except for the water bodies class, which remained stable (Figure 2, Figure 3, Figure 4).

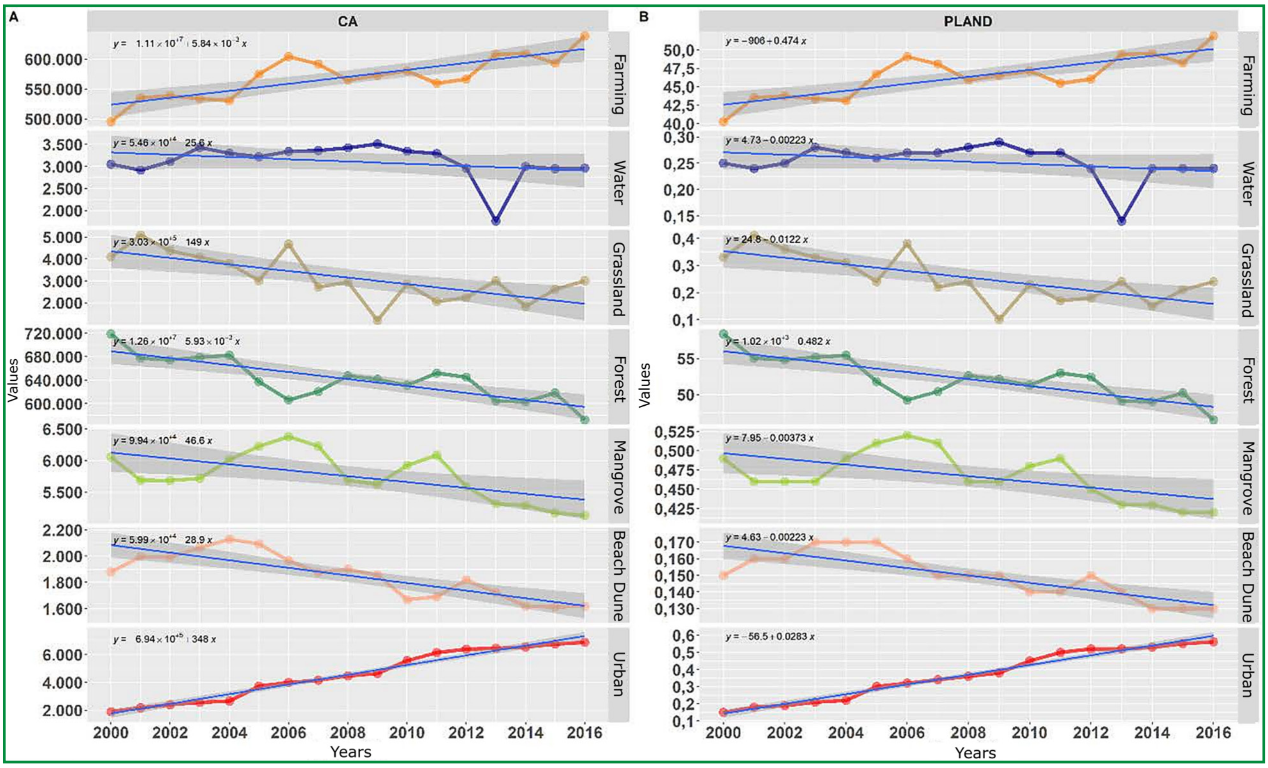
The Urban Infrastructure class experienced rapid growth in landscape occupancy, with CA and PLAND indices demonstrating percentage variations of 263% between 2000 and 2016 (Table 3). Initially, in 2000, this class covered approximately (CA) 1,893.22 ha, expanding to (CA) 6,874.08 ha, corresponding to the values of the PLAND metric. In 2016, 4,914 patches (NP) were identified, with an LPI value of 0.13%.

The grasslands class experienced a 26.7% decrease in landscape occupancy between 2000 and 2016. The area (CA) and PLAND indices reflect a gradual decline in occupancy (Figure 3). However, the LPI value remained consistent, and NP accounted for 3,038 patches in 2016, with a notable peak in 2006 at 4,059 patches. LPI maintained an approximate occupancy of 0.013% (Figure 4).

Beaches and Dunes maintained a similar occupancy proportion according to the CA and PLAND metrics (Figure 3). In 2000, the class occupied (CA) 879.76 ha (18.8 km²), and in 2016, the coverage (CA) reached 1,618.39 ha (16.1 km²), showing a 13.90% decrease from 2000 to 2016 (Table 3).

The Mangrove class experienced a 15.27% loss (2000-2016). A trend of area loss (CA) and an increase in the number of patches (NP) were observed. The LPI indicated patch occupancy at a value of 0.64% in 2000. This class saw an increase in fragments from 2010 (NP=2,968) to 2011 (NP=3,562), an increase of 594 fragments (20% variation), with LPI at 0.12% (Figure 3).

Figure 3 – Behavior of the CA metric class area (ha) of the same-class spot area and PLAND metric (%) of the same-class spot area in the multitemporal series (2000-2016)

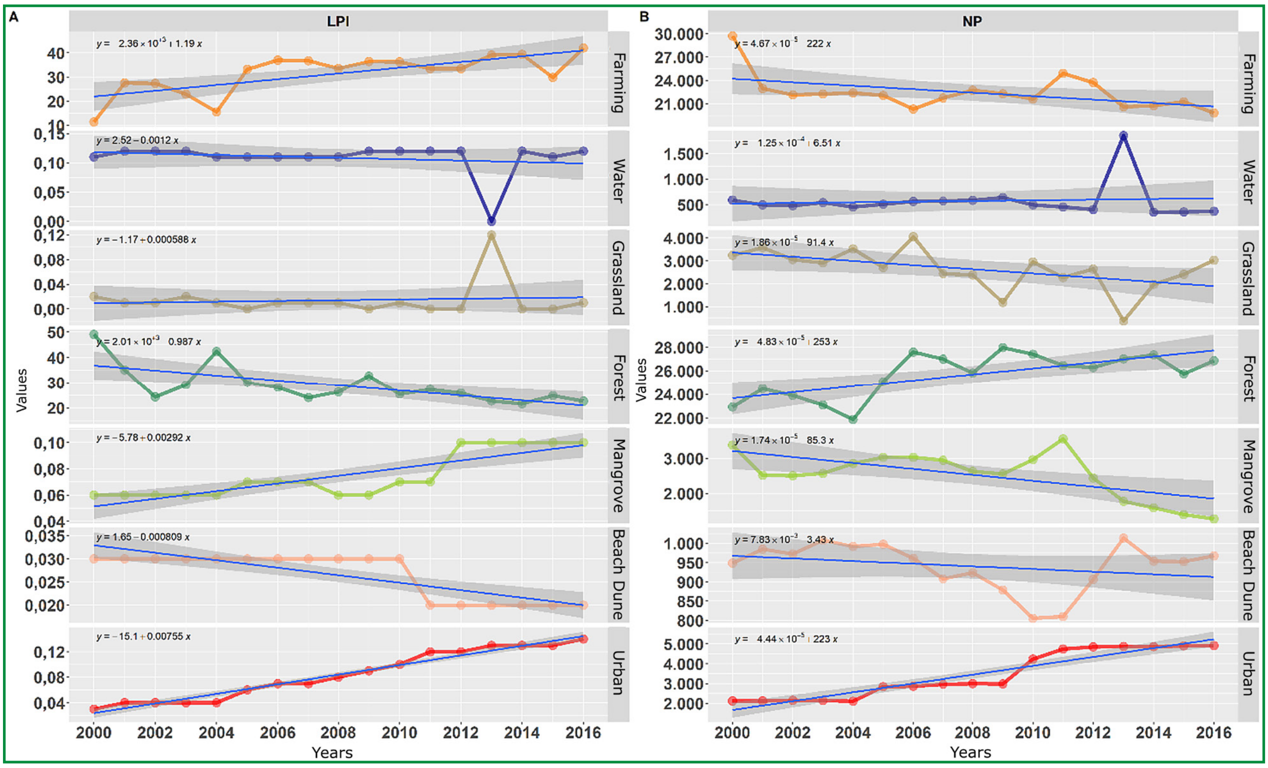



Source: Authors (2019)

In where: The classes (Agropastoris , Water , Grasslands , Forest , Mangrove , Beach and dunes , Urban ); Confidence intervals are represented in gray; Trend lines are shown in blue; The linear equations are presented in the upper left corner of all figures.

The Water Bodies class maintained an average area (CA) of approximately 3,200 ha from 2000 to 2011. However, a change in area was observed in 2013, with an initial area of 3,047.34 ha (30.47 km²) in 2000, decreasing to 1,758.95 ha (17.58 km²) in 2013. These values correspond to the (CA) and (PLAND) metrics (Figure 4). Over the period from 2000 to 2016, the area exhibited a variation, resulting in a 2.8% loss (Table 3).

Figure 4 – Behavior of the LPI metric class area (ha) of the same-class spot area and NP metric (%) of the same-class spot area in the multitemporal series (2000-2016)




Source: Authors (2019)

In where: The classes (Agropastoris , Water , Grasslands , Forest , Mangrove , Beach and dunes , Urban ). Confidence intervals are represented in gray. Trend lines are shown in blue. The linear equations are presented in the upper left corner of all figures.

## 4 DISCUSSIONS

The agropastoral and infrastructure classes exhibit significant occupation within the Atlantic Forest regions and the – Bahia's north coast and agreste region Identity

Territory municipalities. Several studies have focused on areas within the Bahia Atlantic Forest biome: Almeida (2019) investigated land use and occupation evolution in the Punhaí River Basin, Faria (2013) examined territorial occupation dynamics in the coastal zone of Mata de São João and its contradictions, and St. Jean (2017) conducted a spatio- temporal analysis of land use and cover in the Environmental Protection Area – North Coast of Bahia (APA – Litoral Norte), between the Pojuca and Imbassaí rivers. These studies confirm the steady increase in urban infrastructure and agropastoral areas within these regions, a similar result observed in the present study.

The increase in forest formation fragments indicates the replacement of this landscape component by agropastoral and urban infrastructure areas, as evidenced in the 2000-2016 temporal analysis. St. Jean (2017) also found that forested areas were converted into urbanized zones between 1993 and 2010, driven by industrial and tourism growth.

The metrics NP (number of fragments in the landscape) and LPI (largest patch index) indicate a reduction in forest formations across the landscape. The largest fragment, based on the LPI metric in the multi-temporal series, decreased in area, while the number of smaller patches or fragments increased during the period analyzed.

A study on habitat fragmentation and its lasting impact on terrestrial ecosystems by Haddad *et al*. (2015) also notes that the Brazilian Atlantic Forest regions are deforested mainly for agriculture. In the Bahia’s north coast and agreste region, activities related to livestock, forestry, the establishment of large tourism developments, and residential complexes alter natural systems such as mangroves, beaches, and dunes.

The urban infrastructure class demonstrated the most accelerated growth in the landscape over the period analyzed. The CA and PLAND metrics indicate an increase of 263% between 2000 and 2016, a substantial figure given the time interval studied. Consequently, this expansion reduced the areas occupied by the beaches and dunes, grasslands, and water bodies.

The mangrove class requires attention, as its reduction suggests a trend toward increasingly fragmented areas. Data reveal a 15.25% area loss from 2000 to 2016, raising concerns due to these areas' environmental importance. The grasslands, beaches, and dunes classes showed gradual losses in the area, as indicated by the CA and PLAND metrics and analysis of the graphs.

Analysis based on slope coefficients calculated for the CA metric (Table 3) between 2000 and 2016 shows significant changes across land use and cover types. The coefficients indicate that agropastoral areas experienced the highest growth, with an average annual increase of 5,840 hectares, reflecting substantial regional agricultural and livestock expansion. Urban infrastructure also grew, with an average increase of 348 hectares per year, indicating the expansion of urbanized areas. Coefficients for the grasslands and water bodies classes also showed growth, albeit at more moderate rates of 149 and 25.6 hectares per year, respectively.

In contrast, coefficients for natural areas, such as forest formations, mangroves, beaches, and dunes, indicate a declining trend. Forest formations experienced a significant annual loss of about 5,930 hectares, suggesting deforestation and conversion of these areas to other uses. Mangroves, beaches, and dunes also showed annual reductions of 46.6 and 28.9 hectares, respectively, indicating that these natural ecosystems are under pressure from human activities and environmental changes.

These coefficients reveal a clear trend: while areas designated for agricultural production and urban expansion are growing, natural areas, especially forests, are shrinking. This indicates an intensification in land use, which could significantly impact the preservation of local ecosystems and the environmental sustainability of the region.

In this study, the landscape metrics were effective in quantifying broader pattern measurements and detecting significant changes between 2000 and 2016, corroborating results from landscape structure analyses in various Brazilian areas (Kauano *et al*., 2012; Pirovani *et al*., 2015; Silva *et al*., 2015; Saito *et al*., 2016).

Quantification of the classes reveals prominent temporal changes in the landscape, suggesting that local socioeconomic factors largely influence these modifications. The findings of this study can support conservation and forest area maintenance actions, guiding policymakers in establishing environmental policies, such as creating or expanding conservation units within this study region.

## 4 CONCLUSIONS

The area's study of land use and land cover dynamics is highly relevant as it encompasses regions within the Atlantic Forest and Caatinga biomes, historically characterized by unregulated occupation in Brazil. Forest formations are mostly fragmented into small, dispersed patches, compromising the integrity of these areas and contributing to a reduction in biological diversity across the landscape.

The results indicate significant area losses in the mangrove, field, beach and dune, water body, and forest formation classes. In contrast, urban infrastructure and agropastoral activities classes showed rapid growth, with a trend toward future expansion.

Landscape pattern quantification metrics helped to understand land use changes over the analyzed period. Despite some year-to-year variability across classes, specific metrics reveal a typical process of intensified land use, such as the reduction in patch number (NP) and accelerated increase in area (CA) for urban infrastructure and agropastoral activities. These changes are concerning, especially in a region with a large territorial area and socio-economic growth centered on tourism, real estate development, industrial investments, and agriculture. This unregulated dynamic may lead to significant environmental imbalances in regional localities without adopting mitigation measures.

In light of this scenario, studies investigating the dynamic and socio-economic causes in the Bahia's north coast and agreste regions still need to be completed. Therefore, the data and analyses obtained in this study can support the implementation of conservation actions to preserve and maintain forest areas. This information is essential to assist managers and environmental policymakers in decision-making, such as creating and expanding conservation units, particularly in Bahia's north coast and agreste cities. Additionally, the study may assist in adopting viable measures for sustainable land use, aiming for balance and conservation of natural resources.

## ACKNOWLEDGMENTS

This work was supported by the National Council for Scientific and Technological Development (CNPq) and the Ministry of Science, Technology, and Innovation (MCTI) under grant CNPq/MCTI no. 441271/2023-5 – present, past, and future of semi-arid biodiversity: inventories, monitoring, impact of climate change, and implications for the use and conservation of flora, fauna, and fungi. W.J.F.R. was supported by a CNPq research grant under process #314954/2021-0 and by a prospecta 4.0 - CNPq research grant under process #407907/2022-0. R.N.V. and W.S.F.R. received support from the INCT in-tree for technology in interdisciplinary and transdisciplinary studies in ecology and evolution, number 465767/2014-1. R.N.V. and W.S.F.R. were also supported by WRI grant to WRI Brasil, number 73054, related to the land and carbon lab platform. The authors thank the Postgraduate Program In Modeling In Earth And Environmental Sciences (PPGM-UEFS) for their support and collaboration. S.O.W.S. Thanks the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarship awarded.

## REFERENCES

ALMEIDA, R. A. Uso e Ocupação da Terra na Bacia do rio Punhaí, Litoral Norte da Bahia. 2019. **Ciências Exatas e da Terra e a Dimensão Adquirida através da Evolução Tecnológica,** Ponta Grossa-PR: Ed. Atena, v.2 p.256-262.

CEMIN, G. **Avaliação da fragmentação florestal no município de Caxias do Sul-RS: implicações ecológicas e proposição de cenários futuros.** 2014. 123f. Tese (Doutorado)-Universidade Federal do Rio Grande do Sul. Porto Alegre. 2014.

FARIA, G. A. **Natureza, apropriação e resistência: Contradições na dinâmica de ocupação territorial da zona litorânea de Mata de São João**. 2013. 220 f. Dissertação (Mestrado) Universidade Católica do Salvador, Salvador. 2013.

FERNANDES, M. M.; LIMA, A. H. S.; WANDERLEY, L. L.; FERNANDES, M. R. de M.; ARAÚJO FILHO, R. N. Fragmentação florestal na Bacia Hidrográfica do Rio São Francisco, Brasil. **Ciência Florestal**, *[S. l.]*, v. 32, n. 3, p. 1227–1246, 2022. DOI: 10.5902/1980509845253. Available at: https://periodicos.ufsm.br/cienciaflorestal/article/view/45253. Accessed in: 12 Nov. 2024.

GOERL, R. F; SIELFERT, C.A.C; SCHULTZ, G.B; DOS SANTOS, C.S; DOS SANTOS, I. Elaboração e Aplicação de Índices de Fragmentação e Conectividade da Paisagem para Análise de Bacias Hidrográficas. **Revista Brasileira de Geografia Física**, [s.l.], v. 5, p. 1000-1012, dez. 2011.

HADDAD, N. M; BRUDVIG, L.A; CLOBERT, J; DAVIES, K.F; GONZALES, A; HOLT, R.D; LOVEJOY, T.E; SETON, J.O; AUSTIN,M.P; COLLINS,C.D; COOK,W.M; DAMSCHEN,E.I; EWERS,R.M; FOSTER,B.L; JENKIS,C.N; KING,A.J; LAURANCE, W.F; LEVEY,D.J; MARGULES,C.R; MELBOURNE, B.A; NICHOLLS, A.O; ORROCK,J.L; SONG, D; TOWNSHEND,J.R. Habitat fragmentation and its lasting impact on Earth's ecosystems. **Science Advances**, [s.l.], v.1, n.2, 20 mar. 2015.

IBGE 2020. Instituto Brasileiro de Geografia e Estatística (IBGE). Biomas e Sistema Costeiro-Marinho do Brasil: compatível com a escala 1:250.000. Rio de Janeiro: IBGE. Disponível em https://www.ibge.gov.br/: Editorial Geociências.

INEMA- Instituto de Meio Ambiente e Recursos Hídricos. APA Litoral Norte do Estado da Bahia. 2017.

LONGO, R. M.; SILVA, A. L. da; CARVALHO, M. M.; RIBEIRO, A. Írio. Métricas da paisagem e qualidade ambiental nos remanescentes florestais do Ribeirão Quilombo em Campinas/SP. **Ciência Florestal**, *[S. l.]*, v. 34, n. 1, p. e71899, 2024. DOI: 10.5902/1980509871899. Available at: https://periodicos.ufsm.br/cienciaflorestal/article/view/71899. Accessed in: 12 Nov. 2024.

KAUANO, É. E; TOREZAN, J.M.D; CARDOSO, F.C.G; MARQUES, M.C.M. Landscape structure in the northern coast of Paraná state, a hotspot for the Brazilian Atlantic Forest conservation. **Revista Árvore**. Viçosa-MG, v. 36, n. 5, p. 961–970, out. 2012.

MAPBIOMAS– 2019 Coleção 2 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil. Available at: http://mapbiomas.org/pages/methodology. Accessed in: 4 Oct. 2020.

MCGARIGAl, K; CUSHMAN, S. A; ENE, E. **FRAGSTATS v4**: **Spatial Pattern Analysis Program for Categorical and Continuous Maps.** Computer software program produced by the authors at the University of Massachusetts, Amherst. 2012.

METZGER, J. P. O que é ecologia de paisagens? **Biota Neotropica**. São Paulo, v.1, n.1, 2001.

NUNES, J. M. C.; MATOS, M. R. B.; **Litoral Norte da Bahia: Caracterização Ambiental, Biodiversidade e Conservação**. Ciências Biológicas. 1. ed. Salvador- BA: EDUFBA, 2017, 460 p.

PEREIRA, A. L. L.; PAULA, A. de; BARRETO-GARCIA, P. A. B.; BRITO, A. C. de. Efeito de borda sobre a florística e estrutura em Floresta Estacional Semidecidual no Semiárido. **Ciência Florestal**, *[S. l.]*, v. 34, n. 1, p. e72064, 2024. DOI: 10.5902/1980509872064. Available at: https://periodicos.ufsm.br/cienciaflorestal/article/view/72064. Accessed in: 12 Nov. 2024.

PIROVANI, D.B., SILVA, A.G., SANTOS, A.R. Análise da paisagem e mudanças no uso da terra no entorno da RPPN Cafundó, ES. **Cerne**, [s.l.], v. 21, n.1, p. 27–35. Jan. 2015.

SAITO, S.S.N; MOREIRA, M.A; Dos Santos, A.R; Eugenio, C.E; Figueiredo, A.C. Geotecnologia e ecologia da paisagem no monitoramento da fragmentação florestal. **Floresta e Ambiente**, [s.l.], v. 23, p. 201–210. Jun. 2016.

SANTOS R. M. **Padrão temporal e espacial das mudanças de usos da terra e cenários para a conservação da biodiversidade regional do município de São Félix do Araguaia, MT**. 2011. 153 f. Tese (Doutorado), Universidade Federal de São Carlos, São Carlos. 2011.

SANTOS, J. S; LEITE, C.C.C; VIANA, J.C.C; dos SANTOS, A.R; FERNANDES, M.M; ABREU, V.S; NASCIMENTO, T.P; dos SANTOS, L.S; FERNANDES, R.M; da SILVA, G.F; MENDONÇA, A.R. Delimitation of ecological corridors in the Brazilian Atlantic Forest. **Ecological Indicators**, [s.l.], v. 88, p. 414- 424. Mai. 2018.

SEI - Superintendência de Estudos Econômicos e Sociais da Bahia. **Perfil dos Territórios de Identidade da Bahia**/ Série territórios de identidade da Bahia. Salvador-BA: SEI, 2016. 3 v. 2.

SEI -Superintendência de Estudos Econômicos e Sociais da Bahia- **Indicadores Territoriais**. **Litoral Norte e Agreste Baiano,** Salvador-BA SEI, 2019**.**

SEPLAN–Secretaria do Planejamento. Governo do Estado da Bahia. Territórios de Identidade. **Publicações Territoriais,** Salvador-BA**,** 2020.

SILVA, K.G; dos SANTOS, A.R; SILVA, A.G; PELUZIO, J.B.E; FIEDLER, N.C; ZANTTI, S.S. Análise da Dinâmica Espaço-Temporal dos Fragmentos Florestais da Sub-Bacia Hidrográfica do Rio Alegre, ES. **Cerne**, [s.l.], v. 21, n. 2, p. 311– 318. Jun. 2015.

SOUZA, C.M; SHIMBO, J.Z; ROSA, M.R; PARENTE, L.L; ALENCAR, A.A; RUDORFF, B.F.T; HASENACK, H; MATSUMOTO, M; FERREIRA, L.G; SOUZA-FILHO, P.W.M; de OLIVEIRA, S.W; ROCHA, W.F; FONSECA, A.V; MARQUES, C.B; DINIZ, C.G; COSTA, D; MONTEIRO, D; ROSA, E.R; VELÉZ-MARTIN, E; WEBER, E.J; LENTI, F.E.B; PATERNOST, F.F; PAREYN, F.G.C; SIQUEIRA, J.V; VIERA, J.L; NETO, L.C.F; SARAIVA, M.M; SALES, M.H; SALGADO, M.P.G; VASONCELOS, R; GALANO, S; MESQUITA, V.V; AZEVEDO, T. Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. **Remote Sensing.** [s.l.], v. 12, n. 17, p. 2735. Ago. 2020.

ST. JEAN, L. T. **Análise Espaço-Temporal do Uso e Cobertura da Terra na APA- Litoral Norte do Estado da Bahia (1993-2010), Entre os Rios Pojuca e Imbassai.** 2017. 101 f. Dissertação (Mestrado). Universidade Federal da Bahia- UFBA, 2017.

## Authorship Contribution

### 1 Silvana Oliveira Wenceslau Soares

Master in Environmental Sciences

https://orcid.org/0000-0003-2706-6547 • silvanawenceslau@hotmail.com

Contribution: Conceptualization; Writing – original draft preparation; Writing – review & editing; Methodology; Software; Visualization; Formal analysis

**2 Rodrigo Nogueira de Vasconcelos**

Ph.D. in Ecology
https://orcid.org/0000-0002-1368-6721 • rnvuefsppgm@gmail.com
Contribution: Conceptualization; Writing – original draft preparation; Writing – review & editing; Methodology; Software; Visualization; Formal analysis; Funding acquisition; Supervision

**3 Jocimara Souza Britto Lobão**

Ph.D. in Geography
https://orcid.org/0000-0003-4987-190X • juci.lobao@uefs.br
Contribution: Writing – original draft preparation; Writing – review & editing; Methodology

**4 Elaine Cristina Cambuí Barbosa**

Ph.D. in Ecology
https://orcid.org/0000-0001-5979-2178 • elainecambui@gmail.com
Contribution: Conceptualization; Writing – original draft preparation; Methodology

**5 Mariana Martins Medeiros de Santana**

Ph.D. in Ecology
https://orcid.org/0000-0002-5218-7140 • mariana.medeiros@ueap.edu.br
Contribution: Writing – review & editing; Methodology; Software; Visualization

**6 Washington de Jesus Sant'Anna da Franca-Rocha**

Ph.D. in Geology
https://orcid.org/0000-0002-2175-2792 • wrocha@uefs.br
Contribution: Conceptualization; Methodology; Software; Formal analysis; Funding acquisition; Supervision

**7 Deorgia Tayane Mendes Souza**

Ph.D. in Applied Geosciences and Geodynamics
https://orcid.org/0000-0001-6791-3611 • dtmsouza@uefs.br
Contribution: Conceptualization; Writing – original draft preparation; Methodology; Formal analysis

## How to quote this article

SOARES, S. O. W.; VASCONCELOS, R. N.; LOBÃ, J. S. B.; BARBOSA, E. C. C.; SANTANA, M. M. M.; FRANCA-ROCHA, W. J. S.; SOUZA, D. T. M. Spatiotemporal dynamics of land use and cover in the Atlantic Forest Biome: quantifying spatial patterns along Bahia's north coast and agreste region. **Ciência Florestal**, Santa Maria, v. 35, e68141, p. 1-24, 2025. DOI 10.5902/1980509868141. Available from: https://doi.org/10.5902/1980509868141. Accessed in: day month abbr. year.

### Data Availability Statement:

Datasets related to this article will be available upon request to the corresponding author.