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Changes in landscape structure in the Pratigi Environmental Protection Area, Bahia, Brazil

Alterações nos padrões estruturais da paisagem na Área de Proteção Ambiental do Pratigi, Bahia, Brasil

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ABSTRACT

This study examined the landscape structure of a sustainable-use conservation unit within the Atlantic Forest biome in Bahia, Brazil, from a landscape ecology perspective. The primary objective was to analyze the landscape structure of the Pratigi Environmental Protection Area (Pratigi EPA) using structural landscape metrics. The research focused the question: What were the changes in the landscape structure patterns within the Pratigi EPA between 1985 and 2021? Annual land use and occupation data for Brazil from 1985 to 2021 were obtained from the MapBiomas database, and landscape metrics were analyzed using R software. The results indicated that the forest class was predominant in the landscape but decreased from 122,394.15 ha in 1985 to 107,737.29 ha in 2021, a loss of 14,656.86 ha. Conversely, the agriculture class increased from 28,298.88 ha in 1985 to 43,453.62 ha in 2021, representing an increase of 15,154.74 ha. These findings support the hypothesis that the exploitation of natural resources within the Pratigi EPA may reduce biodiversity due to the expansion of agricultural activities. Therefore, new public policies and the implementation of sustainable measures to mitigate environmental conflicts are necessary to preserve ecological and ecosystem processes in the region.

Keywords: Atlantic Forest; landscape ecology; land use and land cover; landscape metrics; remote sensing; sustainable use.

RESUMO

Este estudo examinou a estrutura da paisagem de uma unidade de conservação de uso sustentável no Bioma Mata Atlântica no estado da Bahia, Brasil, sob perspectiva da Ecologia de Paisagem. O objetivo principal foi analisar a estrutura da paisagem da Área de Proteção Ambiental do Pratigi (APA do Pratigi) utilizando métricas estruturais da paisagem. A pesquisa concentrou-se na questão: quais foram as mudanças dos padrões estruturais da paisagem na APA do Pratigi no período de 1985 a 2021? Os dados anuais de uso e ocupação da terra do Brasil de 1985-2021 foram obtidos do banco de dados do MapBiomas, e as métricas da paisagem foram analisadas usando o software R. Os resultados indicaram que a classe floresta era predominante na paisagem, mas diminuiu de 122.394.15 ha em 1985 para 107.737,29 ha em 2021, uma perda de 14.656,86 ha. Por outro lado, a classe agropecuária aumentou de 28.298,88 ha em 1985 para 43.453,62 ha em 2021, o que representa um aumento de 15.154,74 ha. Esses resultados corroboram a hipótese de que a exploração dos recursos naturais na APA do Pratigi pode reduzir a biodiversidade devido à expansão das atividades agropecuárias. Portanto, novas políticas públicas e a implementação de medidas sustentáveis para mitigar os conflitos ambientais são necessárias para preservar processos ecológicos e ecossistêmicos na região.

Palavras-chave: Mata Atlântica; ecologia de paisagem; uso e cobertura da terra; métricas de paisagem; sensoriamento remoto; uso sustentável.

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Introduction

The need to investigate landscape modification processes in Brazil, particularly in the Atlantic Forest biome, has intensified due to several factors: high levels of natural resource exploitation, rapid urban expansion, increased industrial and agricultural activities, and the presence of diverse vegetation physiognomies with associated forest formations and ecosystems (Lopes et al., 2018; Lingner et al., 2020; Solórzano et al., 2021; Diniz et al., 2022). Several vegetation physiognomies in the Atlantic Forest biome are essential for biodiversity and ecosystem process conservation (Dewes et al., 2021; Nahssen et al., 2022), and contribute to the formation of diverse landscape matrices.

Landscape ecology studies have provided valuable information for the development of biodiversity conservation strategies by integrating spatial heterogeneity and analysis scales (Metzger, 2001; Carneiro et al., 2021). Advances in this field have been driven by the use of geoprocessing and remote sensing tools, which enable analyses of spatiotemporal changes in landscape structure (Muñoz-Reinoso et al., 2020; Hesselbarth et al., 2021; Gladson et al., 2023; Stevanato et al., 2023).

Studies analyzing landscape transformations based on historical data from diverse biomes have gained prominence due to the need for a comprehensive understanding of the impacts of human actions on ecological and ecosystem processes, and the importance of environmental conservation of natural resources, fauna, and flora (Souza Junior et al., 2020; Pinho et al., 2023).

According to Karimi et al. (2021) and Ran et al. (2023), landscape structure can be defined through a quantitative assessment of its spatial arrangement (landscape configuration) and diversity (landscape composition). This analysis enables the investigation of the dynamics and evolution of landscape units in space and time by measuring the spatial characteristics of patches (fragments), patch classes, and landscape (mosaics). The recording and analysis of landscape structures using environmental modeling have significantly contributed to quantitative studies in ecology (Lausch et al., 2015). Thus, quantifying spatial arrangements and landscape composition makes it possible to identify and analyze habitat fragmentation and loss, as well as diverse land use and occupation types (Yu et al., 2019; Pedras et al., 2021). Landscape metrics provide comprehensive information on landscape configuration and composition, encompassing measurements of parameters related to fragmentation, shape, aggregation, landscape size, richness, and abundance (Barros, 2018; Istanbuly et al., 2022; Chelotti and Sano, 2023).

Human-induced landscape transformations in the Atlantic Forest biome have been the primary cause of biodiversity loss and the conversion of natural areas for various land-use purposes (Projeto MapBiomas, 2023). According to Rosa et al. (2021), alterations in native forest cover and its spatial arrangement within the Atlantic Forest biome in Brazil have significantly increased forest fragmentations across the landscape. Persistent losses of vegetation cover indicate a reduction in species richness, loss of natural area, and habitat fragmentation, consequently compromising the sustainability of ecological processes and the provision of ecosystem services (Campanili and Schaffer, 2010; Ribeiro et al., 2011; Rezende et al., 2018; Rocha-Santos et al., 2019).

Rigueira and Mariano-Neto (2023) stated that analyzing the landscape structure in the Atlantic Forest serves as environmental conservation strategy because forested landscapes within this biome have exhibited structural changes connected to habitat loss, mainly due to anthropogenic activities, which reinforces that the ecosystem integrity depends on the structural quality of the landscape.

In this context, the Pratigi Environmental Protection Area (Pratigi EPA) stands as a conservation unit established to balance nature conservation with sustainable use of a portion of its natural resources (Brasil, 2000), characterized as a territorial space for environmental protection and socioeconomic development. Natural resources can be exploited within this sustainable-use conservation unit, mainly for agricultural activities such as livestock (pastures) and plantations of cocoa, bananas, and rubber trees (INEMA, 2004). However, agricultural activities and other human impacts can make this conservation unit vulnerable, leading to biodiversity loss.

The Pratigi EPA is one of the highest conservation priorities within the Central Atlantic Forest Ecological Corridor (CCMA), encompassing one of the few remaining Atlantic Forest fragments in the state of Bahia, harboring a significant diversity of species in different extinction categories and species considered rare with abundant populations (Brasil, 2006).

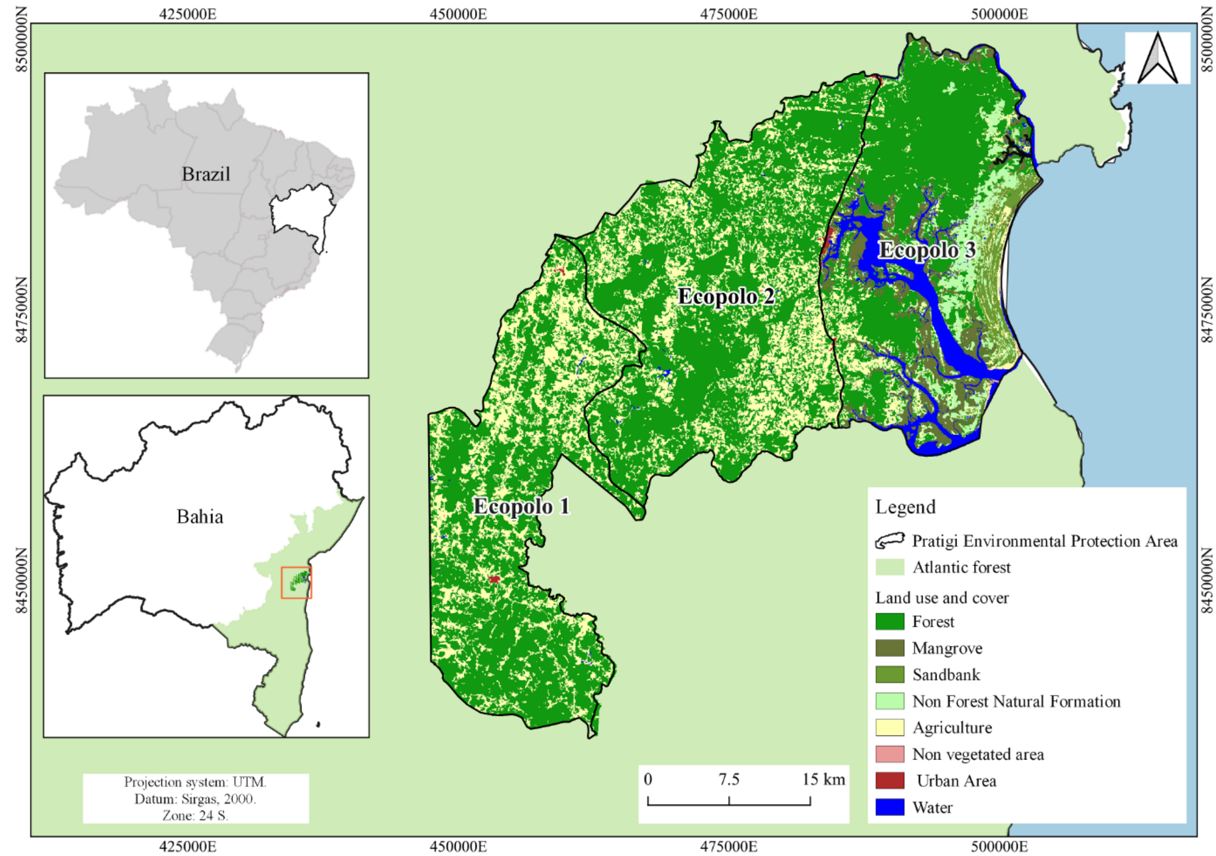
In this context, the approach of this study was to assess patterns of landscape structure within the Pratigi EPA using landscape metrics, combined with geoprocessing and remote sensing data, to answer the following question: What were the changes in the landscape structure within the Pratigi EPA between 1985 and 2021? This analysis can provide valuable insights for identifying potential environmental issues, contributing to decision-making regarding the establishment of priority conservation areas. Additionally, this information can support further research.

Therefore, the objective of the present study was to assess the spatiotemporal changes in landscape structure within the Pratigi EPA based on mapping land use and occupation classes and quantifying landscape metrics from 1985 to 2021.

Material and methods

Study area

The Pratigi Environmental Protection Area (the Pratigi EPA) is located within the Atlantic Forest biome in the Baixo Sul region of Bahia, Brazil. It encompasses the municipalities of Igrapiúna, Ituberá, Ibirapitanga, Nilo Peçanha, and Piraí do Norte (Figure 1). The area is divided into three macro zones with distinct socio-environmental and economic characteristics: Ecopolo I (Cordilheiras; Mountain Ranges), Ecopolo II (Vales; Valleys), and Ecopolo III (Litorâneo; Coasts) (Organização de Conservação da Terra, 2023).



Source: Organização de Conservação de Terras do Baixo Sul da Bahia (2012) and IBGE (2021).

Figure 1 – Location map of the Pratigi Environmental Protection Area, Bahia, Brazil.

The Pratigi EPA is classified as a sustainable-use conservation unit under Law No. 9.985/2000 of the National System for Nature Conservation (SNUC). It was established by State Decree No. 7272, of April 2, 1998 (Bahia, 1998), and its boundaries were later expanded to include the Juliana River Basin, increasing its total area to 85,686 hectares, by State Decree No. 8036, of September 20, 2001 (Bahia, 2001).

According to the Organização de Conservação da Terra (2023), a new boundary has been proposed for the Pratigi EPA, expanding it to approximately 171,000 hectares. This expanded area, which includes the five municipalities covered by the original Pratigi EPA, was selected for the present study because it encompasses Areas of Relevant Ecological Interest (AREI). These areas contain forest fragments in various stages of conservation and regeneration, and are home to endemic and rare species of fauna and flora. Additionally, this region in characterized by low human occupation and private reserves, such as the Michelin Reserve.

The Pratigi EPA is a refuge for one of Bahia's a few remaining Atlantic Forest fragments. It harbors a diverse array of endemic fauna and flora species, including those threatened with extinction, and boasts natural resources characteristic of the region (INEMA, 2023). The predominant vegetation consists of dense ombrophilous forest at various stages of conservation, including tropical forests with high densities of large and medium-sized trees due to the region's climate factors; additionally, the vegetation includes smaller proportions of pioneer formations such as mangroves and restingas (IBGE, 2012).

The region's climate is classified as Af, tropical rainforest, according to the Köppen classification (1918). It features annual rainfall depth exceeding 2,000 mm, and high mean annual temperatures of 24°C, without a well-defined dry season (INEMA, 2004).

The primary watershed in the area is the Juliana River Basin, which provides invaluable water resources, including well-distributed rainfall (Santos Junior and Oliveira, 2015).

The population of the five municipalities encompassed by the Pratigi EPA is concentrated in rural areas, with a predominance of family farming activities (IBGE, 2023). Local income is primarily from cultivating oil and piassava palms, cassava, and clove, cacao, and rubber trees (Fernandes et al., 2009).

The main environmental conflicts in the area include mangrove filling, deforestation, indiscriminate use of pesticides, wildlife hunting, predatory fishing, and a lack of basic sanitation (INEMA, 2023).

Data acquisition

Annual land use and cover maps for Brazil from 1985 and 2021 were obtained from Collection 7 of the MapBiomas platform database (Projeto MapBiomas, 2022). These map images were accessed directly through Google Earth Engine (GEE) via the collaborative network's data access toolkits, which are stored in the cloud.

The study area was delineated based on vector data provided by the Land Conservation Organization (OCT) and imported into GEE. This includes the proposed boundary extension by OCT, covering 171,000 hectares.

Land use and cover classes from the MapBiomas database were reclassified in GEE to identify landscape changes. This process involved converting input values (original data) to output values by reclassifying the original class data using new values (Table 1).

Raster images with the eight reclassified classes were saved and exported to QGIS 3.22.5 software, resulting in land use and occupation maps for the Pratigi EPA covering the period from 1985 to 2021.

Land use and cover changes were quantified using statistical data by calculating landscape metrics with R-Studio 4.3.1 software. This software assists in these calculations using basic commands from the open-source landscape metrics packages in R language, offering a variety of indices for landscape metrics.

Landscape metrics were calculated using the SDMTools (Species Distribution Modelling Tools) package, widely used for processing data related to species distribution and modeling, and which helps calculate statistical measures of patches and fragmentation in landscapes.

The selection of landscape metrics was based on the study of Ribeiro et al. (2009), who quantified forest fragments and analyzed their spatial distribution within an Atlantic Forest biome area.

The chosen landscape metrics aimed to identify general patterns in the Pratigi EPA's landscape, including forest cover fragmentation, the dominant class in the landscape matrix, the variation in the area of each class, and connectivity. The data obtained was used to generate graphs representing the metrics for each land use and cover class in a time series from 1985 to 2021, using the ggplot2 package (Table 2).

Due to its 30-meter spatial resolution, data from the MapBiomas platform database has proven useful for this study's analytical approach, particularly in the efficient development of environmental planning strategies at the regional level. However, there are some limitations. Studies using satellite images with a higher spatial resolution than 30 meters allow for greater terrain detail and, consequently, greater precision in detecting more fragmented areas crucial for ecological restoration (Figure 2).

Table 1 – Reclassification of land use and occupation classes within the Pratigi Environmental Protection Area, Bahia, Brazil.

MAPBIOMAS (Collection 7) classes	Reclassified classes
Forest Formation Savanna (Cerrado biome) Formation	Forest
Mangrove	Mangrove
Wooded Restinga Herbaceous Restinga	Restinga
Wetlands and Swamps, Rocky Outcrops, Grasslands, Apicum, and Other Non-Forest Formations	Non-Forest Formation
Pasture, Temporary Crops, Silviculture, and Land Use Mosaics	Agriculture
Beaches, Dunes and Sandy Areas, Mining, and Other Non-Vegetated Areas	Non-Vegetated Areas
Urban Area	Urban Area
Rivers, Lakes, Oceans, and Aquaculture Areas	Water Bodies

Source: adapted from MapBiomas (2022).

Table 2 – Selected landscape metrics for the Pratigi Environmental Protection Area, Bahia, Brazil.

METRICS	UNIT	DESCRIPTION
Total class area (TA)	TA>0 (ha)	Sum of the area of all fragments (patches) of a class (ha)
Percentage of landscape (PLAND)	0<PLAND≤100(%)	Percentage of landscape occupied by fragments of a same class
Number of patches (NP)	NP≥1 dimensionless	Number of existing fragments of a class in the landscape. It provides information for other metrics and shows the degree of landscape fragmentation
Largest patch index (LPI)	0<LPI≤ 100 (%)	This index corresponds to the percentage of the landscape occupied by the area of the largest patch of a class.
Aggregation index (AGGINDEX or AI)	0<AI≤100(%)	This index refers to the number of adjacent similar patches of the corresponding landscape type. The higher the index, the better the integrity of the landscape and the lower the relative degree of fragmentation.

Source: adapted from McGarigal and Marks (1995).

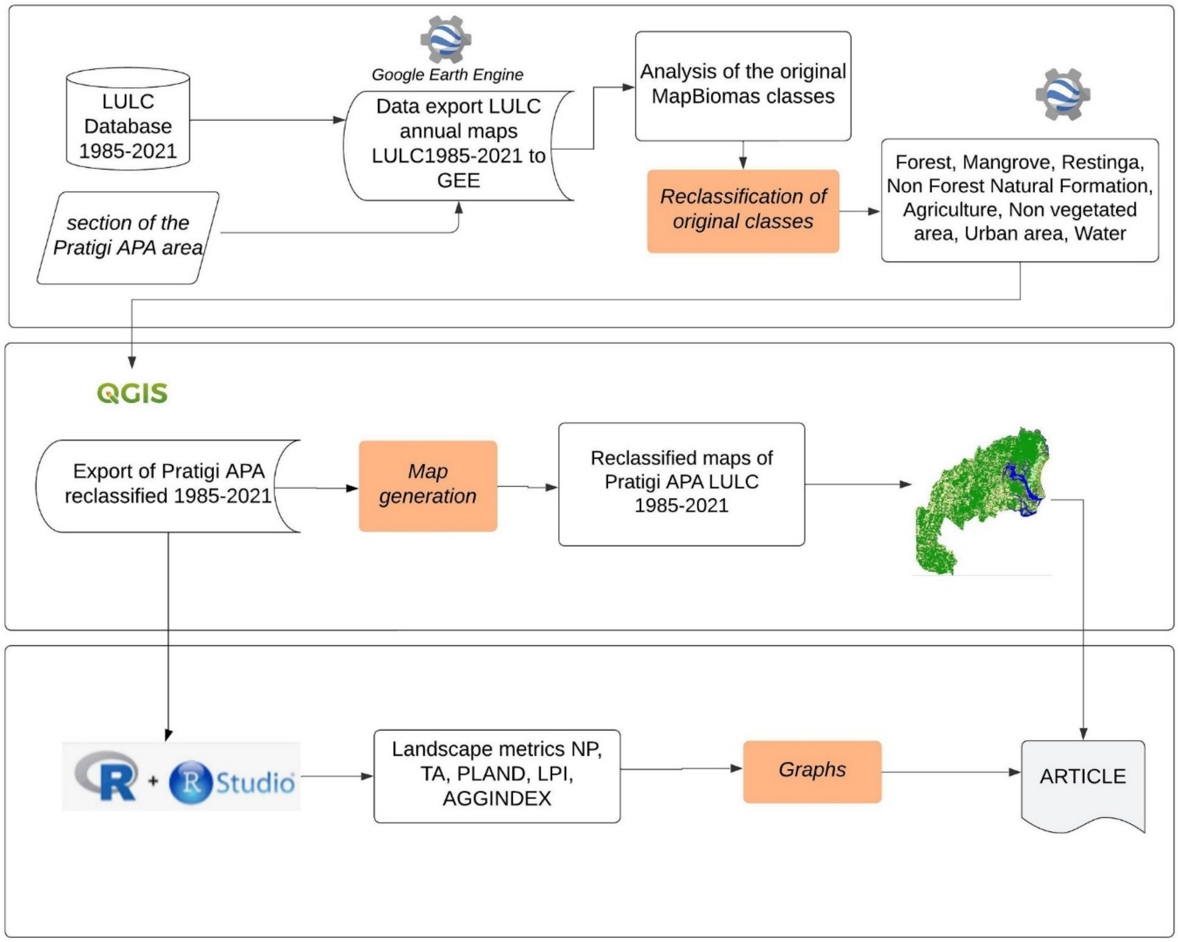


Figure 2 – Flowchart of the study methodology.

Results and discussion

Analyzing the spatiotemporal evolution of land use and cover within the Pratigi Environmental Protection Area (Pratigi EPA) from 1985 to 2021 was essential for identifying the predominant land use and cover classes in the landscape: forest and agriculture (Figure 3).

The quantification of landscape metrics over this period revealed significant changes. The total class area metric, which represents the sum of all fragments of a class in the landscape, showed a decrease in the forest class area from 122,394.15 ha in 1985 to 107,737.29 ha in 2021, corresponding to a loss of 14,656.86 ha and a 12% reduction in native vegetation cover (Figure 4).

The percentage of landscape occupied by fragments of a class (PLAND) indicated that the forest class occupied 69% of the landscape in 1985, decreasing to 61% in 2021. This represents an 8% reduction, corresponding to a relative decrease of 11.59% over the historical data series.

The number of patches (NP) in the landscape for the forest class increased from 650 in 1985 to 1,989 in 2021, representing an addition of 1,339 patches.

The largest patch index (LPI) for the forest class showed a progressive decrease over the years, from 66% in 1985 to 38% in 2021, representing a decrease of 28%. A comparison of the historical data series indicates a relative reduction of 42.42% by 2021, reaching approximately half of the original value.

The aggregation index (AGGIndex), which indicates the compactness of a land use class, showed a 1.89% reduction for the forest class, decreasing from 94.83% in 1985 to 92.94% in 2021. The relative change over the historical series was 1.99%.

The results revealed that the forest class remains the dominant matrix in the landscape, with significant forest patches occupying over 50% of the area. This dominance of forest vegetation cover is crucial for the functioning of the landscape and its ecological processes, especially within the Atlantic Forest biome, which has undergone intense exploitation of its natural resources throughout history.

The PLAND and total area metrics are directly correlated, as the total area decreases with the decrease in the PLAND.

The increase in the NP for the forest class is connected to a decrease in the LPI, indicating landscape fragmentation and an increase in patch diversity. This suggests a landscape with heterogeneous characteristics and a tendency to increase in patches of other classes within the landscape.

AGGIndex is a valuable index for understanding the relative degree of fragmentation within a landscape. It indicates that a higher NP for a class corresponds to a lower AGGIndex value.

The fragmentation of a natural area involves the reduction or division of vegetation cover areas into smaller patches with different characteristics from the original, caused by either natural processes or human actions such as road construction and the establishment of agricultural crops and pastures (Haddad et al., 2015; Siqueira et al., 2021). Analyzing landscape fragmentation is essential as it can result in habitat area reduction, increase edge areas, and fragment isolation, threatening the biodiversity and ecological processes (Andrade et al., 2020).

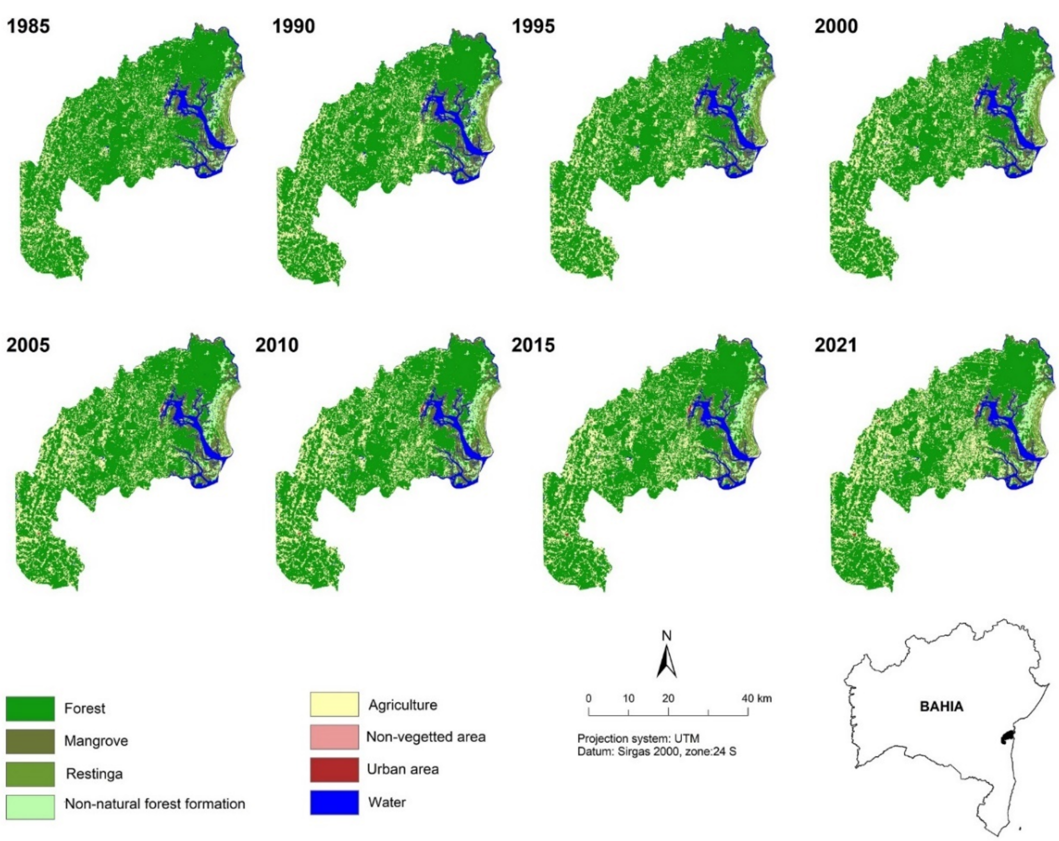
Total area (TA) and NP are valuable indices for evaluating the degree of fragmentation in an area across diverse environments and regions. The analysis of these indices for the forest class showed a concerning trend of increasing numbers of smaller patches over time, along with greater isolation between forest patches. This trend indicates a loss of forest apace in the landscape and an increase in edge areas and spatial heterogeneity.

The larger fragments identified within the forest class have an essential function in preserving biodiversity and ensuring the availability of environmental resources for smaller fragments (Patrício et al., 2019). This suggests the potential for connecting forest patches to larger continuous areas, which can facilitate the maintenance of species, promote ecosystem equilibrium, and support the creation of ecological corridors.

Regarding the agriculture class, its total area increased from 28,298.88 ha in 1985 to 43,453.62 ha in 2021, representing an increase of 15,154.74 ha over the studied period. This expansion was particularly pronounced after 2019, when this class reached 40,724.64 ha (Figure 5).

The PLAND index for the agriculture class showed a substantial increase of 156%, rising from 16% in 1985 to 25% in 2021. The number of patches (NP) decreased from 4,113 in 1985 to 2,622 in 2021, a reduction of 2,128 patches. The largest patch index (LPI) increased from 1% in 1985 to 6% in 2021, indicating a 600% increase in the largest patch size. The aggregation (AGGIndex) also increased by 6%, from 78.59% in 1985 to 83.31% in 2021.

A decrease in the NP of the agriculture class results in an increase in the percentage area of the class in the landscape. The results indicate that agriculture is expanding in the Pratigi EPA landscape, trending towards larger and more aggregated areas.



Source: MapBiomas (2022).
Figure 3 – Map of spatiotemporal evolution of land use and occupation classes within the Pratigi Environmental Protection Area (1985-2021).

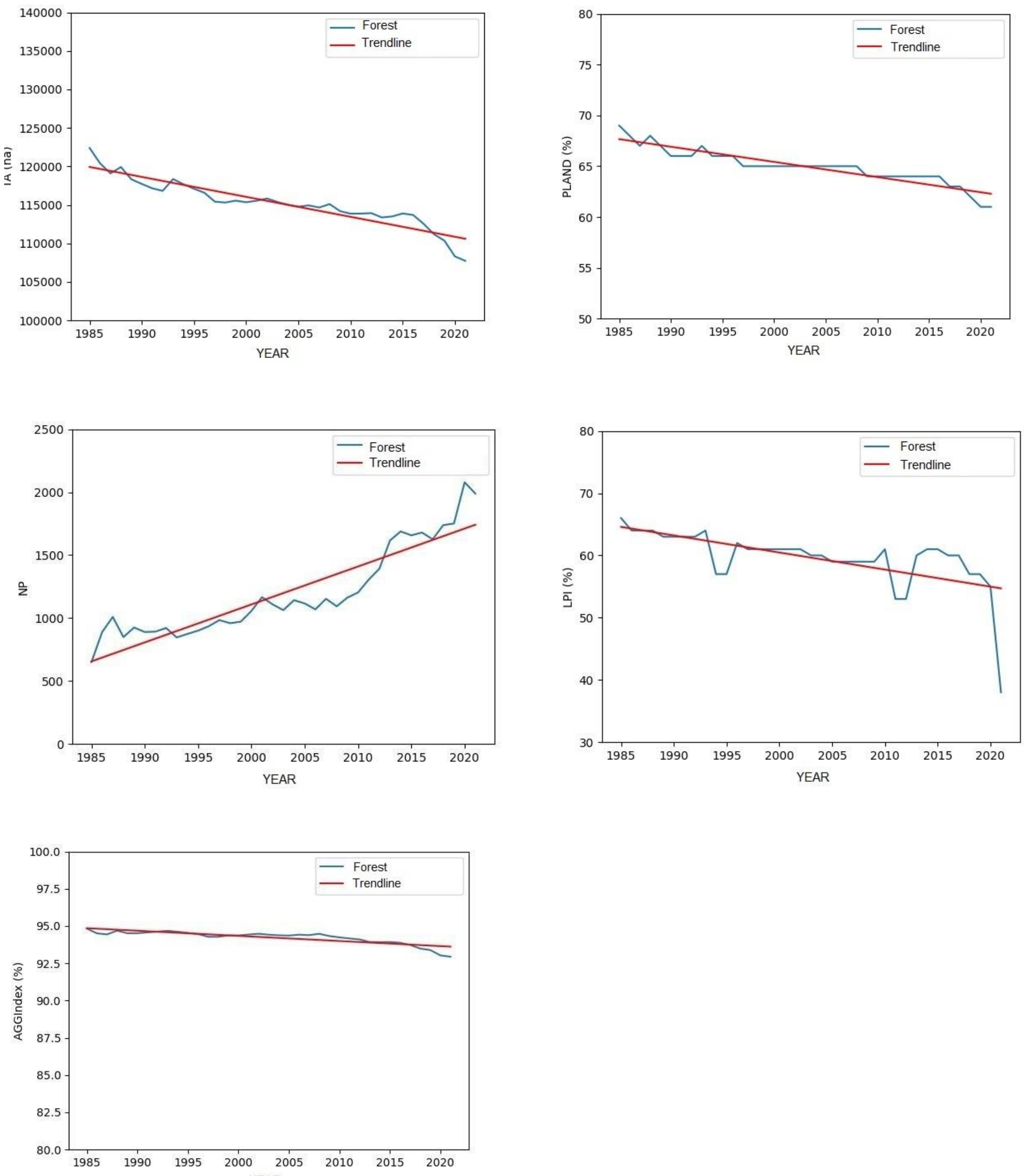


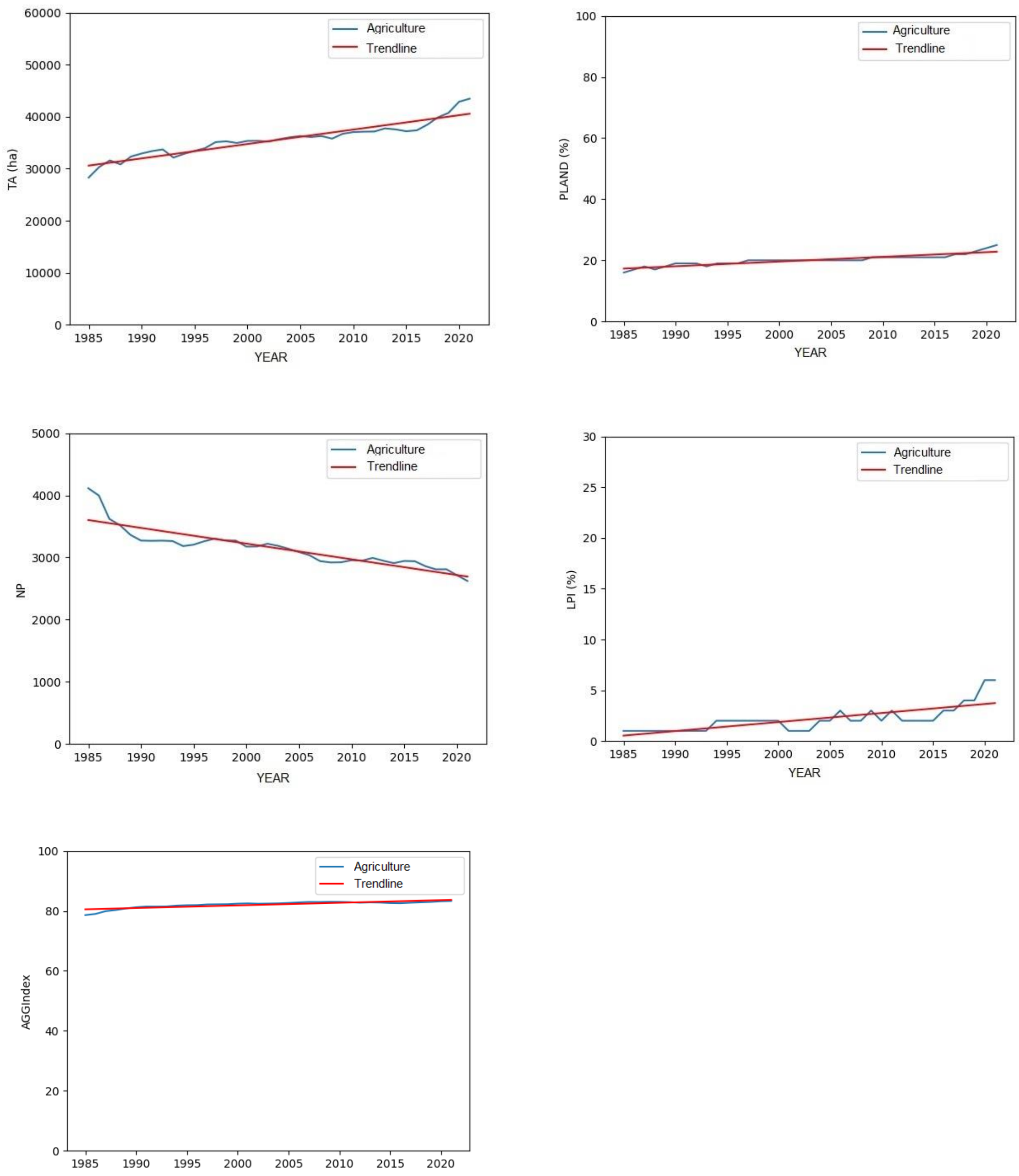
Figure 4 – Evolution of landscape metrics for the forest class within the Pratigi Environmental Protection Area, Bahia, Brazil (1985-2021).

Comparing the total areas of the forest and agriculture classes shows that while the forest class decreased, the agriculture class increased in the Pratigi EPA landscape from 2015 to 2021. This suggests that economic activities may be the main factor driving the observed fragmentation processes, with the potential to promote significant changes in the landscape in the future.

Given the expanding agricultural areas within the Pratigi EPA, Non-Governmental Organizations (NGOs), and public and private initiatives must implement sustainable actions to conserve forest remnants and restore and preserve natural resources. These efforts are crucial for maintaining the local biodiversity and the ecosystem balance.

Despite the agricultural expansion trend, the Pratigi EPA's conservation status remains favorable due to the predominance of forest patches in the landscape. This contrasts with other sustainable-use conservation units in Brazil, where use-related land classes predominate. Therefore, the study area stands out as a significantly important region for biodiversity and the availability of environmental resources.

However, in recent years, the Pratigi EPA has shown concerning trends of landscape changes resembling those of highly fragmented and unprotected areas, including habitat loss, mainly due to the expansion of the agricultural regions. This raises questions about the effectiveness of environmental legislation and the goals of protected area management in Brazil. These challenges involve economic, social, institutional, structural, and territorial control aspects, reflecting conflicts between the productive chain and local populations.



TA: total area in hectares (ha); PLAND: percentage of landscape occupied by forest patches (%); NP: number of patches (dimensionless); LPI: largest patch index (%);AGGINDEX: aggregation index, corresponding to the amount of similar adjacent patches (%). Red lines indicate the trend of the metrics over time.

Figure 5 - Evolution of landscape metrics for the agriculture class within the Pratigi Environmental Protection Area, Bahia, Brazil (1985-2021).

A practical analysis of landscape structure patterns requires a comprehensive understanding of both the configuration (size, shape, density, and connectivity) and composition (number of classes, class percentage, abundance, richness, diversity, and dominance). Therefore, each landscape should be interpreted distinctively based on its unique characteristics.

Conclusion

The study aimed to provide insights into the spatiotemporal patterns of change in the Pratigi Environmental Protection Area (EPA Pratigi), Bahia, Brazil, based on landscape spatial structure metrics from 1985 to 2021. Mapping the spatiotemporal evolution of land use and occupation within the Pratigi EPA for the period allowed the identification of the predominant land use and occupation classes: forest and agriculture.

The analysis of the landscape metrics revealed a significant reduction in the total forest area, representing approximately a 12% decrease in the native vegetation cover. Additionally, an increase in the number of forest patches indicated more significant forest fragmentation across the landscape. In contrast, the agriculture class significantly expanded over the evaluated period. The expansion of agriculture within the Pratigi EPA was accompanied by a reduction in the number of patches, indicating a trend towards larger and more aggregated areas.

The analysis of landscape structural patterns underscored the importance of forest patches in maintaining structural connectivity. The loss of these patches, combined with increased fragmentation, could have serious consequences for biodiversity and ecological processes in the region. Despite the growth of agricultural activities within the Pratigi EPA, conservation measures and sustainable initiatives have helped maintain a satisfactory level of environmental conservation in this sustainable-use conservation unit.

However, the landscape change trends in the study area raise concerns about the effectiveness of environmental legislation and the management of protected areas in Brazil, especially considering conflicts between economic interests and ecological preservation.

The analysis of land use and occupation evolution and landscape patterns provides important insights into landscape changes and their ecological implications, highlighting the need for effective conservation policies and environmental management to ensure the sustainability of these protected areas.

Additionally, a comprehensive understanding of the patterns found in this study requires further analyses focused on connectivity, using spatial graphs that allow for greater precision in detecting and detailing patterns of habitat fragment connections, and their effects on species dispersal. Future studies should include landscape dynamics analyses, investigating change rates and regeneration patterns of different land cover classes, which could help identify rapid-change areas and direct conservation and restoration efforts.

Finally, remote sensing data, such as high-resolution land use and occupation maps should be integrated to ensure a more detailed assessment of changing landscape structures.

Authors' contributions

OLIVEIRA, K.C.S.: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing – original draft, writing – review & editing. AGUIAR, W.M.: conceptualization, data curation, formal analysis, funding, investigation, methodology, project administration, resources, supervision, validation, visualization, writing – original draft, writing – review & editing. VASCONCELOS, R.N.: conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, writing – original draft, writing – review & editing. CURRIHUINCA, L.E.S.: data curation, formal analysis, visualization, writing – original draft, writing – review & editing. CAIAFA, A.N.: conceptualization, formal analysis, investigation, methodology, supervision, validation, visualization, writing – original draft, writing – review & editing.

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