LANDSCAPE ECOLOGY ANALYSIS AND CONTRIBUTIONS OF RURAL PROPERTIES IN AMAZON BIOME

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RESUMEN. El Bioma Amazónico ha estado sufriendo en las últimas décadas por la deforestación y los incendios, y la fragmentación forestal es una de las consecuencias, lo que conlleva impactos negativos en los procesos ecológicos y pérdidas de biodiversidad. El objetivo del estudio fue evaluar métricas del paisaje en dos escenarios para verificar el potencial de las áreas declaradas en el CAR, sobre aspectos ecológicos relacionados con la estructura forestal, en el estado de Rondônia. La metodología consiste en la utilización de métricas de paisaje (área, perímetro, distancia euclidiana al vecino más cercano), en dos escenarios: Actual (datos de la Colección 7 del Proyecto MapBiomas) y Declarado (con la adición de áreas de reserva legal y APP declaradas en el CAR); y análisis de histogramas y pruebas estadísticas. El área de los fragmentos aumentó y la distancia euclidiana entre fragmentos disminuyó. Los histogramas demostraron la frecuencia más alta de áreas más pequeñas, que podrían desempeñar una función ecológica para la dispersión de especies como trampolines ecológicos. La reducción de la distancia entre fragmentos permite un mejor flujo genético en el paisaje. Estos resultados muestran el potencial del CAR para mejorar aspectos estructurales del paisaje amazónico. Los datos y métodos de teledetección son importantes en este tipo de estudios.

Palabras-clave: Métricas del paisaje; Registro Ambiental Rural; Selva Amazónica; Rondônia.

ABSTRACT. The Amazon Biome has been suffering in the last decades from deforestation and fire, and the forest fragmentation is one of the consequences, which leads to negative impacts in the ecological processes and biodiversity losses. The aim of the study was to evaluate landscape metrics in two scenarios to verify the potential of declared areas in CAR, about ecological aspects related to forest structure, in Rondônia state. The methodology consists of the utilization of landscape metrics (area, perimeter, Euclidean distance to nearest neighbor), in two scenarios: Current (Collection 7 data from MapBiomas Project) and Declared (with the addition of legal reserve areas and APP declared in the CAR); and histograms analysis statistical tests. Patches area increased and the Euclidean distance between fragments decreased. The histograms demonstrated the highest frequency of smallest areas, which might perform and ecological function for dispersal of species as stepping stones. The reduction of distance between patches allows a better gene flow in the landscape. These results show the potential of CAR to improve structural aspects on the Amazon landscape. Remote Sensing data and methods are important in this kind of studies.

Keywords: Landscape metrics; Rural Environmental Registry; Amazon Forest; Rondônia.

RESUMO. O Bioma Amazônia vem sofrendo nas últimas décadas com desmatamentos e queimadas, sendo a fragmentação florestal uma das consequências, o que acarreta diversos impactos negativos nos processos ecológicos e perdas de biodiversidade. O objetivo do estudo foi avaliar métricas de paisagem em dois cenários para verificar o potencial de áreas declaradas no CAR, quanto aos aspectos ecológicos relacionados a estrutura florestal, no estado de Rondônia. A metodologia consiste na utilização de métricas de paisagem (área, perímetro,

distância euclidiana ao vizinho mais próximo), em dois cenários: Atual (dados da Coleção 7 do Projeto MapBiomas) e Declarado (com acréscimo de áreas de reserva legal e APP declaradas no CAR); além da análise dos histogramas e testes estatísticos. A área das manchas aumentou, enquanto a distância euclidiana entre os fragmentos diminuiu. Os histogramas demonstraram que a maior frequência é de manchas florestais de menores áreas, que podem desempenhar uma função ecológica para dispersão de espécies na forma de trampolins ecológicos. Já a diminuição da distância entre as manchas florestais permite o melhor fluxo gênico na paisagem. Estes resultados mostram o potencial do CAR em melhorar aspectos estruturais da paisagem amazônica. Os dados e métodos de Sensoriamento Remoto são importantes em análises desta natureza.

Palavras-chave: Métricas de paisagem; Cadastro Ambiental Rural; Floresta Amazônica; Rondônia.

1. INTRODUCTION

Forests provide crucial ecosystem services, including climate regulation, greenhouse gas storage, and biodiversity conservation, but this supply is compromised by negative environmental impacts on these ecosystems. In this context, the Amazon Forest has global influence. Still despite its importance and the effects of disturbances such as edge effects, carbon emissions, and heightened susceptibility to fires, the literature indicates an alarming rise in forest fragmentation taxes within the biome.

Fragmentation is a disturbance characterized by the division of biotopes into smaller patches. It might result from both natural events such as floods and mass movements, as well as anthropogenic activities. It disrupts the structural arrangement of the landscape – an important aspect of the natural environment. According to Basile, Storch, and Mikusiński (2021), the variability in the amount and configuration of habitat types in the landscape, together with their structural complexity, influence observed biodiversity patterns.

Landscape Ecology is a field of study that investigates the relationship between ecological processes and the spatial pattern of a landscape. Since its origin (1930s), it has evolved, and the availability of orbital data and precise cartographic products has propelled this approach towards smaller scales. The use of Remote Sensing data combined with landscape metrics can be helpful in monitoring land degradation and evaluating different structural dimensions of land use changes such as distribution, size, shape, heterogeneity, shape complexity, and fragmentation (AZAREH *et al.*, 2021).

In this context, Rondônia is a state located in the western portion of Brazil where it has been reported forestall loss due to agricultural expansion, logging, and infrastructure development. It leads to spatially affected landscapes, which might cause biodiversity losses, ecological process interruption, and loss in ecosystem services offered.

The deforestation and fragmentation in Rondônia highlight challenges of balance between development and conservation. Thus, it is important to promote sustainable agriculture that can coexist with environmental conservation, linking these practices to the Rural Environmental Registry (CAR, from the portuguese *Cadastro Ambiental Rural*), an important tool for the monitoring and environmental regularization of rural properties. The CAR is one of the criteria for environmental regulation of rural properties, and it must have areas declared to protect biodiversity and reduce fragmentation, such as Permanent Preservation Areas (APP, from the portuguese *Áreas de Preservação Permanente*), restricted use areas, consolidated areas, and Legal Reserves (RL, from the portuguese *Reserva Legal*), according to Brasil (2012). These areas are vital for preserving ecosystems, helping to maintain ecological corridors that facilitate the movement of fauna and the conservation of water resources, as well as reducing the adverse effects of forest fragmentation as established by the Brazilian Forest Code (BRASIL, 2012).

This paper presents some of the results about the investigations about Amazon biome fragmentation. Therefore, the aim of the study was to analyze the potential of areas declared in the CAR to improve ecological aspects of Rondônia state considering Landscape Ecology metrics.

2. METHODOLOGY

2.1. Study area and spatial database organization

The state of Rondônia has a total area of 237,646 km² and had its colonization subsidized by the federal government from the 1970s, which contributed to increasing deforestation rates during the 1980s and 1990s, resulting in significant changes in land use and cover in Rondônia. About 86,000 km² of primary forests were deforested in this state, especially between 1985 and 2005 (ALVES *et al.*, 2021). The primary sector is one of the foundations of the state economy.
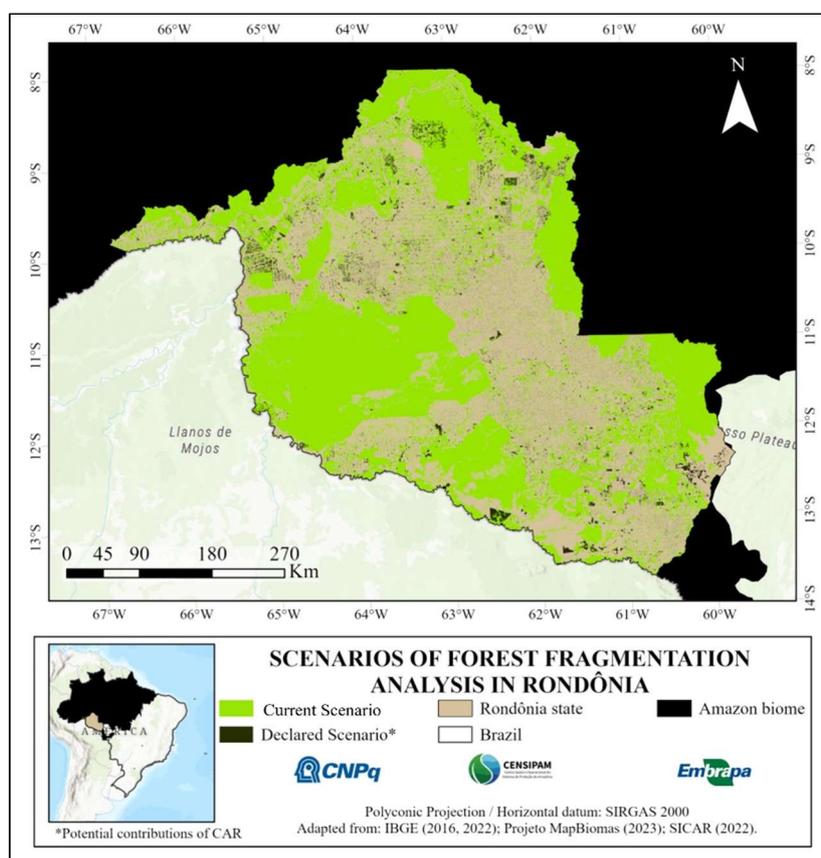

Figure 1. Study area (Rondônia state) and its scenarios of analysis
Source: Own authorship

The territorial divisions for the study were obtained from the Brazilian Institute of Geography and Statistics (IBGE) and include the boundaries of the Amazon biome and other limits. The Land Use and Land Cover data was sourced from MapBiomas Project Collection 7.0, respective to the year of 2021 (PROJETO MAPBIOMAS, 2023). The data were acquired via Google Earth Engine, in raster format (GEOTIF – .TIFF) with a spatial resolution of 30 meters (SOARES *et al.*, 2023a). To represent the forests of the study area, it was selected the

data corresponding to Forest Formation, Savanna Formation, Mangrove, Wooded Sandbank Vegetation, Wetland and Grassland.

The CAR data respective to the year of 2021 were obtained according to Brasco and Carvalho (2022), considering information provided by the Brazilian Forest Service (SFB, *Serviço Florestal Brasileiro*, in portuguese) through the National Rural Environmental Registry System (SISCAR, *Sistema Nacional de Cadastro Ambiental Rural*, in portuguese). From this database, it was extracted the RL and APP, which are part of the Fixed Assets (PI, from the portuguese *Patrimônio Imobilizado*), according to Soares et. al. (2023a).

It was analyzed two scenarios in this study: the "Current Scenario" was compounded with the selected data from MapBiomas Project. In the "Declared Scenario", otherwise, it was considered the PI conversion to forests (through environmental regulations) to be added to "Current Scenario".

All the data pre-processing (reprojections, clips, reclassification, topological checkings, etc.) was performed in ArcGIS Pro 3.1.1 software (ESRI, 2023). The data were projected in the Albers Equal Area Coordinate System, according to the recommendation of IBGE (2023), and referenced to the Geocentric Reference System for the Americas (SIRGAS 2000) horizontal datum, the geodesic reference system for Brazil (IBGE, 2017). For mapping and presentation of the resultant data, the geographic coordinate system was used.

3.2 Landscape metrics analysis of forest fragments

Landscape metrics are defined as methodologies to quantify structural measures of the landscape related to the ecological processes (LANG; BLASCHKE, 2009; MCGARIGAL; MARKS, 1995). Three metrics were evaluated at the patch level: area (hectares – ha), perimeter (meters – m) and, Euclidean nearest-neighbor distance (m). To generate and analyze the data, it was used ArcGIS Pro 3.1.1. software (ESRI, 2023).

3.3 Statistical analysis

The landscape metrics data were evaluated by histograms. To test the hypothesis that the CAR contributes significantly to the landscape metrics of forest fragments in the state of Rondônia, the Mann-Whitney U method was applied with a 5% significance level. This methodology is suitable for datasets that do not have normal distribution (FAY; PROSCHAN, 2010). These procedures were conducted through the Integrated Development Environment (IDE) Spyder from Graphical User Interface (GUI) Anaconda Navigator.

3. RESULTS AND DISCUSSION

Figure 2 presents the Present and Declared Scenario of Rondônia state. Both scenarios have a uniform distribution of forest fragments throughout the study site, but their highest concentrations are in the west, north and east regions. According to Fernandes, Vasconcelos e Campanharo (2022), National Indigenous People Foundation (FUNAI from *Fundação Nacional dos Povos Indígenas*, in portuguese) and SFB, lots of Indigenous Lands and Conservation Units are present in this region. Most of his areas in the state were established before 1999, and they play a highly relevant role in the environmental conservation of the region, as they serve as crucial habitats for a wide range of plant and animal species, as well
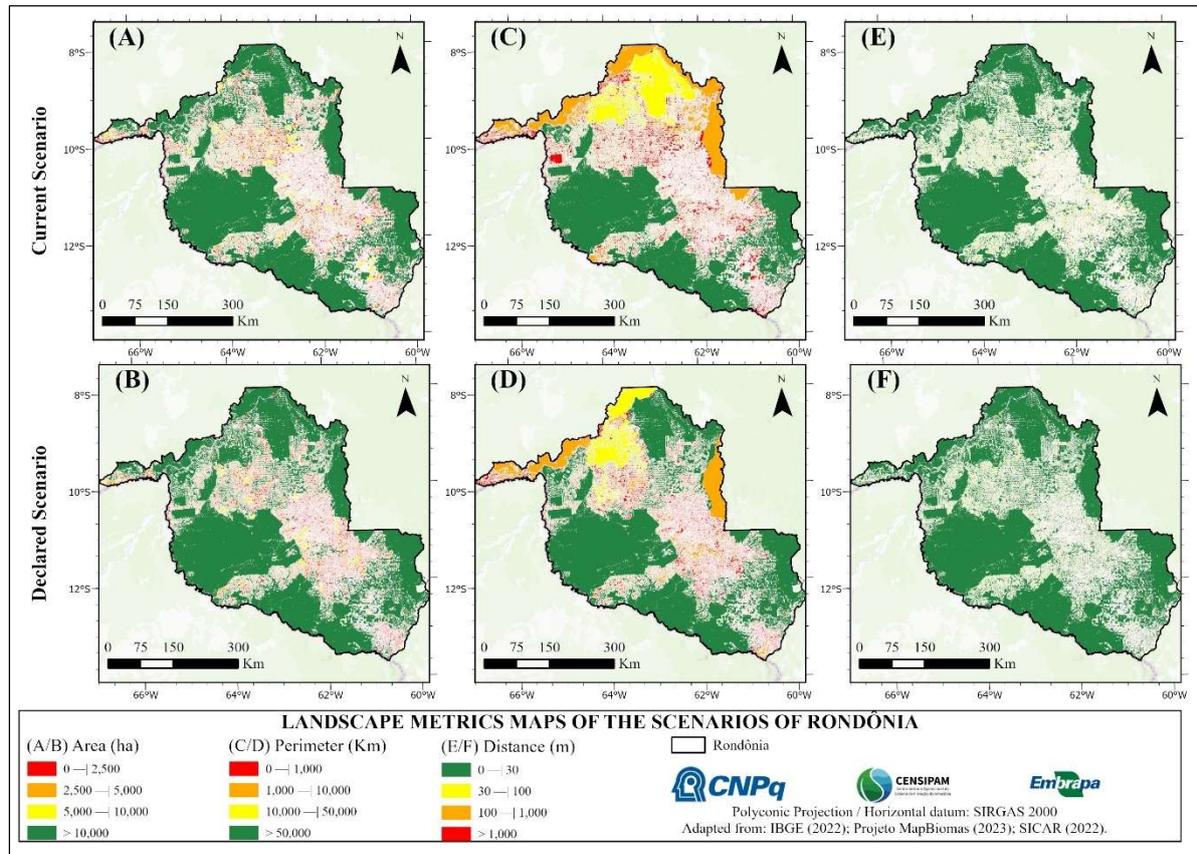
Figure 2. Spatialization of Area (A and B); Perimeter (C and D); and Euclidian nearest-neighbor distance (E and F) for both scenarios of analysis
Source: Own authorship

Oakleaf *et al.* (2017) highlight the RL are fundamental to a succeeded implementation of the Brazilian Forest Code. According to the authors, about 13% of the national territory belongs to this class of SICAR data. It is also explicit the importance of RL for connectivity in the Amazon biome, according to the literature (MORENO, 2022).

CAR is a promising policy for environmental conservation and deforestation decreasing in rural private properties because it facilitates the land use and land cover monitoring. Its implementation and management are important to environmental regularization of rural properties in the Amazon biome, to avoid irregular occupations or land grabbing – known as '*grilagem*' (CARVALHO *et al.* 2019; RASMUSSEN *et al.* 2017). Alix-Garcia *et al.* (2017), in their research to assess the potential of CAR as a deforestation control tool in Mato Grosso and Pará, found that deforestation in these states was reduced by 10% after the registration of rural properties in the registry.

Figures 2(A) and 2 (B) present the area of forest fragments in both scenarios of analysis. It is noticed that it was mapped patches of area from zero to greater than 10,000 ha. In the context of Landscape Ecology, area has relevant meaning: besides being a very widespread and intuitive measure, several other landscape metrics derive from it. In addition, this metric also allows evaluating the forest fragmentation of landscapes by the size of the patches.

The differences between the scenarios Current and Declared, from Figures 2(A) and 2(B), respectively, are subtle. Otherwise, the histograms of this landscape metric support the analysis, and they demonstrate that the frequency of small patches decreases with the implementation of CAR (Figure 3). The histogram of the Current Scenario shows that the highest occurrence was of patches with less than 2,000 ha area. The Declared Scenario, otherwise, shows the raise limit to 3,000 ha.
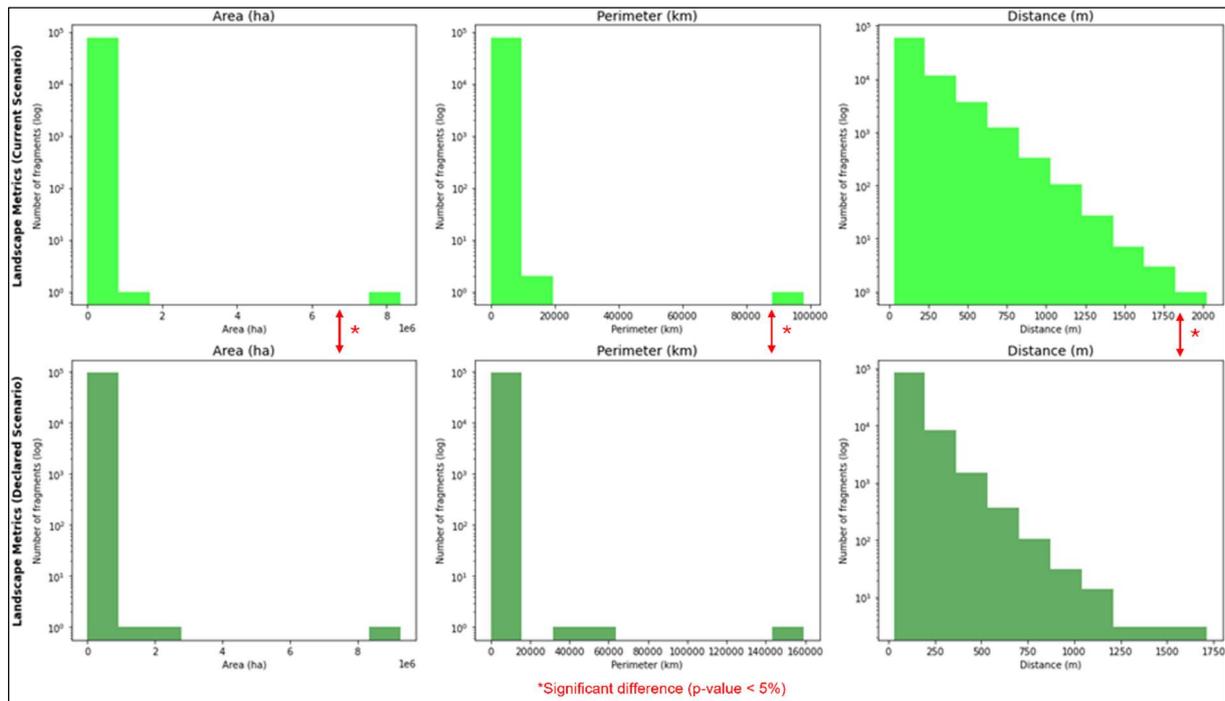

Figure 3. Histograms of landscape metrics of Rondônia state patches considering Current (A) and Declared (B) Scenarios
Source: Own authorship

In both scenarios, it is possible to observe that the smallest class of forest fragments is the most frequent in the state of Rondônia. In the investigation of the forest fragments of the Pará state municipality Dom Eliseu, also belonging to the Amazon biome, Silva *et al.* (2021) also verified the predominance of the smallest patches in the municipality. These results indicate high fragmentation of the biome.

Figures 2(C) and 2(D) show the perimeter of the patches of the analyzed state. In the Declared Scenario there was an increase in the perimeter of the forest fragments in relation to the Current Scenario – Figure 5(A). Perimeter is an edge metric, and it is important in ecotone concept. This measurement is also important for determining several other shape metrics (MCGARIGAL; MARKS, 1995).

The perimeter histograms in Figure 3 indicate the increase of this metric for the forest fragments of Rondônia after the application of CAR in the state. When analyzing landscape metrics in a region with intense deforestation activity in the Colombian Amazon, Argote *et al.* (2022) noticed the reduction of areas and increased perimeter of forest fragments analyzed between 2002 and 2018. The authors pointed out that the increased perimeter exposes the fragment to greater edge effects and, consequently, to habitat loss, fragmentation, biodiversity losses (fauna and flora), especially specialized species, the most vulnerable to predation and hunting (ARGOTE *et al.* 2022; DEVICTOR *et al.* 2011). However, the literature also points

out that the perimeter might be considered as a measure of richness of faunistic and floristic species. Thus, the evaluation of the quality of these edges is important to infer about the results obtained on the edges.

Finally, the maps of the Euclidean nearest-neighbor distance are shown in Figures 2(E) and 2(F). The literature points out that the distance and, consequently, the reach of habitats, is determinant for the survival of the species. According to the study by Villa *et al.* (2021), spatial heterogeneity and dispersal limitation, that is, greater distances between forest patches, can determine the composition of tree species along the forest succession in the Amazon biome. Therefore, forest fragmentation scenarios have a direct influence on the biodiversity of this biome (VILLA *et al.* 2021).

Soares *et al.* (2023b) analyzed the transition time between forest and pasture in the Amazonian biome, and it varied between 1 and 7 years in the state of Rondônia. The authors also pointed out that the transition time (and agricultural establishment) between 2015 and 2019 increased and it might promote forest regeneration in the environment. These regeneration areas facilitate the forest to exercise its ecosystem services such as the genic flow of faunistic and floristic species.

The histograms of this metric indicate the decrease in the distance between the patches in the state of Rondônia with the fulfillment of the declared data in the CAR. These results are important because they demonstrate their potential for the biodiversity of the Amazon biome.

Finally, the results of the MannWhitney U test indicate that there of a significant difference for all metrics evaluated in the present study between the scenarios analyzed. The p-values obtained were less than 5%, that is, which proves the hypothesis of a significant difference between the Current and Declared scenarios. These results are important to attest to the environmental importance of CAR. However, its success is dependent on several agents such as landowners, public inspection agencies, and others. Thus, CAR, one of the largest environmental programs in the world, has many challenges.

CONCLUSIONS

Amazon biome is widely known for its biodiversity, but it has suffered from deforestation and fragmentation impacts. According to the area, perimeter, and Euclidean nearest-neighbor distance landscape metrics, and the statistics tests, CAR declared areas have potential to contribute to decrease forest fragmentation on Rondônia state.

As future investigations, we recommend evaluating other landscape metrics to a complete analysis of the environment and the potential of CAR to contribute to the environment in Rondônia state. Furthermore, this kind of research might include all the Amazon biome to comprehend its dynamic. Remote Sensing data and methods are important and contribute to develop environmental studies and methods to reduce climate change and a sustainable development.

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