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LANDSCAPE CONFIGURATION AND COMPOSITION: MATA DO LIMOEIRO STATE PARK

Luiz Fernando Dada de Oliveira
Centro Federal de Educação Tecnológica de Minas Gerais, Departamento de Ciência e Tecnologia Ambiental (DCTA), Universidade Federal de Minas Gerais, Programa de Pós-graduação em Análise e Modelagem de Sistemas Ambientais, Belo Horizonte, MG, Brasil
luizfdada@gmail.com

Vicente Toledo Machado de Morais Junior
Universidade Federal de Uberlândia, Instituto de Ciências Agrárias (ICIAG), Núcleo de Estudos, Pesquisa e Extensão em Planejamento e Manejo da Paisagem Florestal (NUPLAMFLOR), Monte Carmelo, MG, Brasil
vicente.morais@ufu.br

Daniella do Valle
Universidade Federal de Minas Gerais, Programa de Pós-graduação em Análise e Modelagem de Sistemas Ambientais, Belo Horizonte, MG, Brasil
dovalledani@gmail.com

Guilherme Wince de Moura
Universidade Federal de Uberlândia, Instituto de Biologia (IB), Programa de Pós-graduação em Ecologia e Conservação dos Recursos Naturais, Núcleo de Estudos, Pesquisa e Extensão em Planejamento e Manejo da Paisagem Florestal (NUPLAMFLOR), Uberlândia, MG, Brasil
guilherme.wince@ufu.br

Luciano Cavalcante de Jesus França
Universidade Federal de Uberlândia, Instituto de Ciências Agrárias (ICIAG), Núcleo de Estudos, Pesquisa e Extensão em Planejamento e Manejo da Paisagem Florestal (NUPLAMFLOR), Monte Carmelo, MG, Brasil
luciano.franca@ufu.br

Daniel Brianezi
Centro Federal de Educação Tecnológica de Minas Gerais, Departamento de Ciência e Tecnologia Ambiental (DCTA), Belo Horizonte, MG, Brasil
brianezi@cefetmg.br.com

ABSTRACT

The spatial organization of the landscape is essential for spatial planning, securing ecosystem services, and addressing climate challenges. Human activities should be planned according to their impacts, promoting ecological improvements in line with global environmental guidelines. The management of critical conservation areas requires strategies adapted to the scale of the protected area. This research analyzed the landscape of the Mata do Limoeiro State Park (PEML) and its surrounding region in the context of protected area management. Landscape metrics, geospatial tools, and field validation were used to assess fragmentation, connectivity, and landscape diversity. Landscape Functional Units (LFUs) were mapped (1:10,000 scale) and spatial modeling techniques were used to identify priority areas for conservation. The results showed that 78% of the biodiversity conservation areas were within the park, while 80% of the areas relevant for sustainable management were outside the park boundaries, highlighting the need for integrated planning. The contrast between the preserved vegetation inside the park and the surrounding agricultural landscape underscores challenges such as habitat fragmentation and human-wildlife conflict. The findings reinforce the urgency of sustainable management strategies, conservation awareness, and collaborative efforts to enhance ecological resilience both inside and outside protected areas.

Keywords: Landscape management. Forest conservation. Conservation Unit.

CONFIGURAÇÃO E COMPOSIÇÃO DA PAISAGEM: PARQUE ESTADUAL DA MATA DO LIMOEIRO

A organização espacial da paisagem é essencial para o planejamento territorial, para garantir serviços ecossistêmicos e enfrentar desafios climáticos. Atividades humanas devem ser planejadas conforme seus impactos, a fim de promover melhorias ecológicas alinhadas às diretrizes ambientais globais. A gestão de áreas críticas para conservação exige estratégias adaptadas à escala da área protegida. Esta pesquisa analisou a paisagem do Parque Estadual Mata do Limoeiro (PEML) e sua região limítrofe no contexto da gestão da área protegida. Foram utilizadas métricas paisagísticas, ferramentas geoespaciais e validação de campo para avaliar fragmentação, conectividade e diversidade da paisagem. As Unidades Funcionais da Paisagem (UFPs) foram mapeadas (1:10.000) e técnicas de modelagem espacial identificaram áreas prioritárias para conservação. Os resultados mostram que 78% das áreas de conservação da biodiversidade estão dentro do parque, enquanto 80% das áreas relevantes para manejo sustentável estão fora, evidenciando a necessidade de um planejamento integrado. O contraste entre a vegetação preservada no parque e a paisagem agrícola circundante destaca desafios como fragmentação do habitat e conflitos homem-fauna. Os achados reforçam a urgência de estratégias de manejo sustentável, sensibilização para conservação e esforços colaborativos para aumentar a resiliência ecológica dentro e fora das áreas protegidas.

Palavras-chave: Gestão da paisagem. Conservação florestal. Unidade de conservação.

INTRODUCTION

The configuration of basic landscape elements can be analyzed to identify ecological processes that benefit humans (Turner, 2005; Duarte, 2016). Understanding these interactions is essential to obtain a complete view of the impact of public policies and management of heterogeneous landscapes (Saidi; Spray, 2018). By comprehending landscape patterns and spatial organization, we can enable planning and management of the said area by identifying target areas for conservation or restoration, thus guaranteeing their ecosystem services. Such practices have been identified as pivotal in addressing the climate crisis (Duarte, 2016; Gambarini, 2022).

Planning human activities that have the least environmental impact, that are economically viable, and promote social justice enables the maintenance of landscape services through its multifunctionality and the processes generated by a range of unique ecosystems, including both natural and modified habitats (Frank *et al*., 2012; Hodder *et al.*, 2014; Dutra, 2016). This approach has the potential to contribute to global commitments such as actions to combat climate change and protect life on Earth – the 13th and 14th Millennium Development Goals (UN, 2012) –, and the AichiGoals and Objectives for Sustainable Development (CBD, 2010), which emphasize food security, water security, and biological conservation, as well as socio-ecological benefits.

Numerous countries have adopted public policies for environmental conservation and protection of natural areas, intending to mitigate and adapt to climate impacts, and seeking to meet global commitments (Mawdsley; O'Malley; Ojima, 2009). Protected areas are key tools for the climate agenda, biodiversity conservation, and ecosystem maintenance, ensuring natural resources and ecosystem services that support human life (Watson *et al*., 2014).

These conservation areas are influenced by their surroundings, which can have negative impacts on environmental conservation. Preserving biodiversity and its associated ecosystem services requires the presence of natural habitats close to protected areas to connect landscapes (Goodwin; Faring, 2002), and to prevent the island phenomenon in the protected ecosystem.

The reality of these conservation areas often does not coincide with the management of adjacent activities, leading to social conflicts and environmental losses. Thus, the management of regions outside the protected areas is correlated with the ecosystem benefits of the landscape. It usually requires community participation and local governance for the conservation of the landscape's environmental resources.

Brazilian biomes have been identified as global biodiversity hotspots (Myers *et al*., 2000, Conservation International, 2023). The Cerrado and the Atlantic Forest, in Minas Gerais – both important conservation units that promote the protection of ecosystems – have historically been degraded by extractive activities and extensive land use, such as mining, agriculture, cattle ranching, and increasing urbanization. Therefore, the Mata do Limoeiro State Park (Parque Estadual Mata do Limoeiro - PEML) – located in Itabira, Minas Gerais – was established by Decree 45.566/2011 (Brasil, 2011) and plays a key role in regional environmental conservation. The last management plan developed for the park includes data until 2014, and, since then, the results of conservation efforts as well as the importance of the park in the context of environmental education and tourism in the region remain outdated.

Therefore, this research sought to characterize and analyze the landscape metrics of the Mata do Limoeiro State Park (PEML), classified as a Full Protection Conservation Unit in Brazil's National System of Conservation Units, and its bordering region. This goal aims to identify priority areas for sustainable management, to provide scientific input to the management team to work with the community in the region, and to collect up-to-date data on the reality of the landscape in the area studied. Also, it intends to provide the management with data on the risks and sensitivities of the conservation unit.

METHODS

Study area

The focus area of this research is Mata do Limoeiro State Park, a Full Protection conservation unit, located in Ipoema, district of Itabira, state of Minas Gerais. The park is one of the mountain ranges inserted in the southern part of the Serra do Espinhaço Range, and is part of other protected areas, such as the Serra do Espinhaço Biosphere Reserve, a natural world heritage site according to UNESCO (2009), and the Espinhaço mosaic.

The PEML protects a rich ecosystem in an ecotone region in the transition between the Atlantic Forest and Cerrado biomes. The natural vegetation characteristics of this region include forest formations such as gallery forests, seasonal semi-deciduous forests, and savanna formations (such as Cerrado *stricto sensu* and *campo rupestre)*, with the presence of many endemic species and other species of interest for conservation (IEF, 2013).

The study area defined for the development of this research includes the boundaries of the PEML and a closed polygon extending of 500 meters from the park, with headquarters located in zone 23 K (Universal Transverse Mercator, UTM), with coordinates 664278.57 meters east and 7833370.62 meters south. The total study area is 3,285.93 hectares and is illustrated in Figure 1.

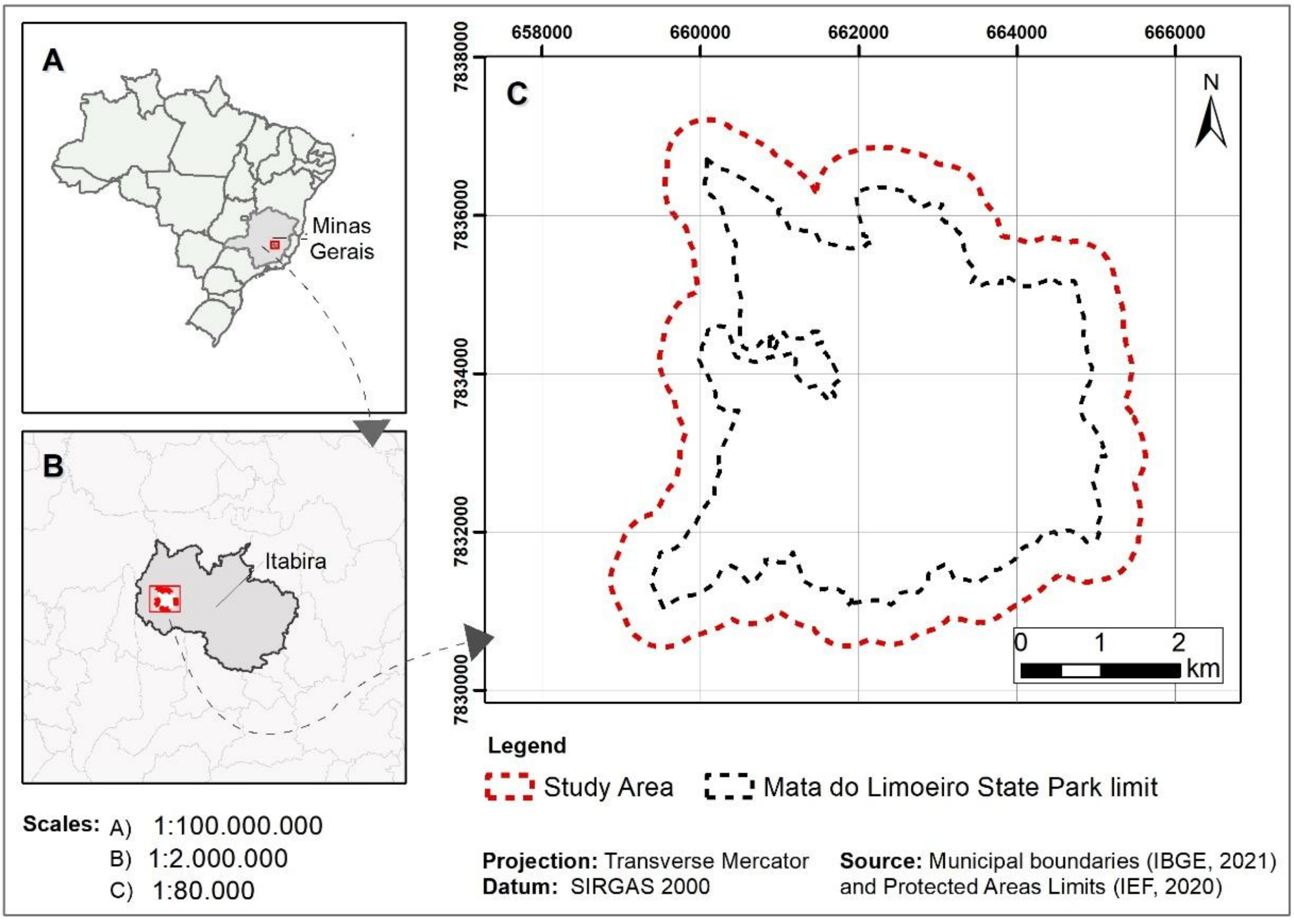
Within the park boundaries, there are large areas of well-preserved and protected ecosystems. However, the region outside the park boundaries showed a matrix composed of extensive anthropic vegetation, mainly exotic grasses (*Brachiaria* spp.), and a livestock management system. This characteristic enables us to understand the main anthropic pressures on the park, including threats such as deforestation, fires, hunters, and the presence of domestic animals, all of which are common in the region.

Characterization of Landscape Functional Units

Based on the secondary data obtained from the literature on the characteristics of the region, we validated the information in the field in a spatialized manner. The landscape of the study area was assessed by comparing it with qualitative and quantitative information of the area.

Following the guidelines of Weber (2019) and Bedê *et al.* (1997), a scale of 1:10,000 was used to map the study area. The functional unit is represented by the unique characteristics of each fragment and named according to the dominant matrix unit. The structure of the local vegetation physiognomy (which is also determined by the unit of analysis) includes an environmental role (as well as a social role when applied in areas of anthropic interest) and specific use byspecies as habitat.

Figure 1 - Study site in Mata do Limoeiro State Park, Ipoema/Itabira, Minas Gerais, Brazil



Source: The authors.

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The following steps were taken to map and analyze the area: field planning, *in situ* characterization, and data processing. The software QGIS 3.26.3 was used to prepare the layout, the landscape-specific key to map the functional units, a spreadsheet for field characterization, and a smartphone software for navigation and locating coordinate points (Avenza Maps 4.2.2).

With the information collected and digitally mapped, we were able to perform a series of analyses on local environmental systems, enriching the research with a more precise spatialization and understanding of the area.

A set of criteria was established to correlate the units according to the analysis of interest in order to identify possible zones for the park team to plan management strategies based on the use and purpose of each region. Based on the anthropic activities involved in the landscape and the ecological potential of each region, a spatialization of the functional units was produced and divided into three groups: (I) Environments with anthropic potential, defined by the landscape units with buildings, whether housing or support; (II) Important areas for sustainable management, considering the environments in the agricultural context of the region of the park; (III) Landscape relevant for the conservation of biodiversity, composed of forested, hydromorphic, and rocky outcrop environments.

Both the internal and external areas of the park boundaries were considered for these potential regions to understand the impact of the protected area. In this way, landscape analysis helps identify areas inside the park that require management or alternative cultivation or restoration methods, areas with anthropic potential for environmental education, and relevant areas for conservation and preservation.

The cartographic bases used for this study were (i) municipal boundaries (IBGE, 2021), (ii) protected area boundaries (IEF, 2020), (iii) functional units: collected during field campaigns (Oliveira, 2022).

Landscape Metrics

A qualitative-quantitative analysis of landscape metrics was performed using *FragStats* v4.2 software. The metrics were selected based on the methodology proposed by Duarte (2016) and were adapted to the context of the study area. Our objective was to identify metrics that represent the composition and configuration of the landscape, which would allow fora spatial understanding of the effects of land use and land cover changes on the complexity of the landscape.

Composition

Shape Index (AWMSHI)

This index is a measure of the complexity of patch shapes compared with a standard shape (such as a square) of the same size. The closer it is to 1 (lower limit), the more regular the shape of the fragment, and the values increase with the complexity of the fragment shape. This metric is also weighted by the patch area size. (Supp Material- 1)

Shannon Diversity Index (SHDI)

This index quantifies the diversity of classes found in landscapes. In addition to the number of classes, the SHDI is also modulated by the proportion of classes in relation to the total area, i.e., the more equitable the areas of the classes are, the higher the value of the index.

Configuration

Distance to the nearest neighbor (ENN_MN)

This metric measures the distance between the closest patches (neighbors) of the classes in the study area and is used to assess the connectivity. This result is also influenced by the size of the fragments, as larger patches have a greater weight on the degree of connectivity observed.

Number of patches (NP)

Indicates the total number of patches of each class; used as one of the simplest metrics to evaluate fragmentation processes.

Finally, the classes were spatialized according to their average area, based on the moving window method (which considers the landscape gradient model),. The *Dinamica* EGO 7 software was used to calculate a Kernel density heat map for these classes, showing areas of greater influence, aiming to identify priority areas for sustainable management in the park.

RESULTS AND DISCUSSION

The landscape of the Mata do Limoeiro State Park is a matrix with “Forest and rural environments”, which occupies 2,000 hectares, followed by significant patches of “Environments in an agricultural context” covering 966.57 hectares.

The extent and composition of each landscape unit are listed in Table 1 along with a description of the environmental indicators. Figure 2 shows the composition and spatial configuration of landscape units in the study area.

Table 1 - Landscape units and their indicators in Mata do Limoeiro State Park

Landscape unit	**Sublevel 1**	**Sublevel 2**	**Environmental indicators**	**TA – AI**
Environments presenting construction or rural aspects (2.13%)	Village or neighborhood with an arrangement of residences		Dwellings at a considerable density for rural areas; Proximity and continuous movement of people; Presence of domestic animals; Less natural trees; More elaborate fences and presence of walls;	13.44 - 0.70
	Headquarters, farmhouses, and isolated dwellings		Larger properties; More open space in the landscape; Simpler fences and gates; Presence of domestic animals near the house; Orchards and forestation with exotic species;	23.33 - 6.39
	Construction and supporting alterations to the landscape (access, roads, corrals, barns)		Anthropic changes in the physical organization of land; Continuous movement and use of vehicles and anthropic equipment; No developed or elaborate constructions, but some supporting constructions (e.g., roof);	33.11 - 15.98
Environments in farming contexts (29.42%)	Horticulture and family farming	Annual crops with periodic rotation	Crop species; More frequent management compared to perennial crops;	0.67 - 0.00

Landscape unit	Sublevel 1	Sublevel 2	Environmental indicators	TA – AI
		Perennial crops (coffee, fruit, cotton)	Crop species; Less frequent management compared to annual crops;	0.53 - 0.00
	Pasture with exotic grasses	Clean pasture for intensive use, sparsely distributed trees	Presence of cattle and fresh manure; Points of erosion; Large quantity of termite mounds	157.91 - 4.59
		Clean pasture for extensive use, sparsely distributed trees	Presence of more dispersed cattle and fresh manure; Points of erosion; Large number of termite mounds	285.29 - 43.81
		Overgrown pasture in intensive use	Presence of trees and more developed creeping vegetation and undergrowth; Presence of cattle and fresh manure	22.39 - 6.24
		Overgrown pasture in extensive use with remnant trees	Remnant trees; Less occurrence of manure; Larger termite mounds	295.57 - 126.79
		Abandoned overgrown pasture with remnant trees	Old and dry manure; Fewer termite mounds; Regenerating vegetation; Greater connectivity between patch remnants;	204.21 - 61.38
Forest or savannah environments (60.88%)	Reforestation areas	Reforestation with exotic species	Planting of exotic species; Monocultures;	1.92 - 1.92
		Reforestation with native species	Planting of native species; Species diversity;	22.13 - 0.00
	Native forest and savannah vegetation	Regenerating capoeiras (secondary vegetation composed of grasses and sparce shrubs)	Regenerating forest fragments; Average height of individuals (up to 10 meters); Pioneer and primary individuals and species;	300.76 - 210.73
		Cerrado strictu sensu with woody grassy vegetation	Characteristic xylomorphism for woody species; Presence of shallow and dry soil; Vegetation with sparse shrubs;	10.31 - 10.31

Luiz Fernando Dada de Oliveira
Vicente Toledo Machado de Morais Junior
Daniella do Valle
Guilherme Wince de Moura
Luciano Cavalcante de Jesus França
Daniel Brianezi

Landscape unit	**Sublevel 1**	**Sublevel 2**	**Environmental indicators**	**TA – AI**
		Secondary seasonal semi-deciduous forest (SDSF)	Stratified tree canopy; Lianas, epiphytes and bromeliads in the middle layers; Tree vegetation at considerable height (>15 meters); Arboreous individuals with expressive diameter widths at breast height (>10 centimeters); Presence of tree climax species;	1665.48 - 1357.13
Hydromorphic environments (3.87%)	Wet, marshy, and humid areas		Presence of aquatic plants, such as taboa and other species; Geomorphology of the terrain; Local microclimate; Characteristic of dry season / rainy season;	117.13 - 79.91
	Watercourses with gallery and riparian forest		Significant lotic or lentic watercourse captured by satellite imagery; Riverbeds with natural and representative riparian vegetation; Characteristic geomorphology; Presence of rocks	10.64 - 10.64
Rocky outcrop environments (3.70%)	Rocky outcrops with vegetation		Pedology characteristic of the study area; High altimetry; Region of common and proximal spatialization; Shallow soil with rocky characteristics; Xeromorphic and sparse vegetation;	121.55 - 72.56

TA: Total area, in hectares; IA: area inside the park, in hectares.

Source: The authors.

In the western part of the PEML, there is a greater concentration of vegetation in the continuous fragments in the region outside the park. On the other hand, the landscape of the eastern region has undergone changes due to the development of agricultural activities close to anthropic regions, creating a noticeable contrast between landscape units. Moreover, there are communities located to the north of the park headquarters and to the west, within an area dedicated to livestock farming, due to the recent implementation of the park (eight years prior to field mapping). The rugged relief observed in the region influences the landscape owingto the effects of runoff and water accumulation, forming areas of flooding and/or natural fragments.

Approximately 78% of the areas relevant for biodiversity conservation are located within the PEML and are under its protection. The park area includes 25% of the environment suitable for human activities and is mainly characterized by roads. The areas for sustainable management are mostly (80%) in the outer perimeter of the park, and 242 hectares of these areas are located in the inner region (7% of the park).

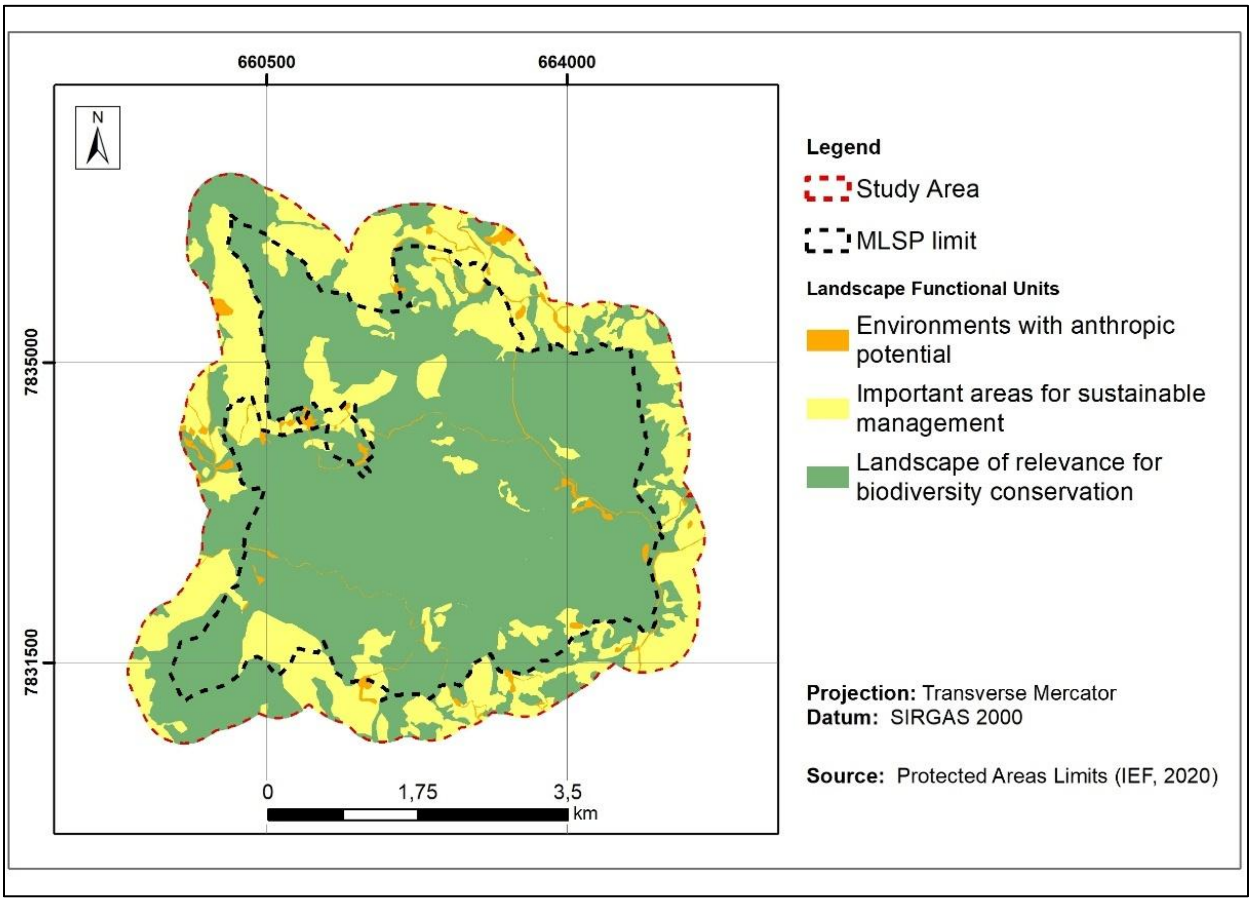
The landscape composition and configuration metrics are listed in Table 2. The values clearly show that, based on the SHDI value, the landscape at the outer boundary of the park has a greater diversity of classes than the inner areas. Regarding the outer area, the number of patches (NP) is well distributed among the classes, with those of “Important areas for sustainable management,” which have the largest average extensions (AREA_MN). The average fragment shapes (SHAPE_AM) were also similar. It shows a low shape variation between the classes, as well as the distance to the nearest neighbors (ENN_MN), with an average of 57 meters between patches, which refers to the level of fragmentation of the landscape outside the park.

In the internal context, the areas of “Landscape of relevance for the conservation of biodiversity” showed few fragments (NP) but a large average size (AREA_MN). Additionally, "Areas with anthropic potential"

in the inner region of the park showed high fragmentation and high shape value (SHAPE_AM), indicating patches with extended shapes. The classes exhibited a higher mean distance between the nearest neighbors (ENN_MN), except for the first class, which had the lowest index compared to all scenarios.

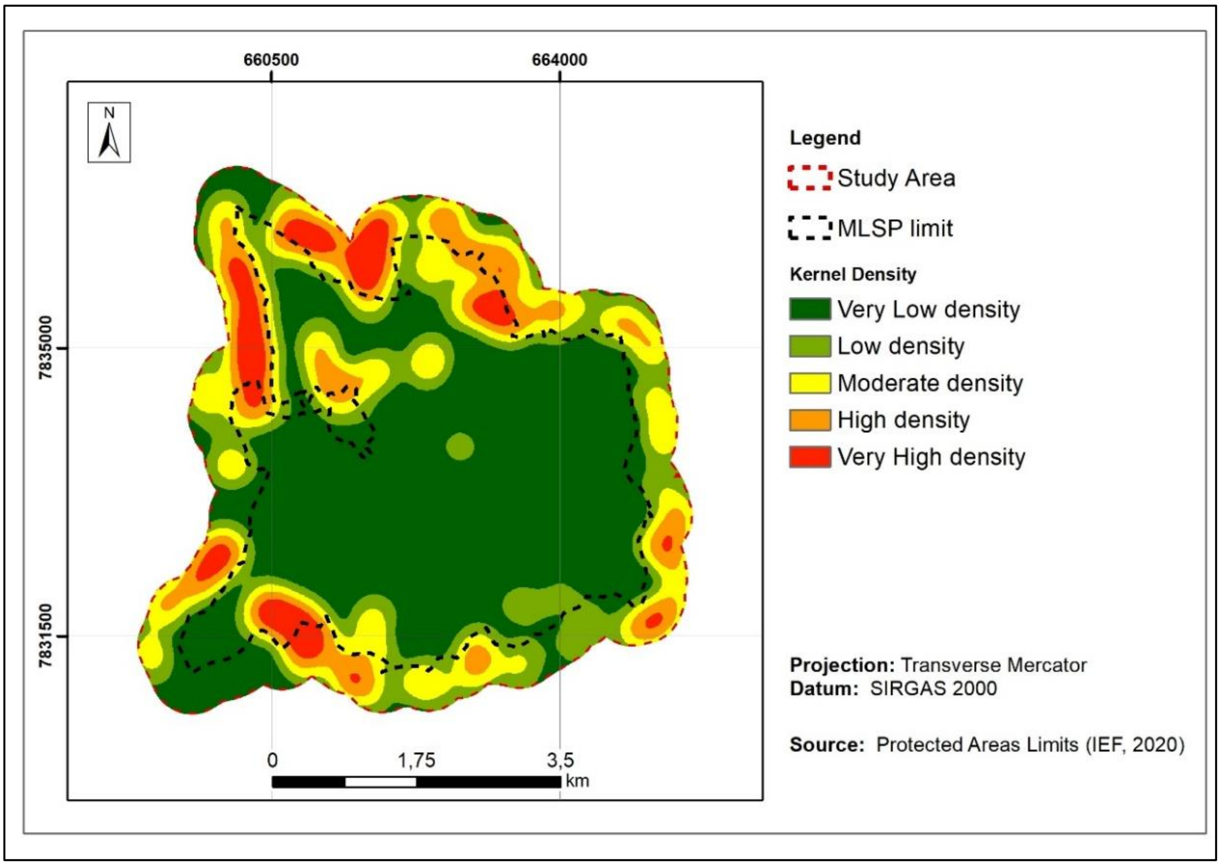
The result of the heat map (Kernel density), formed by the average area metric of the "Important Areas for Sustainable Management," with spatialization in a moving window, is shown in Figure 3. The inner northern area of the park is more influenced by these areas than the rest of the park, and typically, the central region does not have areas of high density in this class.

Figure 2 - Functional units mapped in the study area



Source: The authors.

Figure 3 - Heat map considering the areas of highest densities occupied by the class "Important areas for sustainable management."



Source: The authors.

The results showed a landscape with a matrix formed by preserved vegetation inside the park, with fragments of areas altered by anthropogenic activity. The external region is mainly composed of conventional land use environments in an agricultural context. From the above figure, the northern region of the park has a higher density of areas important for sustainable management. Therefore, decision-makers should prioritize ecological restoration measures and ecosystem development activities in this region, along with environmental education initiatives for the neighboring community. The implementation of actions aimed at improving the environmental quality of the area will make the park's edge effect more effective within a broader landscape. Other areas with high density, located in the southern part of the park, can also be considered priority areas for management activities. Owing to the local slope (higher elevation areas) and their lower proximity to other relevant areas, the implementation of community engagement initiatives and the development of participatory governance strategies may be beneficial for the park's border region in the medium and long term.

“Areas of anthropic potential” have experienced a series of impacts and specific pressures on biodiversity, due to socio-environmental characteristics that are less present in the analyzed landscape. These areas represent the participation of the local communities in the region. In these areas, environmental education initiatives are needed to address the importance of protected areas and ensure local ecosystem benefits, as well as the possible impacts of anthropic proximity to the local fauna, such as roadkill, attacks by domestic animals, and hunting. Actions that raise awareness of the importance of preserving native vegetation, fire prevention and control, and the role of the community in these actions are also valid. An important example that can be highlighted is the role played by several community actors in fighting recent fires in PEML.

“Important areas for sustainable management” are largely present in this region, which indicates a change in vegetation structure. This dynamic reveals a loss of biodiversity due to the loss of native forest cover, which, in turn, reduces communities and areas of natural habitats (Cardozo *et al.,* 2014; Silva, 2019).

The typical landscape of agricultural areas is composed of pastures in use and in regions with morphologies such as slopes and valleys, sometimes with steeper reliefs. Environmental imbalance has been shown to be one of the main consequences of traditional agricultural practices, resulting from the reduction of biodiversity in ecosystems and the invasion and spread of pests and diseases in crops (Cândido *et al.,* 2016). According to the 2005 Millennium Ecosystem Assessment, invasive species are one of the main causes of biodiversity loss worldwide (Watson *et al*., 2014). This can also be observed on a national scale, threatening the integrity and survival of populations of native species.

In addition to the biodiversity impact, the use of pasture increases negative pressures on other environments. Livestock contributes to habitat fragmentation, reduces the connectivity between forest environments and species that depend on this habitat, and reduces landscape permeability. This means that it also affects functional connectivity, increases resistance factors for foraging activities, movement, and reproductive behavior, and can alter predation rates, to name a few ecological processes that are critical for wildlife (Forero-Medina; Vieira, 2007). The alteration of native land cover for anthropogenic purposes also has negative impacts on the physical environment, such as soil compaction, increased erosion processes, and soil and water pollution (Wust; Tagliani; Concato *et al.,* 2015).

Table 2 - Metrics of the study area in the region of Mata do Limoeiro State Park. CA: Total class area (hectare); NP: Number of Patches; AREA_MN: Average area of the patches; SHAPE_AM: Average shape weighted to patch size; ENN_MN: Distance to the nearest neighbor index; SHDI: Shannon diversity index

Limits	**Potential areas**	**CA**	**NP**	**AREA_AM**	**SHAPE_AM**	**ENN_MN**	**SHDI**
INNER	Environments with anthropic potential	23.08	150	3.0984	4.9581	42.1094	0.4292
	Areas of importance for sustainable management	242.14	56	22.7579	2.0316	90.9504	
	Landscapes important for biodiversity conservation	1743.62	5	1738.9849	5.6734	85.5672	
OUTER	Environments with anthropic potential	46.58	84	2.3006	3.0922	55.0245	0.8102
	Areas of importance for sustainable management	722.61	46	107.7736	3.9153	49.4778	
	Landscapes important for biodiversity conservation	513.75	63	54.9807	3.0721	68.5278	

Source: The authors.

Conventional land management is one of the primary drivers of global climate change. It contributes to the release of greenhouse gases, changes in natural nutrient cycles, and water problems, thereby affecting ecosystem services (Declerk *et al*., 2016). It is of the utmost importance to raise awareness and educate regional stakeholders on the possibilities of sustainable agricultural systems with lower impacts.

To enable relevant and reliable ecosystem restoration, regional actors must be involved in the conservation process with a collective construction of knowledge (Metzger *et al.,* 2017). The park is highly regarded for its environmental education potential for local communities and tourists and is nationally recognized for its projects and activities (Oliveira L. *et. al*., 2021). Environmental education initiatives developed at PEML are a valuable strategy for the inclusion and promotion of teaching-learning opportunities related to sustainable ecotourism. These benefits collectively contribute to the success of the park in its conservation efforts (Ferreira *et al*., 2015; Oliveira *et al*., 2018; Oliveira A. *et al*., 2021).

There is environmental pressure in the agricultural context in the natural landscape of the park. In the last dry season (August 2022), a fire of large proportions originated from the northern region of the park, starting in rural properties located on the margins of the PEML, where grazing activities are conducted. The heat map demonstrates that the location where the fire occurred was a region with a high density of conventional land management classes. It is evident that there is a need for conscious and sustainable management in the region, as these areas are associated with negative pressures on the park.

Fragments of natural seasonal semi-deciduous forests (SDSF), which cover large areas of the park, are one of the most threatened forest types in the Atlantic Forest. They occur mainly because of anthropogenic pressures, such as agriculture and human settlement, with most of the remaining preserved fragments located in conservation units (Dexter *et al*., 2018; Silva, 2020). These forested environments are capable of biocenosis, generating habitats for wild species, and ensuring their reproduction, thus contributing significantly to local biodiversity. These environments are present in the areas of “Landscapes important for biodiversity.” If conducted in a responsible manner, ecotourism practices in these forest regions can be an effective tool for the conservation of fragile environments (Zoysa, 2021). The region of this area has global ecological importance, as it is situated in an ecotone area between two biomes that are global biodiversity hotspots (Myers *et al*., 2000, Conservation International, 2023). Most of the identified SDSFs are in intermediate to advanced stages of natural regeneration and are therefore legally protected by Brazilian legislation (Law 12.651/2012; Brasil, 2012). A notable feature is the role of protecting water bodies, which is carried out by riparian and gallery forests that border rivers and other watercourses. The connection between these formations in the landscape ensures water quality, an ecosystem service that, together with conservation practices, contributes to the maintenance of soil nutrients and reduction of erosion (Duarte; Ribeiro; Paglia, 2016). In the Ipoema region, livestock management and the lack of spring protection have a negative impact on water quality, despite the areas protected by the park (Ferreira *et al*., 2018). In addition, environmental education activities in the region promote low-impact practices in the community as well as public policies for basic sanitation.

Regarding the benefits of promoting the conservation of habitats for endemic species, the Mata do Limoeiro State Park region shelters relevant fauna and flora for conservation, including species on the Red List of animals at risk of extinction (IEF, 2013). Thus, guaranteeing the preservation of these environments would promote the conservation of endangered species. The PEML protects a rich ecosystem in an ecotone region in the transition between the Atlantic Forest and Cerrado biomes.

We propose a preservation scenario for 80% of environments with potential for the management and protection of wildlife. If we consider this same proportion for all 409 Brazilian parks (UNEP-WCMC & IUCN, 2021), as presented for PEML, out of the 36,437.750 hectares, approximately 29,150,200 hectares would be preserved. This represents about 3.2% of the Brazilian territory as an important area for biodiversity. If other parks within the Atlantic Forest were to have 80% of their land protected like PEML, it would total approximately 1,871,096 hectares of preserved biome fragments (UNEP-WCMC & IUCN, 2021).

The land use evaluation of the Itacolomi State Park (ISP) in Minas Gerais (Fujaco, Leite and Messias, 2010) provides interesting results for comparison with the PEML scenario. Natural features in the ISP, after almost 30 years of conservation, have extended to 92% of its territory. For PEML, implemented approximately eight years ago, these environments cover 80% of its territory. According to the authors, the results of the research show that the simple creation of Conservation Units (CU) is not enough to preserve natural resources, as effective action by public authorities is required. The authors pointed out that the increase in natural areas is a consequence of conservationist activities. Nevertheless, activities aimed at implementing a management plan focused on the conservation and protection of areas with the community around the park compose a strategy that brings positive results for the preservation of ecosystems. Aligned with educational plans for schools and environmental education, it integrates the community with the park and raises awareness of respecting and valuing this precious natural asset (Fujaco; Leite; Messias, 2010).

Management Challenges

The conservation unit must not be seen as an island but as part of the system that it comprises. The challenges in managing this park include socio-environmental issues, pressure from adjacent areas, and the local culture of traditional land use. It is necessary to establish a scenario for local community governance to address these issues.

Quantifying and analyzing the landscape around this CU is critical for a holistic understanding of its reality. To promote efficient management, it is necessary to understand the relationships between anthropic activities and conservation units. The success of conservation actions, participation of local communities, support of community leaders, and public policies that support environmental guidelines are essential. Therefore, positive impacts go beyond the local environmental sphere. As social agendas are intrinsically related, these initiatives contribute to achieving the goal of climate justice worldwide (Erbaugh *et al.*, 2020).

Collaborative governance of a conservation unit implies the representation of local communities in decision making (Eklund; Kabeza, 2017). Consequently, areas characterized by an anthropic context should be considered a priority for environmental awareness and education activities to consolidate support and a sense of belonging, as well as to foster new environmental actors and increase the engagement of the local community.

Local communities are responsible for monitoring sustainable management areas because of conservation pressures that prioritize actions in hotter areas on the heat map. These activities also influence negative pressures on the park, such as fires, in areas that require alternative sustainable management practices for livestock exploitation in the region.

Areas in need of recovery and restoration practices were identified in the park and surrounding regions. They must be protected to ensure ecosystem services and sustainable development in the region, areas with potential for actions regarding environmental education activities, and key areas for conservation and preservation.

The characterization and mapping of the functional units of the PEML, including their sizes and geospatial dispositions, provides relevant data for the park’s management team. They can be used to update their Management Plans and identify opportunities and sensitivities of the CU. The use of the map for environmental education and awareness of the importance and ecological significance of CUs for biodiversity contributes to maintaining the integrity of the physical environment and climate.

The park’s Management Plan, with periodic revisions and incorporation of new data, must be constantly updated to support strategic actions in the management of the Conservation Unit (Santos, 2016). In the case of PEML, the plan was prepared in 2014 with a large amount of information about the region during the creation and implementation of the park. However, a gap exists in the current CU context. Some progress has been made in dealing with degraded areas, showing signs of regeneration in certain regions; however, accurately measuring this is a challenge for future studies.

This research can also be directed towards the application of geodiversity to conservation, with landscape assessment studies on physical characteristics and anthropic impacts. This would allow us to understand geo-environments and their vulnerabilities within the conservation unit (Dias *et al*., 2002, Batista; Santos; Santos, 2009). The understanding of geodiversity allows the assessment of these sensitive areas in an alternative manner and the proposal of different forms of management and influence.

The park is a powerful instrument for the conservation and implementation of national environmental policies (Liz Carneiro, 2021). The results of this conservation unit create effects not only for the surrounding communities but also for its volunteers and researchers, and guarantee ecosystem benefits for future generations.

CONCLUSIONS

To increase the efficiency of conservation area management, it is necessary to consider the landscape in which it is located. The results of this study demonstrate that the internal landscape of the park effectively fulfills its conservation role and guarantees several ecosystem services. However, there is constant pressure from anthropogenic activities that occur in the region adjacent to the park. By combining sustainable management practices, environmental education, and the motivation of local agents, aligning them with the objectives of the park results in greater efficiency in the management of protected areas. This guarantees the benefits of conservation.

The concept of ecosystem services and how they are maintained through conservation efforts may not be well understood or recognized by local communities. Therefore, the importance of environmental awareness and educational activities for the local population and tourists through community-based ecotourism is emphasized.

The generated heat map shows priority areas for management and provides support for the planning and management of the different functional units of the landscape that make up the study area. This understanding is crucial for the proper management and development of conservation measures.

The issue of ecosystem services must be explained to the target audience to understand how the local population benefits from the conservation of natural resources. The development of community governance to benefit the environment enables efficient management in the region outside the park, not only within the boundaries of the conservation unit. This methodology could also be applied to other conservation units.

To extend this research in the area, we suggest expanding the scope of analysis to include additional conservation units, such as a mosaic system or a biosphere reserve.

An integrated assessment of the spatiotemporal dynamics of the landscape is a compelling way to assess and quantify the efficiency of park management in recent years. Research on the development of local governance and public policies that enable alternative management strategies in this landscape context is highly valuable. In conclusion, we expect that these results will contribute to the development of better management practices in Mata do Limoeiro State Park, enabling it to achieve the objectives proposed when it was created.

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REFERENCES

BARONA, E.; RAMANKUTTY, N.; HYMAN, G.; COOMES, O. T. The role of pasture and soybean in deforestation of the Brazilian Amazon. **Environmental Research Letters**, 2010. v. 5. (2). https://doi.org/10.1088/1748-9326/5/2/024002

BATISTA, E. R.; SANTOS, R. F. D.; SANTOS, M. A. D. Construção e análise de cenários de paisagem em área do Parque nacional da serra da Bocaina. **Revista Árvore**, v. 33 p. 1095-1108. 2009. https://doi.org/10.1590/S0100-67622009000600012

BEDÊ, L. C. et al. Manual para mapeamento de biótopos no Brasil: base para um planejamento ambiental eficiente. 2. ed. Ver. **Belo Horizonte, Fundação Alexander Brandt** 1997. 146 p.

BRASIL. Lei n. 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis nos 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis nos 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória no 2.166-67, de 24 de agosto de 2001; e dá outras providências. 2012. **Diário Oficial da União, Brasília**, **DF**, Ano CXLIX, n. 102, 28 maio 2012. Seção 1, p.1. Disponível em <http://portal.in.gov.br/>Acesso em 10 março de 2013.

CÂNDIDO, C. C. et al. Análise da sustentabilidade na produção familiar: Caso dos produtores de hortifrutigranjeiros da associação Ecovárzea - PB. In: santo, G. A.; LIRA, W. S. (Orgs.). Indicadores de Sustentabilidade para Agroecossistemas: Aplicações em diversos tipos de cultivo e práticas agrícolas no estado da Paraíba. Campina Grande: **EDUEPB**,394p. 205-238. 2016.

CÂNDIDO, C. C. et al. Análise da sustentabilidade na produção familiar: Caso dos produtores de hortifrutigranjeiros da associação Ecovárzea - PB. **EDUEPB**, 2016. p. 205-238.

CARDOZO, F. Da S. et al. Analysis and assessment of the spatial and temporal distribution of burned areas in the Amazon forest. **Remote Sensing**, v. 6, n. 9, p. 8002-8025, 2014. https://doi.org/10.3390/rs6098002

CDB, Convenção sobre Diversidade Biológica. **O Plano Estratégico para a Biodiversidade 2011-2020 e as Metas de Biodiversidade de Aichi**. Documento UNEP/CBD/COP/DEC/X/2, (outubro de 2010), 113. 2010. doi: https://doi.org/10.1111/cobi.12383

CONSERVAÇÃO INTERNACIONAL. Hotspots de Biodiversidade - **Conservation International**. 2023. https://www.conservation.org/priorities/biodiversity-hotspots Acesso em 17 abr. 2023.

DECLERCK, F. et al. Ecossistemas agrícolas e seus serviços: a vanguarda da sustentabilidade? **Opinião Atual em Sustentabilidade Ambiental**, v. 23, p. 92–99, 2016.

DEXTER, K. G et al. Inserting Tropical Dry Forests into the discussion on Biome Transitions in the Tropics. **Frontiers in Ecology and Evolution**. v. 6, n. 104, 2018. https://doi.org/10.3389/fevo.2018.00104

DIAS, H. C. T et al. Geoambientes do parque estadual do Ibitipoca, município de Lima Duarte-MG**. Revista Árvore**, 26, 777-786. 2002. https://doi.org/10.1590/S0100-67622002000600014

DUARTE, G. T. Os serviços das paisagens: uma abordagem teórica e aplicada para planejamento visando múltiplos benefícios. Dissertação (Ecologia, Conservação e Manejo da Vida Silvestre). – Belo Horizonte – UFMG. 2018.

DUARTE, G. T.; RIBEIRO, M. C; PAGLIA, A. P. Modelagem de serviços ecossistêmicos como ferramenta para definição Prioridade Áreas de Conservação. **PLOS UM**, v. 11, n. 5, 2016.

DUARTE, G. T.; RIBEIRO, M. C; PAGLIA, A. P. Modelagem de serviços ecossistêmicos como ferramenta para definição Prioridade Áreas de Conservação. **PLOS UM**, v. 11, n. 5, 2016.

EKLUND, J.; CABEZA, M. Qualidade da governança e eficácia das áreas protegidas: conceitos cruciais para o planejamento da conservação. **Anais da Academia de Ciências de Nova York**, 1399(1), 27–41. 2016. https://doi.org/10.1111/nyas.13284

ERBAUGH, J. T. et al. Global Forest restoration and the importance of prioritizing local communities. **Nature Ecology & Evolution**, v. 4, 1472–1476. 2020. https://doi.org/10.1038/s41559-020-01282-2

FERREIRA, I. F. M. et al. Determinação da capacidade suporte de trilhas do Parque Estadual Mata do Limoeiro, Itabira (MG), Brasil. **Nature and Conservation**, v.9, n.1, p.13-26, 2012. http://doi.org/10.6008/SPC2318-2881.2016.001.0002

FERREIRA, R. P. S. et al. Caracterização da qualidade da água dos afluentes do Córrego Macuco, distrito de Ipoema, Itabira (MG). **Research, Society and Development**, v. 7. 2018. https://doi.org/10.17648/rsd-v7i6.234

FORERO-MEDINA, G.; VIEIRA, M. Conectividade funcional e a importância da interação organismo-paisagem. **Oecologia Brasiliensis**, v. 11, (4), p. 493-502. 2007. https://doi.org/11.10.4257/oeco.2007.1104.03.

FORERO-MEDINA, G.; VIEIRA, M. Conectividade funcional e a importância da interação organismo-paisagem. **Oecologia Brasiliensis**, v. 11, (4) 2007, p. 493-502. https://doi.org/11.10.4257/oeco.2007.1104.03.

FRANK S. et al. A contribution towards a transfer of the ecosystem service concept to landscape planning using landscape metrics. **Ecological Indicators** v. 21. p. 30–38. https://doi.org/10.1016/j.ecolind.2011.04.027

FUJACO, M. A. G.; LEITE, M.G.P.; MESSIAS, M. C. T. B. Análise multitemporal das mudanças no uso e ocupação do Parque Estadual do Itacolomi (MG) através de técnicas de geoprocessamento. **Revista Escola de Minas**, v. 63, p. 695-701, 2010.

GAMBARINI, A. Zero deforestation and conversion are critical to a credible 1.5°C **PATHWAY**. p. 5. 2022.

GAMBARINI, A. Zero deforestation and conversion are critical to a credible 1.5°C PATHWAY. p. 5. 2012.

GOODWIN, B. J.; FAHRIG, L. Como a estrutura da paisagem influencia a conectividade da paisagem? **Oikos**, v. 99, n. 3, pág. 552–570, 2002.

HODDER K. H. et al. O manejo da conservação em escala de paisagem melhora a provisão de serviços ecossistêmicos? **Int J Biodivers ciência Ecossistema servir** v.10 p. 71–83. 2014 https://doi.org/10.1080/21513732.2014.883430

IBGE – Instituto Brasileiro de Geografia e Estatística. **Base Cartográfica Contínua do Brasil: versão 2021. Rio de Janeiro**: IBGE, 2021. Disponível em: https://www.ibge.gov.br/geociencias/downloads-geociencias.html?caminho=cartas_e_mapas/bases_cartograficas_continuas/bc250/versao2021/ . Acesso em: 15 mar. 2024.

IEF (Instituto Estadual de Florestas de Minas Gerais)**. Base de Dados Geoespaciais de Unidades de Conservação - IEF**. Belo Horizonte: IEF, 2020. Disponível em: [https://liferay.meioambiente.mg.gov.br/web/ief/w/base-de-dados-geoespaciais-de-unidades-de-conservacao-]. Acesso em: 15 mar. 2024.

IEF (Instituto Estadual de Florestas de Minas Gerais). **Plano de manejo do Parque Estadual Mata do Limoeiro / Bicho do Mato Meio Ambiente**. 2013. Minas Gerais. t. 1, v. 1. 292 p.: il. Disponível em http://biblioteca.meioambiente.mg.gov.br/publicacoes/BD/Encarte%201%20-%20An%c3%a1lise%20geoambienta%20Limoeirol.pdf. Acesso em 12 de fevereiro 2022.

LIZ CARNEIRO, S. Parque Estadual Mata do Limoeiro como política pública. Dissertação (Mestrado em Estado, Governo e Políticas públicas) 2021.

Mawdsley J. R.; O'Malley, R. D.; Ojima S. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation**. Conservation**. **Biology**. V. 23, p. 1080–1089 2009. https://doi.org/10.1111/j.1523-1739.2009.01264.x

METZGER, J. P. et al. Best practice for the use of scenarios for restoration planning. Current **Opinion in Environmental Sustainability**, v. 29, p. 14–25. 2017.

MYERS, N. et al. Biodiversity hotspots for conservation priorities. **Nature**, v. 403(6772), p. 853–858. 2000. https://doi.org/10.1038/35002501

OLIVEIRA, A. L. A. et al. Inovação em Educação Ambiental: um estudo de caso sobre a trilha dos sentidos do Parque Estadual Mata do Limoeiro**. Revista Brasileira De Educação Ambiental.** v. 16(3) p. 429–438. 2021. https://doi.org/10.34024/revbea. 2021

OLIVEIRA, A. L. A. et al. Inovação em Educação Ambiental: um estudo de caso sobre a trilha dos sentidos do Parque Estadual Mata do Limoeiro**. Revista Brasileira De Educação Ambiental.** v. 16(3) p. 429–438. 2021. https://doi.org/10.34024/revbea. 2021

OLIVEIRA, L. F. D. (2022). Análise de paisagem como subsídio para avaliação ambiental de unidades de conservação estaduais em Minas Gerais (Trabalho de conclusão de curso). Centro Federal de Educação Tecnológica de Minas Gerais. Disponível em: https://www.eng-ambiental.bh.cefetmg.br/wp-content/uploads/sites/187/2022/04/Luiz-Fernando-Analise_de_Paisagem-OLIVEIRA_LFD_2022-VF.pdf**.** Acesso em: 15 mar. 2024.

OLIVEIRA, A.C. et al. Estudo da capacidade de carga em trilha no Parque Estadual da Mata do Limoeiro, Itabira (MG). **Revista Brasileira de Ecoturismo** v.10 p.789-804. 2018.

OLIVEIRA, L. F. D. et al. Percepção sobre uso dos recursos hídricos e saneamento nas comunidades do entorno do Parque Estadual Mata do Limoeiro, Itabira/MG. **Anais eletrônicos do 31º CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL - SANEAMENTO RURAL. ABES**. v 31º, 578. 2021.

OLIVEIRA, L. F. D. et al. Percepção sobre uso dos recursos hídricos e saneamento nas comunidades do entorno do Parque Estadual Mata do Limoeiro, Itabira/MG. **ANAIS DO CONGRESSO. XII - Saneamento Rural.** 2021. p. 1-10.

ONU, Organização das Nações Unidas**. Objetivos de Desenvolvimento Sustentável**. 2012. Disponível em: https://brasil.un.org/pt-br/sdgs. Acesso em: 20 jul. 2021.

SAIDI, N.; SPRAY, C. Ecosystem services bundles: challenges and opportunities for implementation and further research**. Environmental Research Letters**, v. 13, n. 11, p. 113 2018.

SANTOS, N. B. Efetividade dos planos de manejo na gestão de parques estaduais de Minas Gerais. Dissertação (Mestrado em Ecologia, Conservação e Manejo da Vida Silvestre) – Belo Horizonte – UFMG. 2016.

SANTOS, N. B. Efetividade dos planos de manejo na gestão de parques estaduais de Minas Gerais. **Dissertação de Mestrado em Ecologia, Conservação e Manejo da Vida Silvestre. Universidade Federal de Minas Gerais - UFMG.** Belo Horizonte. 2016.

SILVA, L. S. Diversidade florísca, filogenéca e estrutura em fragmentos de florestas estacionais semideciduais no Espinhaço Meridional. Dissertação (Doutorado em Ciência Florestal) – Diamantina - UFVJM 2020.

TURNER M. G. (2005) Landscape ecology: what is the state of the science? Annual Review of Ecology, Evolution, and Systematics. V. 36 p. 319–44. https://doi.org/10.1146/annurev.ecolsys.36.102003.152614

Turner MG (2005) Landscape ecology: what is the state of the science? Annual Review of Ecology, Evolution, and Systematics. V. 36 p. 319–44. https://doi.org/10.1146/annurev.ecolsys.36.102003.152614

UNEP-WCMC & IUCN (2021) Protected Planet Report 2020. **UNEP-WCMC and IUCN:** Cambridge UK; Gland, Switzerland.

UNESCO. Espinhaço Range Biosphere Reserve, Brazil. 2009. Disponível em: https://en.unesco.org/biosphere/lac/espinhaco. Acesso em: 26 jul. 2021

WATSON J. E. M. et al. The performance and potential of protected areas. **Nature**. v. 515, p. 67–73. 2014. https://doi.org/10.1038/nature13947

WEBER, M. Mapeamento ambiental integrado: práticas em ecologia da paisagem**.** Markus Weber. 1 ed. – Curitiba: **Appris**, 2019. 119 p.

WÜST, C. et al. A pecuária e sua influência impactante ao meio ambiente. CONGRESSO BRASILEIRO DE GESTÃO AMBIENTAL. p. 1-5. 2015

ZOYSA, M. D. Forest-Based Ecotourism in Sri Lanka: A Review on State of Governance, Livelihoods, and Forest Conservation Outcomes**. Journal of Sustainable Forestry**. 2014. doi:10.1080/10549811.2021.1943450

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