

Urban Expansion and the Provisioning of Ecosystem Services in Nova Serrana, Minas Gerais, Brazil

Expansão urbana e o fornecimento de serviços ecossistêmicos em Nova Serrana, Minas Gerais, Brasil

Expansión urbana y prestación de servicios ecosistémicos en Nova Serrana, Minas Gerais, Brasil

L'expansion urbaine et les services écosystémiques rendus à Nova Serrana, Minas Gerais, Brésil

Charles Fonseca 

Universidade Federal de Minas Gerais
charlesof@ufmg.br

Carlos Lobo 

Universidade Federal de Minas Gerais
carloslobo@ufmg.br

Sônia Maria Carvalho Ribeiro 

Universidade Federal de Minas Gerais
soniacarvalhoribeiro@cart.igc.ufmg.br

Rodrigo Leitão 

Universidade Federal de Minas Gerais
rodrigonz7@ufmg.br

ABSTRACT

Fragments of native vegetation within the landscape play a crucial role in providing ecosystem services (ES). Ecosystem services have become increasingly important in recent years, particularly in response to recurrent land use changes. This article aims to identify and analyze the impacts of urban expansion in Nova Serrana, MG, Brazil, on the provision of local ecosystem services. Landscape metrics were used to quantify changes in spatial composition and to comprehend the outcomes of processes that occurred over 15 years. Our results indicate a loss of 781 hectares of natural vegetation patches (including forests and savannah), mainly attributed to the expansion of urban areas. Furthermore, field campaigns revealed additional environmental issues not apparent in satellite images, such as local flooding, loss of springs, and air pollution from shoe factories. These issues are all consequences of the degradation of ecosystem services.

KEYWORDS: environmental losses; landscape metrics; urbanization.

RESUMO

Os serviços ecossistêmicos têm se tornado cada vez mais importantes nos últimos anos, principalmente em resposta às recorrentes mudanças no uso do solo, onde os fragmentos de vegetação nativa inseridos na paisagem desempenham um papel crucial na provisão de tais serviços. Este artigo tem como objetivo identificar e analisar os impactos da expansão urbana no município de Nova Serrana, MG, Brasil, sobre a provisão de serviços ecossistêmicos locais. Foram utilizadas métricas da paisagem para quantificar as mudanças na composição espacial e compreender os resultados dos processos ocorridos ao longo de um período de 15 anos. Nossos resultados mostram que houve uma perda de 781 hectares de manchas de vegetação natural (incluindo florestas e cerrado), principalmente devido à expansão das áreas urbanas. Além disso, as campanhas de campo revelaram outros problemas ambientais, não aparentes nas imagens de satélite, como inundações locais, perda de nascentes e poluição do ar por fábricas de calçado, todos eles consequências da degradação dos serviços ecossistêmicos.

PALAVRAS-CHAVE: perdas ambientais; métricas da paisagem; urbanização.

RESUMEN

Los servicios ecosistémicos han adquirido una importancia creciente en los últimos años, especialmente en respuesta a los recurrentes cambios en el uso del suelo, donde los fragmentos de vegetación nativa dentro del paisaje desempeñan un papel crucial en la provisión de dichos servicios. Este artículo pretende identificar y analizar los impactos de la expansión urbana en el municipio de Nova Serrana, MG, Brasil, sobre la provisión de servicios ecosistémicos locales. Se emplearon métricas del paisaje para cuantificar los cambios en la composición espacial y comprender los resultados de los procesos ocurridos durante un período de 15 años. Nuestros resultados muestran que hubo una pérdida de 781 hectáreas de parches de vegetación natural (incluidos bosques y sabanas), principalmente debido a la expansión de las zonas urbanas. Además, las campañas de campo revelaron problemas medioambientales adicionales, no evidentes en las imágenes de satélite, como inundaciones locales, pérdida de mananciales y contaminación atmosférica por fábricas de calzado, todas ellas consecuencias de la degradación de los servicios ecosistémicos.

PALABRAS-CLAVE: pérdidas ambientales; métrica del paisaje; urbanización.

RÉSUMÉ

Les services écosystémiques sont devenus de plus en plus importants ces dernières années, en particulier en réponse aux changements récurrents d'utilisation des terres, où les fragments de végétation autochtone dans le paysage jouent un rôle crucial dans le rendu de ces services. Cet article vise à identifier et à analyser les impacts de l'expansion urbaine dans la municipalité de Nova Serrana, MG, Brésil, sur les rendus des services écosystémiques locaux. Des mesures paysagères ont été utilisées pour quantifier les changements dans la composition spatiale et pour comprendre les résultats des processus qui se sont déroulés sur une période de 15 ans. Nos résultats montrent qu'il y a eu une perte de 781 hectares de parcelles de végétation naturelle (y compris des forêts et des savanes), principalement en raison de l'expansion des zones urbaines. En outre, les campagnes de terrain ont révélé d'autres problèmes environnementaux, non visibles sur les images satellite, tels que les inondations locales, la disparition des sources et la pollution de l'air par les usines de chaussures, qui sont tous des causes de la dégradation des services écosystémiques.

MOTS-CLÉS : pertes environnementales ; mesures du paysage ; urbanisation.

INTRODUCTION

Rapid population growth and unplanned urbanization processes pose significant challenges to the environment. As cities expand to accommodate growing populations, natural landscapes are often transformed into urban areas, resulting in the loss of vital ecosystems and biodiversity. The conversion of land for residential, commercial, and industrial purposes leads to deforestation, habitat destruction, and fragmentation, ultimately threatening the stability of local ecosystems.

In 2024, the world population reached 8 billion inhabitants, 54% of whom live in urban areas, with a projected growth of 9 billion by 2037 (UN, 2024). In recent decades, the decline in mortality rates in peripheral countries like Brazil has led to a rise in the population residing in and around metropolises (LOBO, 2016), causing environmental degradation (O'SULLIVAN, 2020), which directly impacts the quality of life of the residents (MARTINE et al., 2010). Environmental degradation has also contributed to the weakening of human interrelationships, as these are socio-cultural processes directly influenced by the environment (RIBEIRO et al., 2015).

Urbanization is perhaps one of the most obvious points of tension in the relationships between humans and nature. Urban landscapes bring together the consensuses and contradictions of modern society, which tend to cross political boundaries, in addition to hegemonic dichotomies, such as the relationship between rural and urban (OJIMA, 2007).

The effects of urbanization have not been restricted to the metropolises and their immediate peripheries. It has also affected regional centers and medium-sized cities, which have become important destinations for migration due to industrial facilities and, consequently, job opportunities (MOULIN, 2010).

The landscape consists of a diverse mosaic of land uses with specific compositions and configurations. Through interactions across space and time, these land uses influence spatial processes (landscape functions) that are linked to the provision of Ecosystem Services (ES). ES are benefits derived from ecosystems to maintain and improve people's quality of life (ANDRADE & ROMEIRO, 2009). Land use is associated with the provision of ecosystem services. Therefore, land use change and ES feature prominently in discussions on land-use planning, especially in landscape ecology. Landscape ecology assesses physical components and energy flows, examining spatial changes and is highly transdisciplinary (METZGER, 2001). Landscape ecology also considers the socio-cultural contexts that are integral to landscapes

(Carvalho-Ribeiro et al., 2018; Hinata et al., 2020). Ecosystem services are the result of complex arrangements provided by ecosystems for the well-being of humans (BURKHARD et al., 2009; DE GROOT, 1992; MA, 2003; MA, 2005; UUEMAA et al., 2013).

ES are often categorized as regulation, provision, cultural, and support (COSTANZA et al., 2017; MA, 2003). However, the relationship between ecosystem composition (different land uses) and ecosystem services is not simple. The benefits derived from ecosystem services are part of natural capital, which comprises the stocks that originate from nature, such as native vegetation, water reserves, nutrients in the soil, and biodiversity. In the market's evolutionary process, the availability of natural capital directly influences the development and improvement of new products. To meet market demand, including food production, natural resources have become essential elements that need to be increased (COSTANZA, 2000).

Regulatory services are connected to ecosystem functions such as water and air quality, climate regulation, soil stability, and disease control, among others. Provision is facilitated by natural resources, which allow water to infiltrate and percolate, or semi-natural resources, such as agriculture. Provisioning services encompass more than just food items; they also include sources of energy such as minerals, coal, firewood, and access to water. Cultural services predominantly include non-material values attributed to contemplating and learning about the landscape, as well as spiritual and aesthetic values. The interpretation of a landscape is inherent to the group that utilizes it (CARVALHO-RIBEIRO et al., 2018). Support services act as the link between the other categories. They have an indirect, long-term influence on humans (MA, 2003; ANDRADE & ROMEIRO, 2009).

The assessment of landscape composition becomes a valuable measure for understanding changes in spatial configuration over time. (PEREIRA et al., 2013; RIITTERS, 2019).

Landscape metrics are tools that help study the relationship between land uses and their patterns (LAUSCH; HERZOG, 2002; LIN et al., 2020; SOWIŃSKA-ŚWIERKOSZ; SOSZYŃSKI, 2014). Based on this understanding, it is possible to measure and examine the supply of ecosystem services, especially in areas where the landscape has been changing.

Landscape metrics can be used to quantify spatial components and analyze correlations that allow the quantification of gains and losses in land use classes such as native vegetation or agriculture (LANG et al., 2009). Metrics

describe the landscape using parameters such as area, shape, quantity, size of fragments or patches (parts of a land use class), distance, among others. The structural and functional recognition of metrics provides a basis for planning appropriate future actions for landscapes that exhibit fragility in the connectivity of the fragments within the matrix in which they are embedded (LANG et al., 2009; PEREIRA et al., 2013).

The municipality of Nova Serrana, located in the central west region of Minas Gerais, Brazil, is a typical example of the urbanization process resulting from the expansion of the industrial park. Economically, the municipality stands out in the footwear production sector, being one of the main regional and national hubs (FERREIRA et al., 2016; SANTOS et al., 2012; SUZIGAN et al., 2005). The concentration of companies in this sector has led to economic growth, generating direct and indirect jobs. This, in turn, has encouraged a significant influx of migrants to the municipality. Despite the positive economic scenario in 2015, the municipality lost 25% of its native vegetation (7,085 hectares out of the total area of the municipality) due to a low concentration of natural cover (Savannah and Atlantic Forest), caused by the substitution of native vegetation with anthropogenic land uses. Land use in Nova Serrana is defined as the utilization of land by humans and includes categories such as native vegetation, urban areas, industrial zones, pastures, and agricultural areas, among others.

Given this context and considering the dynamics of the municipality's landscapes, some questions arise: What are the consequences of urban expansion on the supply of ecosystem services in Nova Serrana? What measures could enhance the quality of ecosystem service provision for the local population, beyond the purely economic benefits associated with this expansion? The aim of this study is to identify and analyze the possible impacts of accelerated urbanization on ecosystem services in the municipality.

In order to find answers, it was necessary to take the following steps:

- Quantify and analyze changes in landscape structures and functions between 2000 and 2015 using landscape metrics.
- Identify the urban and rural impacts that have the greatest influence on the municipality.
- Describe and interpret the results of the landscape metrics within the conceptual framework of ecosystem services to comprehend their potential connections.

The study is relevant because it utilizes landscape metrics to reveal indicators of recurring socio-environmental problems and can be applied in various

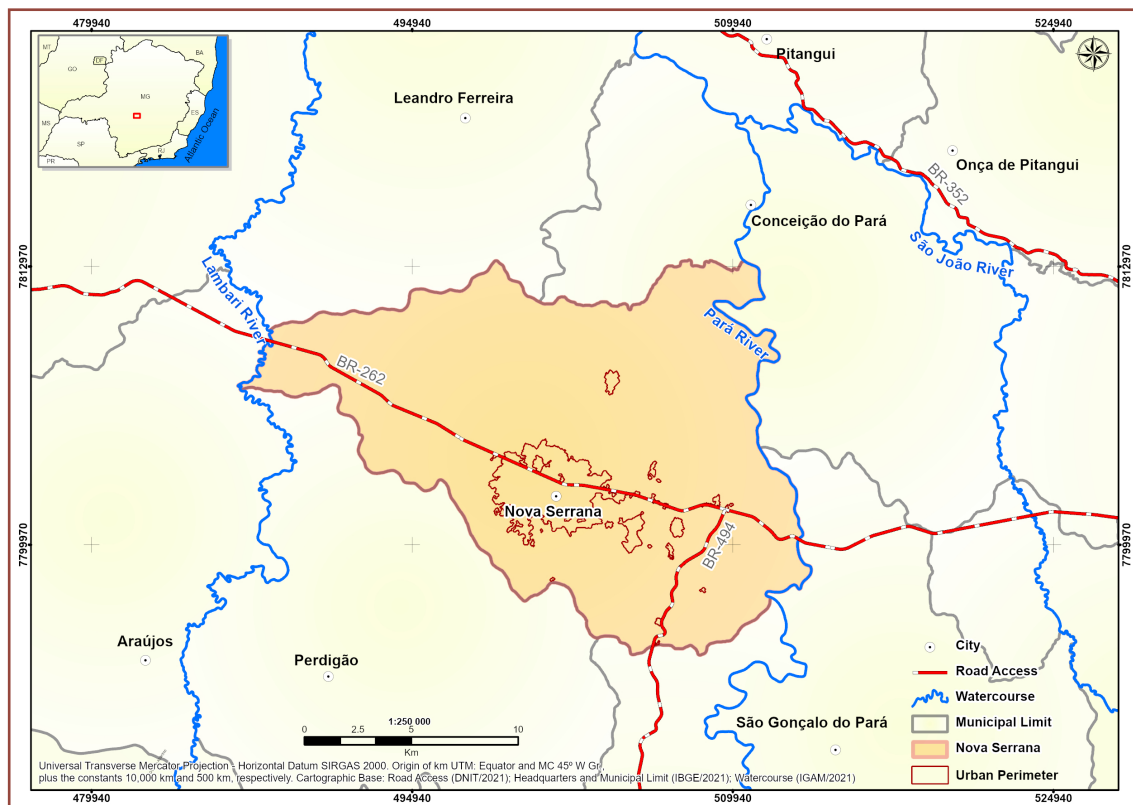
municipalities across the country. The work quantifies the accelerated process of urbanization and highlights potential public actions to mitigate its effects. In the academic field, we aim to invest in identifying ecosystem services and advancing complementary methodologies to understand environmental dynamics in a territory where urbanization is a prominent phenomenon.

METHODOLOGY

Case study: Characterization of Nova Serrana

The municipality of Nova Serrana, with a total area of 282.472 km² (IBGE, 2020), is located in the mesoregion of western Minas Gerais (refer to Figure 1), southwest of the state capital.

Figure 1 - Location of the municipality of Nova Serrana, Minas Gerais



The main road access to the municipality is via Federal Highway 262, which connects the Triângulo Mineiro to the Belo Horizonte Metropolitan Region. Federal Highway 494 also connects the municipality to Divinópolis, the main urban center of the region. The municipal boundaries are established to the east by the Paraíba River and to the west by the Lambari River (see Figure 1), both tributaries of the São Francisco River. Nova Serrana's urban layout de-

veloped along the banks of the Fartura stream, a tributary on the left bank of the Pará River, providing water to the municipality.

Nova Serrana is located in the Cerrado biome, and its original vegetation cover consists of scattered patches of forest (gallery forest, riparian forest, and cerradão) and grassland (campo sujo and campo limpo) phytophysiologicals (IBGE, 2020). The Fartura stream has an average altitude of 700 meters, and its valley is shaped by the hydrographic network and surrounded by slopes with an average altitude of 850 meters.

Natural forest formations have been lost, disregarding the legal distances established by Law (Law 4.771/1965; Law 12.651/2012), especially along the stream banks, which are now part of the urban landscape. Urban land uses in Nova Serrana have limited areas of vegetation. In conjunction with the sparse vegetation, an increase in the average temperature has been recorded in the central urban area. No actions were observed in the municipality regarding national or regional programs for the conservation, restoration, and cultural appreciation of the Cerrado. Programs such as Cerratinga, Floresta Mais, CEPF-Cerrado, Emporio do Cerrado, NCAVES, among others, are important for strengthening environmental, social, and cultural aspects (Bachi et al., 2023). On a local scale, there are also few actions for restoration or conservation, which may be hindered by the municipality's heated real estate market.

In terms of relief, the valley around the Fartura stream was shaped by dissection processes, with water flowing from northwest to southeast, following the difference in altitude, directing the tributary of the Pará River. It should be noted that the sub-basin also drains the slopes on both banks, where a significant portion of the urban area is situated. The sediment produced by water erosion has historically been carried to the Pará River and then to the São Francisco River. Currently, in addition to sediment, there is also a high load of total phosphorus, ammoniacal nitrogen, total suspended solids, *Escherichia coli*, surfactants, and turbidity from domestic and industrial sewage discharged into the river (OLIVEIRA et al., 2017), which influence the quality of water for human use and also create favorable environments for diseases. The excess of built-up area, not only on the banks of the stream but also in large parts of the sub-basin, considerably reduces the process of water infiltration. Surface runoff is intense during periods of rain. Associated with this issue, illegal urban settlements in streambeds are periodically impacted by flooding.

Nova Serrana History of occupation and growth

Before its emancipation in 1953, Nova Serrana was a small village where passing cattle drovers used to rest. During this period, residents began producing leather goods from local livestock (CROCCO et al., 2003). Livestock farming was the initial activity that led to changes in land use, as plant formations were replaced by pastures. Leather had established itself as a raw material for various productions. At this time, the first footwear was produced by local families (CROCCO et al., 2003).

In the 1980s, the municipality began transitioning from leather to synthetic raw materials for manufacturing sneakers. This shift in production led the city to emerge as the national hub for sports footwear (SANTOS et al., 2012). In 2010, Nova Serrana accounted for 50% of all footwear industries in Minas Gerais (FERREIRA et al., 2016). It currently has around 1,200 shoe industries, with an annual production of 105 million pairs and 44,000 people employed (SINDINOVA, 2020).

In the 1980s, Nova Serrana had a resident population of 9,266. In the 2010 Census, 73,699 people were registered. In 2020, the municipality reached 105,520 inhabitants, which represents an overall gross growth of 1,138% in 40 years (IBGE, 2020). Between the 15 years evaluated in the survey (2000 to 2015), the population increased from 37,000 inhabitants to 91,000, representing a growth of 246%. In relation to the municipal territory, this growth represents a high demographic density, nearly eight times that of the state record.

While Minas Gerais has an average population density of 33.42 inhabitants/km², Nova Serrana has 261 inhabitants/km² (IBGE, 2020), with the majority of the population consisting of migrants (SUZIGAN et al., 2005). The municipality has a higher per capita income than the state average. In Minas Gerais, the average is 1.3 minimum wages per formal worker, while Nova Serrana reaches around 1.7 minimum wages (IBGE, 2020). The availability of jobs and competitive incomes, among other attractions, such as the search for socio-environmental amenities (desire for greater integration with nature, less expectation of violence, and less chaotic urban mobility), have led to a high migratory flow to the municipality. This influx increases local population growth due to the positive migratory balance effect.

Social perspectives on the composition of landscapes

Urban areas have often been considered the privileged locus of socio-environmental conflicts and contradictions, key to identifying patterns of land

use, occupation, and production/appropriation of space. Urban space is often perceived as distinct from rural space, not only as a particular geographical and ecological entity but also as a component of the social division of labor and the productive activities conducted within it. However, the various “urban ideologies,” carried out for generations, did not allow us to grasp the essence of urban life by normalizing the processes of occupation and exclusion of certain social groups (CASTELLS, 1975), interpreting them as almost natural and temporary phenomena. Souza (2018), for example, draws attention to the danger of separating the natural sciences from the social sciences. Analyzing the composition of a landscape without considering both aspects runs the risk of being incomplete and superficial, without gaining access to the real parameters that shape space. Harvey (1981) posits that, in the capitalist system, the built environment is produced to facilitate the movement of production, circulation, exchange, and consumption flows. This implies the development of physical material infrastructures to fulfill production requirements. In this sense, Nova Serrana’s urban architecture evolved over time and space, with the main goal being to create an urban landscape that was adaptable for industrial purposes.

The built environment represented an extension of the fixed capital of production into the urban space and was not essentially a social space. In this respect, Henri Lefebvre also made important contributions to understanding the meaning of socially produced urban space, which is the result of relations involved in the reproduction of everyday life. Based on the concept of the political economy of space, Lefebvre (2006) discusses the relationship between space and society. He suggests that analyses of urbanization should emphasize the process and integrate the political dimension of space into both theory and practice. Still on this aspect, as Carlos (2015) points out, the urban is essentially a spatial dimension of human action. Whatever it is, it is effectively realized through economic, social, cultural, and environmental processes. If we consider that the production of space is a condition, means, and product of social reproduction, we can construct the hypothesis that the accumulation of capital takes place through the reproduction of urban space (CARLOS, 2015).

According to Corrêa (1993), urban space is simultaneously fragmented, articulated, a social reflection, a social condition, a symbolic field, and a field of struggle. The socio-spatial organization of cities is materialized by the production, maintenance, and reproduction of land use patterns. According to the same author, urban space involves a variety of land uses juxtaposed to each

other, defining areas such as central, commercial, residential, industrial, and others. They translate into the spatial organization of the city, which is shaped by the actions of social agents with their own interests, strategies, and spatial practices, in a historically contradictory and conflicting process (CARLOS, 2015). Among the various manifestations of contradictions and conflicts arising from and associated with the process of production and appropriation of space, attention is drawn to those arising from the expansion of the so-called "urban fabric" and its contact with the surrounding "non-urban environment," which materialize on the fringes and peripheries, both metropolitan and in other large and medium-sized urban centers in the interior, as is the case in Nova Serrana. The municipality has a dense and complex urban fabric that is rapidly expanding through new subdivisions, necessitating a continuous redefinition of its urban perimeter. This urban expansion, when viewed from a physical perspective, reaches into areas traditionally classified as rural. In the case of Nova Serrana, this expansion is evident through the conversion of pasturelands, and to a lesser degree, forest formations and cerrado ecosystems.

Today, in several urban centers such as Nova Serrana, the expansion of the urban fabric is evident through manifestations of contradictions and conflicts that arise from the process of production and social appropriation of space. These contradictions and conflicts have become even more significant with the intensification of the urbanization process in the last decades of the previous century, which includes the acceleration of demographic growth and the concentration of population in expanding urban areas. Apart from the social and economic effects of the process of expanding urban space, which are not addressed in the empirical exercise presented in this work, attention is drawn to the impacts resulting from what Monte-Mor (2019) referred to as the extensive effects of urbanization on the environment. Using the concept of extensive urbanization, which also includes the effects of urbanization beyond the altered physical space, Monte-Mor (2019) emphasizes the importance of identifying distinct levels and forms of urban fabric expansion. This expansion often involves typical peripheral areas where vegetation cover is destroyed due to dense and incomplete occupation. Still, according to this author, in the same work on urban analysis, adopting an environmental perspective, the focus should be on conserving ecological conditions that are conducive to various communities, highlighting their connection to social and biological diversity. This work aims to utilize the concept of ecosystem services and landscape metrics to evaluate a dimension of the urbanization process.

Data collection and analysis

To understand the impact of urban sprawl on the supply of ecosystem services, two-time frames were selected for analysis: 2000 and 2015, a period marked by major population expansion. The additional population of 54,000 during the years of the study alone corresponds to 50% of the population in 2020. This is coupled with the spread of urban sprawl, which grew significantly, encompassing approximately 163% of the area in 2000.

The land use and vegetation cover databases, with a spatial resolution of 30 meters, Collection 5.0, made available by the MapBiomas Project (MAPBIOMAS, 2019), were used to assess urban development. The territorial area of Nova Serrana was delimited based on data from the municipalities of Minas Gerais, provided by the Brazilian Institute of Geography and Statistics (IBGE). The boundaries of the urban grid, forest fragments, and other land uses from Mapbiomas were compared with the mapping in the Municipal Master Plan (Complementary Law 36/2022). The free software QGIS Desktop 3.16.16 was used to process the rasters and vectors and create the respective maps and tables.

The analysis model used to understand the composition of the landscape was the Patch-Matrix-Corridor (PMM) because the municipality's territory exhibits significant changes in the landscape structure caused by human activities. These changes are recognized as hemerobia (LAUSCH et al., 2015) and provide a clear distinction between land use classes, which can be measured by landscape metrics. Two TIFF images (rasters - 2000 and 2015) were acquired and used as inputs to produce statistical parameters relevant to spatial structures and functions (MCGARIGAL et al., 2002). The software used to identify landscape structures (composition and configuration) was Fragstats, version 4.2. When analyzing the parameters for each cell, orthogonal and diagonal neighbors were considered. For each central pixel, the contacts with the other eight pixels surrounding it were taken into account. Statistically, this makes it possible to measure the spatial dependence between pixels, which in computer processing translates into a spatial autocorrelation metric (CÂMARA et al., 2004). The levels evaluated were fragment, class, and landscape, available in the Fragstats software. At each level, metrics were selected that were deemed relevant to the aim of the investigation (see Chart 1). Levels are the spatial divisions used for landscape analysis. Through them, it is possible to evaluate just one fragment separately (a forest fragment); in classes (a set of forest fragments in an area); or together in a landscape (a set of different fragments such as forest, pasture, and urban).

Chart 1 – Metrics used in the analysis

Nível	Métricas
Fragment	AREA – area of the fragment in hectares. PERIM – perimeter of the fragment in meters or kilometers;
Class	CA – area of the fragments of the class in hectares; PLAND – percentage of the landscape in the class; LPI – percentage of the landscape occupied by the largest fragment measured; TE – total edge of the fragments in the class; AREA_MN – average area of the fragments in the class; AREA_SD – standard deviation between the areas of the fragments in the class; SHAPE_MN – average shape index of the fragments in the class; SHAPE_SD – standard deviation of the shape of the fragments in the class; ENN_MN – average Euclidean distance of the nearest neighbor; ENN_SD – standard deviation of the Euclidean distance of the nearest neighbor; NP – number of fragments per class; PD – density of fragments in the class;
Landscape	AREA_MN – average area of the landscape; AREA_SD – standard deviation of landscape area SHAPE_MN – average shape index of landscape fragments; SHAPE_SD – standard deviation of landscape fragment shape; PR – landscape richness; PRD – landscape richness density; SHDI – Shannon diversity index.

Source: prepared by the authors.

To analyze land use and occupation using landscape metrics, it is necessary to consider certain elements, including the matrix, the patches or fragments, and the corridors. The matrix is the dominant entity that surrounds the patches and corridors, consisting of natural or man-made elements. Its main characteristics include occupying the largest relative area of the landscape, having a greater degree of connectivity with other elements, and exerting a direct influence on flows (LANG & BLASCHKE, 2009). In the case of Nova Serrana, the matrix can demonstrate impermeability characteristics and act as a barrier between forest fragments (Martensen, Pimentel, & Metzger, 2008). In the municipality, the landscape is dominated by vast areas of pasture, replacing natural formations, particularly the Cerrado.

The patches or fragments represent various land uses, including forest patches, urban patches, and agricultural patches. Patches are the smallest units of the landscape mosaic (LANG & BLASCHKE, 2009). In the case of

natural patches, when they are isolated, they significantly reduce their biogenic potential. Therefore, connections are essential for the dynamics between species.

Corridors are elongated portions of land use classes. During a matrix, they can enable connections or even segregation, depending on the context in which they are found (FORMAN & GODRON, 1986). For example, a corridor formed by species native to the region between forest patches can contribute to gene flow, thereby increasing the number of species. On the other hand, if the corridor is dominated by exotic species, such as a eucalyptus plantation, it may act as an obstacle for some species (SOWIŃSKA-ŚWIERKOSZ & SOSZYŃSKI, 2014; WANG et al., 2022).

Connectivity between patches and corridors is crucial for the survival of species and the maintenance of ecosystem services (MARTENSEN; PIMENTEL; METZGER, 2008; WANG et al., 2022). Fragmentation, on the other hand, is characterized by the breaking up of homogeneous formations into smaller areas (McGARIGAL, 2015). The process of segregation can lead to the isolation and even complete disappearance of a fragment due to the edge effect (WEI et al., 2022). The edge effect in forest patches is characterized by a decline in the number of species due to direct contact with the anthropized matrix. In other words, species at the edges are more affected than those located inside the patch.

The study of spatial organization began with metrics based on characteristics such as area, shape, connection, and diversity, which enabled us to comprehend the organization of the landscape. Each metric provides insights into the behavior of land uses over time. As a priority, the metrics should be examined together for adequate spatial consistency (BOTEQUILHA-LEITÃO; AHERN, 2002), as joint analysis enables a systemic coherence of the landscape (BOTEQUILHA-LEITÃO; AHERN, 2002; CARVALHO-RIBEIRO; LOVETT, 2009).

Area metrics provide information on the quantity of a specific land use within the landscape. They are crucial primarily for assessing the availability of resources. Shape metrics elucidate the relationship between a fragment and the external environment, such as the matrix or another fragment type. The shape is used to interpret the interference of edge effects. Connection metrics measure the permeability between fragments of the same species in the matrix. Finally, diversity metrics report the magnitude of the composition of the landscape structure. They show the degree of homogeneity and heterogeneity in a specific spatial area.

The selection of ecosystem services evaluated in the research was determined by the current spatial organization of the municipality, as many services are interconnected with the quality of structures and their ecological functions (BURKHARD et al., 2009; DUARTE et al., 2018; UUEMAA et al., 2013). Thus, we aimed to identify services that were significantly impaired in the municipality and their correlation with various land uses. Four categories of ecosystem services were defined by the Millennium Ecosystem Assessment (MA) of 2003 (Chart 2).

Chart 2 - Ecosystem services affected in Nova Serrana

Category	Damaged ecosystem services
Regulation	Microclimate Air quality Rainwater quality Disease control Flood control
Provisioning	Wild food Cultivated food
Cultural	Natural aesthetics Cultural aesthetics Recreation
Support	Water supply Biological diversity

Source: prepared by the authors.

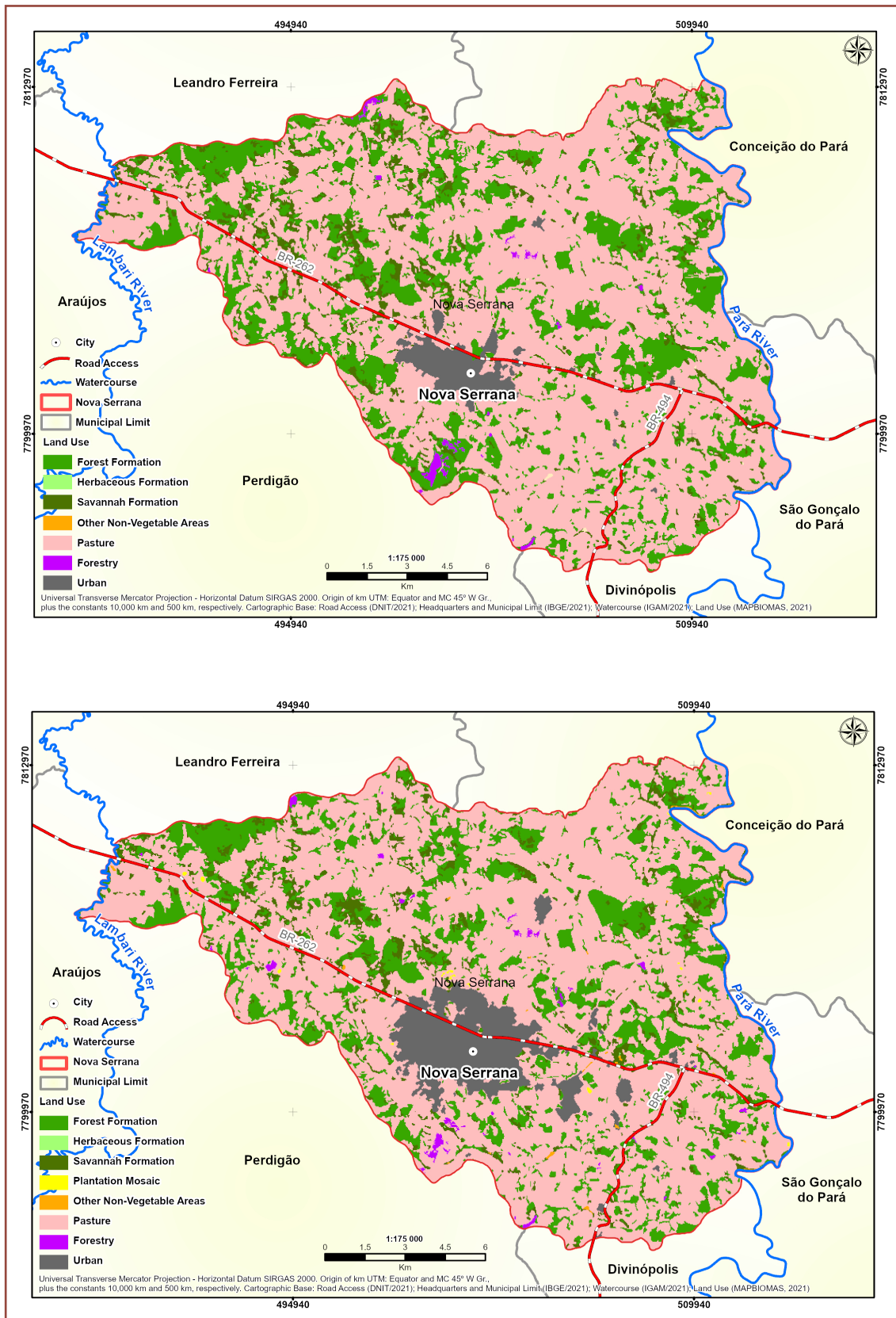
Between July and December 2020, technical visits were conducted in the field to verify the accuracy of the mapping and to identify spatial elements and processes that were not discernible in the images. During the study, six field campaigns were conducted to cover both the dry and rainy periods in the region. This made it possible to verify and assess the various phenomena influenced by climatic factors on the landscape configuration, phytophysionomies, and urban layouts in the municipality, as identified through the analysis and interpretation of the images in the office.

RESULTS AND DISCUSSIONS

The expansion of the urban fabric

The cartograms shown in Figure 2, which represent the classes of land use and vegetation cover in the municipality of Nova Serrana, made it possible

Figure 2 – Land use and vegetation cover in Nova Serrana, 2000 and 2015



Source: prepared by the authors.

to identify the areas with the most significant landscape changes during the analyzed period. In general, there was a clear expansion of urban sprawl, which occurred in both a north/south and east/west direction. Both expansions bordered, to a certain extent, the main highways in the municipality: BR-262 and BR-494. The main urban area is comprised of residential areas, businesses, and industries, serving as the central sector of the municipality. The secondary areas, which form new neighborhoods, consist mainly of residential properties, but there is also a significant presence of footwear industries.

Table 1 – Evolution of land use classes between 2000 and 2015

Land use	Area (ha)		Variation	
	2000	2015	ha	%
Forest formation	5,971.40	5,385.40	- 586.09	- 9.81
Herbaceous formation	6.60	3.20	- 3.36	- 51.22
Savannah formation	1,954.10	1,778.80	- 175.24	- 8.97
Mosaic of plantations	ND	24.60	ND	ND
Other non-vegetated areas	55.70	56.90	+ 1.20	+ 2.15
Pasture	19,389.40	18,932.20	- 457.20	- 2.36
Forestry	115.40	121.80	+ 6.42	+ 5.56
Urban	728.40	1,918.10	+ 1,189.69	+ 163.34

Source: prepared by the authors.

The absolute and relative variations exhibited an increase for the classes linked to urban sprawl, along with forestry and other non-vegetated areas, as depicted in Table 1. A portion of the environmental impact of this expansion is evident in the depletion of natural vegetation, including forest formations, savannah formations, and herbaceous formations, ultimately leading to substantial alterations in local pastures.

Table 2 – Urban sprawl over land use classes from 2000 to 2015

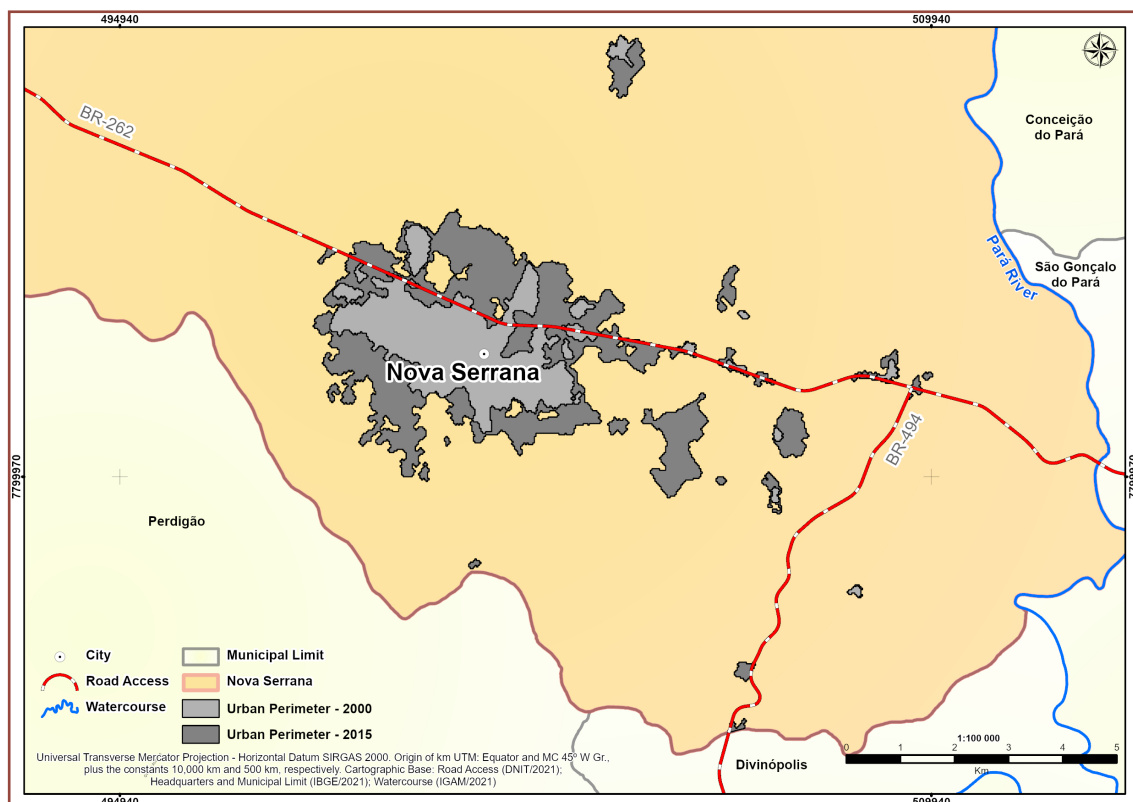
Land use (2015)	Area (ha) 2015	Land use (2000)	Area (ha) 2000
Urban	1,918.1	Forest formation	- 72.5
		Herbaceous formation	- 2.9
		Savannah formation	- 50.9
		Other non-vegetated areas	- 0.9
		Pasture	- 1,061.1
			- 1.4

Source: prepared by the authors.

As shown in Table 1, urban sprawl grew by 163% from 2000 to 2015. This means that the urban fabric (Table 2) expanded by around 1,189.70 hectares, at the expense of areas (ha) of pasture (-1,061.1), forest formations (-72.5) and savannah formations (-50.9).

The shift in land use as a countermeasure to urban expansion in the municipality is evident. Considering only the losses due to urban expansion, pasture experienced the highest reduction at 89.19%. Forest formations decreased by 6.10%; savannah formations by 4.28%; herbaceous formations by 0.24%; and forestry and other non-vegetated areas by 0.19%. Despite the small percentage of conversion compared to pasture, the ecosystem losses are significant because natural formations are essential for maintaining ecosystem services. In addition, in 2000, the total area covered by natural vegetation had a small representation in the landscape context (28%). The losses between 2000 and 2015 have reduced the natural vegetation cover to 25%.

Figure 3 – Urban dynamics for the period 2000-2015



Source: prepared by the authors.

The growth of Nova Serrana's urban sprawl can be observed in Figure 3, which clearly illustrates its extensive expansion, particularly through the development of a perimeter collar around the municipal headquarters and the

BR-262 and BR-494 highways. These highways play a crucial role in facilitating the inflow of inputs and the transportation of goods. The perimeter expansion analyzed between the years was based on the mapping compiled by Nova Serrana City Hall and the images obtained from the Mabiomas project.

Landscape metrics

Fragment

Concerning the fragment, only the urban sprawl was quantified because the aim was to measure its expansion during the years analyzed. In 2000, the municipal center covered an area of 728.40 hectares and had a perimeter of 34 kilometers. In 2015, the same municipal center had an area of 1,918.10 hectares and a perimeter of 59 kilometers. The urban area increased by approximately 163%, while the perimeter expanded by 173%. In 2000, the most densely populated areas were still flat or gently sloping, close to the Fartura stream. Subsequently, the urban network expanded towards the slopes in the northeast and southeast. Due to physical interpositions, the urban structures circumvented the obstacles, leading to a significant increase in the perimeter.

Classes

The pasture area covered 19.40 thousand hectares in 2000 and 18.90 thousand hectares in 2015. Pastures cover approximately 68.70% (PLAND) of the entire municipal territory, but they are almost disconnected from agricultural activities, which were significant before the industrialization phase. The average pasture area (AREA_MN) is 1.50 thousand hectares, with a considerable standard deviation (AREA_SD) of around 1.60 thousand hectares, indicating a high degree of variability in the size of the fragments. The number of fragments (NP) fell from 141 to 118 over the years due to parts of the fragments being replaced by urban areas.

Forest and savannah are the ecosystems directly linked to the quality of local ecosystems. Together, they occupied 28% of the territory in 2000 (21% forest and 7% savannah) and 25% in 2015 (19% forest and 6% savannah). These ecosystems had a high number of fragments (NP) in 2000, with 818 and 885, and in 2015, with 873 and 863. The behavior exhibited by the classes illustrates various instances of degradation. The forest formation experienced increased fragmentation and a moderate reduction in the size of each fragment area. In the savannah formation, degradation is more advanced. The reduction in fragments has led to the complete extinction of some patches.

The largest fragment (LPI) of the forest formation was 1.2 hectares, and the savannah formation was 0.2 hectares in 2015. It should be noted that the biome of western Minas Gerais is the Cerrado (Savannah), which is almost extinct in the municipality, and in 2015 represented 6.3% of the land cover. Despite the reduction in area, the average shapes (SHAPE_MN) for 2000 and 2015 were the same at 1.5, which confirms the complexity of the fragment shapes before the investigation. Geometrically varied shapes, such as those present in the research area, other than the circle and the square, are highly susceptible to the edge effect.

These natural formations, including forests and savannahs, had an average distance (ENN_MN) between the fragments of 97 m and 131 m in 2000. In 2015, the distances increased to 137 m and 161 m. There was also an increase in the standard deviation (ENN_SD) between 2000 (65 m; 88 m) and 2015 (96 m; 127 m). These figures indicate a reduction in habitat and increased heterogeneity of distances. The small size of natural fragments limits the number of species and the size of the animals that inhabit them. Moreover, the greater distance between fragments impedes the migration and colonization of other patches.

The urban area experienced the most significant expansion during the analyzed period. In 2000, it accounted for 2.6% of the landscape, while in 2015, it accounted for 7%. The fragments increased in number (from 14 to 24) and size, with the average area (AREA_MN) being 53 hectares in 2000 and 81 hectares in 2015. The significant growth was mainly due to migration to the municipality attracted by the abundance of job opportunities in the shoe industry. The classes of forestry, herbaceous formations, other non-vegetated areas, and mosaic of plantations collectively had a low contribution to the composition of the landscapes across different time scales.

Landscape

The landscape level allows for a comprehensive assessment of the spatial composition of all the fragments. When comparing the average areas (AREA_MN) of all the fragments and their respective deviations (AREA_SD), it was observed that the values remained practically the same (14 ha; 420 ha). The high value of the standard deviation demonstrates the variability in the size of the fragments inherited from previous eras, which were already characterized by intensive land use.

The average shape (SHAPE_MN) with a value close to 1.5 confirms the anthropogenic influence in all classes. When we compare the diversity of frag-

ments (PR) (7 and 8), we can conclude that there has been a slight increase. However, it should be noted that the increased fragments were from classes with minimal representation in the ecosystem landscape, specifically forestry and other non-vegetated areas.

The Fragment Richness Density (PRD) metric, which measures the number of fragments per 100 hectares, corroborates the low diversity of the landscape compositions, with respective values of 0.025 and 0.028. Due to the increase in landscape richness (PR), the Shannon index (SHDI), which measures landscape diversity, also increased between the years 0.90 and 0.98. However, these variations did little to improve the environment. What's more, of the classes presented, the only ones that would contribute to a real increase in species richness would be the forest and savannah formations. A previous analysis revealed that these formations are currently diminishing.

In metrics that measure variability in diversity, such as PR, PRD, and SHDI, it is important to consider the characteristics of the patches. In the case of Nova Serrana, at the landscape level, the increase in the number of patches led to an increase in heterogeneity indices. However, some of the new patches are detrimental to the environment, such as exposed soil.

Impacts on ecosystem services

Observing the composition of the landscape and its influence on ecosystem services is a challenging task (DUARTE et al., 2018), but it is of paramount importance if sustainable planning is to be established for the various land uses associated with different types of vegetation cover. In the investigation of landscape change in Nova Serrana, it was found that accelerated urban growth has brought instability to a specific set of ecosystem services. This instability has either caused or worsened recurring socio-environmental problems in the municipality. These problems must be analyzed in the inseparable light of natural and human aspects, since both coexist in the configuration of the landscape (SOUZA, 2018). The socio-environmental problems identified include flooding during the rainy season, disappearance of water bodies, constant erosion, excessive concentration of pollutants in the air from industries, limited natural refuges, decreased family farming activity, and low landscape attractiveness. It's worth noting that spatial navigation in urban environments demands a discerning eye because of the complexity and heterogeneity of the landscape. Therefore, in addition to technological tools and inputs to aid analysis, fieldwork is essential to capture dissent.

The results of the survey showed that in the regulation category, the main impacts are on services within the urban area itself. The municipality has a significant concentration of pollutants, which lead to respiratory and thermal discomfort. Heat dispersion is hindered by the central area being situated in a valley surrounded by slopes that act as foothills.

Another regulatory service jeopardized by urban development is the dynamics of watercourses, especially the Fartura stream. The smaller and larger riverbeds, which should absorb excess water during periods of flooding and sporadic inundation, are now taken up by residential and industrial areas. During rainy periods, flooding is expected in various parts of the municipality, especially in properties located close to the watercourses. Added to this is the high level of surface runoff on slopes with high gradients, low ramp lengths, and mostly impermeable surfaces caused by the urban fabric. The Fartura stream is also contaminated with urban sewage, making it a potential source of disease.

Soil sealing, which used to be limited to flat areas, has now extended to slopes and hilltops. As a result, the support category has also been affected, as the service provided by the water sources is in sharp decline, leading to the extinction of two natural lagoons and numerous springs that were integral to the municipal water system. The loss of biological diversity is also a concerning factor in the municipality. The reduction in natural formations contributes to a greater homogenization of the landscape, with pastures remaining predominant. As a result, species that require a larger area, such as the ocelot (*Leopardus pardalis*), maned wolf (*Chrysocyon brachyurus*), and giant anteater (*Myrmecophaga tridactyla*) (JUNIOR & ARAÚJO, 2007), are becoming increasingly rare.

The contraction experienced by natural formations also affects the provision category. The small size and jagged shapes of the patches contribute to the edge effect, which impacts native species that are inconspicuous in the landscape, particularly near the urban center. Although the territory has a large area of pasture, it is underutilized, and agricultural food production is scarce. On some rural properties, you can see orchards established by humans for family consumption, but the presence of wild species, particularly from the Cerrado, is uncommon in the landscape.

The cultural category is affected by multiple factors. The population is mostly composed of migrants who, motivated by the job offers, have little attachment to the place. The cultural aspect associated with rural areas has a low aesthetic value. There are no natural or rural products or services availa-

ble for the local population or visitors. It was also observed that the socio-environmental problems identified in Nova Serrana are also perceived in other cities around the world, as demonstrated by Xie et al. (2017), Dadashpoor et al. (2019), Narducci et al. (2019), among others. In other words, these problems are typical of areas where urban and economic growth has ignored or given little priority to the potential benefits of ecosystem services.

Through research, it is also possible to provide support for the secondary question: What measures would improve the quality of ecosystem services provided to the population? Some of the measures include: complying with the land use and occupation policy in accordance with federal and state laws; plant recomposition and/or active restoration of public lands with Cerrado species, and incentives for private individuals to do so; the creation of ecological corridors in strategic locations between areas with greater biodiversity; effective enforcement of regulations to control pollutants emitted by industries; the protection and planting of native species around springs; and the establishment of a municipal program to recycle and properly dispose of urban waste. It is known that there are many other actions that could be listed, but we have selected those with high adherence rates that can be implemented within a short to medium time frame.

As a strategy to mitigate environmental degradation caused by urbanization in Brazil, it is crucial to incorporate the objectives outlined in the Sustainable Development Goals (SDGs), which are integral to the 2030 Agenda, into the legislation governing the municipal budget system. According to the CNM (2016), to achieve the goals of the SDGs, municipalities need to select indicators that will allow them to direct their efforts toward implementing plans, projects, and actions. For instance, the Human Development Index (HDI) is linked to SDG 10 (reducing inequalities) and can also be associated with SDGs 6 (drinking water and sanitation), 11 (sustainable cities and communities), 12 (sustainable production and consumption), 13 (action against global climate change), and 15 (life on land).

FINAL CONSIDERATIONS

Although ecosystem services have entered academic discussions and the context of public policies worldwide, there is little evidence of their effectiveness in public management. However, when Earth Science (ES) applies scientific concepts to practical use, it becomes an important indicator for measuring changes in the landscape. For example, by observing the reduction

of savannah formations in Nova Serrana to critical values, there are strong indications that the tipping point has been reached, at which the power of spontaneous regeneration is lost. The savannah formations, despite being surrounded by underused pasture for agricultural purposes, are unable to regenerate on their own. Active restoration, such as planting natural species in strategic areas, needs to be carried out through public programs and projects. Despite recognizing the need for active restoration, there is no evidence of any action in this direction, such as active projects in the country like Cerratinga, Floresta Mais, CEPF-Cerrado, Emporio do Cerrado, NCAVES, and others. Faced with a lack of action to preserve or restore natural formations, other sectors, such as the real estate market, have gained importance. In Nova Serrana, the sector is directly linked to urban expansion by providing new allotments and neighborhoods for industrial and residential purposes. For this market, land and areas without vegetation are more attractive because they involve less bureaucracy for construction.

In urban areas, the actions taken by the municipality's public administration in response to major issues, such as the annual floods, are primarily reactive and short-term. An example of this is the Municipal Contingency Plan, which lists risk areas and identifies agencies to be activated in the event of emergencies. This strategy is necessary to assist citizens who are at risk. However, in order to solve this problem, as well as others, it is necessary to broaden the scale of observation and understand that the urban landscape is closely linked to natural landscapes, which provide the most important ecosystem services for sustaining life and reducing negative impacts. The Municipal Master Plan introduces new regulations for spatial occupation and aims to alleviate recurring issues. Linked to this is the need for a policy to raise awareness among the population and involve them in actions that promote collective well-being.

Ecosystem services, especially in urban centers, are deeply linked to urban environmental health. Therefore, paying attention to land use planning will have a positive impact on people's quality of life by improving the environment, strengthening socio-cultural relations, and reducing chronic phenomena such as flooding. ●

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Received: 04/23/2023

Accepted: 04/16/2024

Available online: 06/28/2024

