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Landscape Ecology applied to the study of the Atlantic Forest

Eric Bem dos Santos[a], Rejane Magalhães de Mendonça Pimentel[b], Milena Dutra da Silva[c]

[a] Universidade Federal de Pernambuco-UFPE, Campus Recife. Av. Prof. Moraes Rego, n. 1235, Cidade Universitária, Recife, Pernambuco, Brasil. CEP: 50670-901. E-mail: eric.bem@ufpe.br.
[b] Universidade Federal Rural de Pernambuco-UFRPE, Campus Recife. Rua Manoel de Medeiros, s/n, Dois Irmãos, Recife, Pernambuco, Brasil. CEP: 52171-900. E-mail: rejane.pimentel@ufrpe.br.
[c] Universidade Federal da Paraíba-UFPB, Campus IV. PB-04, Centro, Rio Tinto, Paraiba, Brasil. CEP: 58051-900. E-mail: milena.dutra@academico.ufpb.br.

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ABSTRACT

Understanding the metric and dynamic behavior of Atlantic Forest landscapes is of fundamental importance for planning and decision-making, especially regarding the recovery of degraded areas and the creation of public policies for biodiversity protection/conservation. From this perspective, landscape ecology is an extremely important tool. The aim of the study was to understand the forms and applications of landscape ecology in relation to studies in the Atlantic Forest. Regarding the methodology, this research should be classified as bibliographic, specifically a narrative literature review. The results bring definition, origin/evolution, calculations (area, edge, core, and proximity), and applications. It is concluded that landscape ecology should be understood as a new and promising area, the use of landscape metrics brings to the ouse approach of maps and satellite images, allowing a larger scale of the study, whether cartographic, spatial, and/or temporal, enabling visualization of the landscape in different perspectives and from the analysis of its phytogeographic structure.

Keywords: Ecology, urbanism, geoprocessing, phytogeography.

Introduction

According to the decree in the Federal Constitution of 1988, the Atlantic Forest officially became a Biosphere Reserve by UNESCO and Natural Heritage (Dantas et al., 2017). Among the main motivations for this recognition is the high level of biological diversity, which makes the Atlantic Forest one of the great repositories of world biodiversity having high levels of endemics. Unfortunately, even with the recognition of its importance, the Atlantic Forest is among the most threatened domains on Earth and, therefore, an intensification is necessary for the protection of its remnants (Varjabedian, 2010).

Approximately 145 million inhabitants of 3,429 municipalities, proportional to 72% of Brazil's population live in areas of the Atlantic Forest domain (SOS Mata Atlântica, 2010). Of these municipalities, the small and medium-sized ones in Brazil stood out, given the intense transformations in land use and occupation, especially in the last four decades, caused by urban sprawl and rural activities, even more pronounced in small cities (Lopes & Henrique, 2010).

Due to the consequences of these changes, forest fragments are being created in the municipality, causing a very common and harmful phenomenon for the entire biological community: forest fragmentation (Dantas et al., 2017). This phenomenon is a process where a certain extensive and interconnected area is shredded, giving way to small forest patches of reduced size (Varjabedian, 2010). Considering this perspective, studies that research the functional relationships between the metric characteristics of forest fragments with the ecology of Atlantic Forest vegetation through data collected remotely have been the focus of many studies, especially focused on forest and urban aspects.

Understanding the metric and dynamic behavior of the landscape of this biome is of fundamental importance for planning and decision-making, especially regarding the recovery of degraded areas and the creation of public policies for the protection/conservation of biodiversity and maintenance of preserved areas (Fahrig, 2021).

Considering Odum & Barrett (2008), and Costa (2020), Landscape Ecology can be defined as a "holistic" approach involving the study of landscape patterns, the dynamics between the elements that make up this pattern, and the most varied relationships over time. The monitoring and study of the ecosystems of the Atlantic Forest through landscape ecology has been one of the most discussed and explored themes among those that encompass geotechnologies.

Currently, most studies of Landscape Ecology focus on landscape patterns and interactions and their modifications over time, analyzing natural and anthropic landscapes (Costa, 2020). Fahrig (2021) considers Landscape Ecology as a relatively new science and requires further studies that provide the improvement of existing techniques of landscape research, especially when the emphasis is on the degree of interaction and connectivity of the elements that compose it.

In view of the urgency of studies on the Atlantic Forest and the growing number of applications of landscape ecology to these studies (Nascimento & Laurance, 2006), especially the use of landscape metrics, this research aimed to understand the forms and applications of landscape ecology linked to studies in the Atlantic Forest.

Material and Methods

According to the classification of Gil (2019), this research should be classified as bibliographical, of the narrative literature review type. The research involved the survey of scientific publications such as articles, dissertations, theses, books, and official documents. They were acquired in all years and thematic areas, in whose titles, abstracts, and keywords contained some subject relevant to the ecology of the landscape linked to studies in the Atlantic Forest. The research involved a survey of studies published on the following platforms: SciELO, Web of Science, and Scopus (Elsevier). These academic content platforms were chosen according to their scope and importance.

The studies are from the period between 1970 and 2021, considering Boolean operators and filters in English and Portuguese, not restricting the thematic area. The keywords and operators that were searched were: “Atlantic Forest” and “landscape ecology”; “Atlantic Forest” and “matrix quality”.

Based on the combination of ["Atlantic Forest" and "landscape ecology"], no articles were found in SciELO. However, 161 articles were found on the Web of Science and 72 articles on Scopus (Elsevier). For the search query ["Atlantic Forest" and "matrix quality"], no articles were found in SciELO. However, 43 articles were found on the Web of Science and 6 articles on Scopus (Elsevier).

Based on the dynamic reading of titles and abstracts of the 282 articles found, 27 were used to construct the results and the present discussion. The eligibility criterion for these studies is compatibility with the objective of the current research.

Results and Discussion

As we can read in the following topics, the results and discussions constructed based on the selected articles provide a broad and enlightening view of the main concepts and the current state of research conducted in this field, stimulating further research in this area and promoting scientific progress.

Definition

Before discussing the definition of Landscape Ecology, it is important to know what ecology is. According to Martins et al. (2004), Ecology is the science that studies the interactions of organisms in their environment. Knowing that these interactions involve processes and are therefore variable in time. According to Martins et al. (2004), ecology and the environment are directly related to the concept of physical space.

Historically, ecology in its principle focused on the study of processes in which space had "homogeneous" characteristics. However, the studies of ecosystems in isolation proved to be limiting in the understanding of the phenomena that occur among the most varied ecosystems. Therefore, the study of the landscape as a "whole" requires applications of various natural and anthropic aspects and variables (Martins et al., 2004; Guerra & Marçal, 2009)

According to Metzger (2001), the beginning of landscape ecology is very similar to that of ecosystem ecology, that is, part of the observation of the interrelations of the biota, including man, with the environment, building a whole. The forerunner and first scholar to use the term "landscape" in research around ecology was the geobotanist, Alexander von Humboldt, still in the 19th century, under the definition of "total characteristic of a given terrestrial region" (Metzger, 2001).

The landscape definition is different from the ecosystem definition. While Troppmair (2000), when defining an ecosystem, states that it is a "system", where there is interdependence between its components, the presence of a cycle of matter and self-regulation mechanisms, for Troll (1971) cited by Martins et al. (2004) the definition of landscape is the spatiality and heterogeneity of the physical space where man dwells. The interaction of these two concepts gave rise to Landscape Ecology.

Landscape Ecology is a relatively new science and requires further studies that provide the improvement of existing landscape research techniques, especially when the emphasis is on the degree of interaction and connectivity of the elements that compose it (Costa, 2020). Currently, most studies of Landscape Ecology focus on the patterns and interactions of the landscape and its changes over time, analyzing both the natural landscapes and the landscapes constructed by the action of man (Casemiro, 2009).

According to Porto & Menegat (2004), the main purpose of this new area of knowledge is to build a link between natural and human systems, including agricultural and urban activities that continuously change the landscape, that is, according to the objectives of this research, previously mentioned, the concepts of Landscape Ecology will be of great importance for research construction. The integration of concepts of Landscape Ecology as the metric of the landscape means much more than a change in man's attitude towards nature, but also the rescue of lost precepts, especially from the industrial revolution (Metzger, 2001; Porto & Menegat, 2004; Martins et al., 2004).

Historic

Landscape Ecology emerged around 1930 when geographer Carl Troll observed that all methods in natural science were trapped at the heart of landscape science (Costa, 2020). The concept also comes from the greater concern in studying spatial heterogeneity, seeking to understand the interactions of a community with the abiotic system (Costa, 2020).

Odum & Barrett (2008) considered Landscape Ecology defined as a "holistic" approach involving the study of landscape patterns, the dynamics between the elements that make up this pattern, and the most varied relationships over time.

According to a survey by Rodriguez, Silva & Cavalcanti (2007) the emergence of the first physical-geographic ideas related to the dynamics of natural phenomena and the first concepts of landscape as a notion is linked to the genesis of Landscape Ecology, around 1850 – 1920. Between 1920 and 1930 began the influence of other areas of science, building the notion of interaction between the different actors of the landscape, culminating in the development of the concepts of small-scale differentiation of the landscape in 1955.

From 1955 to 1970 there was a focus on the analysis of regional and local level problems working with the taxonomy, classification, and cartography of vegetation. From 1970 on, systemic, quantitative methods have been introduced and landscape ecology is developed close to what we know today.

From 1985 to the current moment, the interrelation of the structural-spatial and dynamic-functional aspects of landscapes, focusing on fragments of preserved ecosystems, united with the integration and the same scientific direction of biological and geographical conceptions about landscapes consolidated the ecology of the landscape we know today (Rodriguez, Silva & Cavalcanti, 2007; Costa, 2020). Gathering the data from Rodriguez, Silva & Cavalcanti (2007), Odum, Barrett (2008), and Costa (2020) we built the timeline (Figure 1).

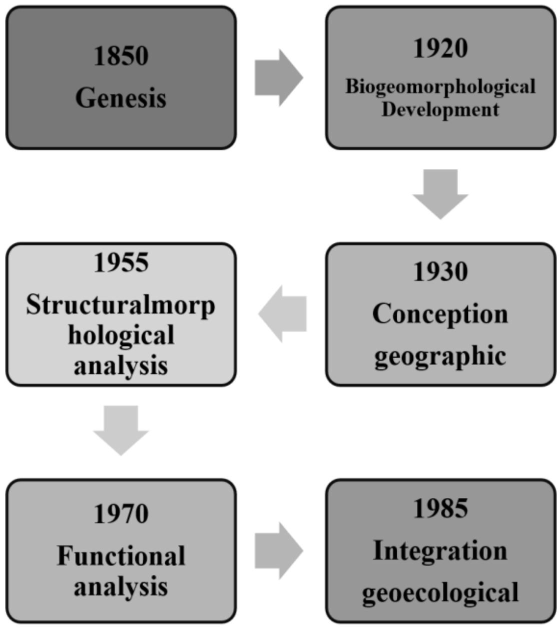

Figure 1. Landscape ecology timeline. Font: Santos, Pimentel & Silva (2022).

Calculations

Considering the evolution of geotechnologies, in the social use of geographic information systems (GIS), new technologies, and new parameters were incorporated into the studies of Landscape Ecology. Among these new techniques applied to Landscape Metrics gained prominence. In view of the analyses performed in the technique, some authors call it 'matrix quality' or 'Landscape Metrics'. They are among the most calculated parameters: area, core, and edge (Lang & Blaschke, 2009). It is noteworthy that the following calculations have their applicability aimed at studies in areas of the Atlantic Forest, given that other biomes have their different floristic compositions.

Area

Considered the parameter closest to reality and more widespread among researchers, the Patch is used to calculate many other measures that are performed directly or indirectly on their data (Santos, Silva & Albuquerque, 2020). The spatial parameter "Area" has great importance from the ecological point of view, mainly related to the analysis of other attributes (Lang & Blaschke, 2009).

The Area is an indispensable parameter for measuring habitat diversity, given the species-area relationship, where larger areas should house more species than smaller ones (Bennett, 2003), besides indicating the most beneficial habitats in the attributes of space and availability of food for the most species (Santos, Silva & Albuquerque, 2020). According to Lang & Blaschke (2009), Equation 1 is used for the calculation of the area.

$$\text{Area} = 0{,}5 \cdot \sum (xi+1-xi)(yi+1+Yi) \qquad \text{Eq.(1)}$$

They are geographic coordinates x and y of the i-eleventh (support point of the analyzed fragment).

Edge

Forest remnants in direct contact with a given anthropic matrix form the so-called edge that promotes changes in the physical, chemical, and biological parameters of ecosystems, characterizing the so-called edge effect (Santos, Silva & Albuquerque, 2020). The edge effect can be divided into abiotic, direct biological, and indirect biological (Santos, Silva & Albuquerque, 2020).

Abiotic factors are linked to environmental changes where exposure to wind occurs, high temperatures, moisture dysregulation, and unusual solar radiation (Redding et al., 2003). In turn, direct biological effects involve phytosociological changes caused by abiotic factors near the edges of the fragment (Galetti, Alves-Costa & Cazetta, 2003). Regarding indirect biological effects, its alterations are linked to the interaction between species and individuals, causing predation, and parasitism among other ecological disorders Galetti, Alves-Costa & Cazetta, 2003; Redding et al., 2003). To calculate the border is used Equation 2 (Lang & Blaschke, 2009).

$$\text{Edge} = \sum \sqrt{(xi+1-xi)^2+(yi+1+Yi)^2} \qquad \text{Eq.(2)}$$

They are geographic coordinates x and y of the i-eleventh (support point of the analyzed fragment).

Core

Consider Core the spaces inside the forest fragments, except the edge. Fragments that did not present an edge area have a higher level of fragility and high susceptibility to anthropic actions (Dantas et al., 2017). For the calculation, the formula (Lang & Blaschke, 2009) is used following Equation 3.

$$\text{Core} = [\, 0{,}5 \cdot \sum (xi+1-xi) + (yi+1+Yi) \,] - [\sum \sqrt{(xi+1-xi)^2 + (yi+1+Yi)^2} \,] \qquad \text{Eq.(3)}$$

They are geographic coordinates x and y of the i-eleventh (support point of the analyzed fragment).

Proximity

Forest fragmentation and consequent edge effects tend to increase the degree of isolation of species from an ecological point of view, which may result in the extinction of fragments with less area and more isolated. The proximity brings the degree of isolation of the landscape, where the shorter the distance, the greater the connection between the forest fragments, facilitating the movement of the biota and the genetic flow. In turn, fragments with large distances will have a greater degree of isolation from the spots that make up the landscape (Silva & Souza, 2014). According to Lang and Blaschke (2009) for the calculation of the proximity is used Equation 4.

$$\text{Proximity} = \sum Ai/di \qquad \text{Eq.(4)}$$

Are A-area and D-distance of the i-tenth (support point of the analyzed fragment)

Discussion

The study of these parameters in the ecology of the landscape concerns the composition, that is, the presence and number of spots, as well as the pattern, which concerns the spatial distribution and configuration of these forest spots, thus cauterizing the overall structure of the landscape. To analyze the overall structure of the landscape, a set of aspects is needed, such as the area, edge, core, and proximity of preserved forest fragments, considering the scale of the study and spatial resolution of the sensor that will be used.

Based on these data, Casemiro (2009) classifies the heterogeneity of the landscape into two types: 'micro' when the distribution of the types of landscape elements around a point is similar at any point in the Landscape, and 'macro' heterogeneity when the arrangement of landscape elements varies between sections of the observed area.

However, no landscape is completely 'micro' or 'macro', with mixtures between its characteristics. In addition to heterogeneity analysis, parameters of landscape ecology are important in characterizing the distribution of landscape elements, that is, configuration.

The configuration of the landscape is the way forest fragments and their characteristics are distributed in each landscape. Casemiro (2009) states that everything is related, however, the closest objects are more related than the more distant objects, this statement applies to animals, seeds, heat, nutrients, genes, and information, in addition to numerous interactions of ecosystems (Mace, Norris & Fitter, 2012; Costa, 2020).

With the in-depth study of ecosystems, we know that energy and mineral nutrients flow from one system to another, within ecosystems or between ecosystems. In turn, analyzing behavioral aspects, the species present directional movements for spots in conditions equal to or like their original habitat. Combining these studies and their data is obtained from the so-called principle of 'spatial flow', useful not only to justify landscape ecology studies but also to estimate which ecosystems to consider in terms of management and planning of the territory (Mace, Norris & Fitter, 2012). This concern is even more special in the Areas of the Atlantic Forest, due to its strong anthropic interactions and intense fragmentation process (Varjabedian, 2010).

Conclusion

This research showed that Landscape Ecology, much more than a new area of ecology, constitutes an innovative and interdisciplinary category of systemic, qualitative, quantitative, and precise analysis, adding multiple views of ecology to the concept of cartographic and geographic information system (GIS). This approach to Landscape Ecology allows a greater understanding of how geographic space is framed over time and what actions for these changes to be beneficial for the conservation of preserved ecosystems.

The use of landscape metrics brings to the approach the use of maps and satellite images, allowing a larger scale of the study, be it cartographic, spatial, and/or temporal, enabling visualization of the landscape from different perspectives and from the analysis of its phytogeographic structure.

It is concluded that landscape ecology should be understood as a new and promising area of science and its main object of study, currently, is the patterns and interactions of the landscape and its changes over time, in this perspective its indispensable applications in the study of the Atlantic Forest is undeniable, in view of the intense anthropic activities that occur in its domain. However, because it is new, further studies are needed to improve the techniques and parameters. One of the main challenges of Landscape Ecology today is to create extensions in free software to further popularize techniques, especially the application of Landscape Metrics.

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