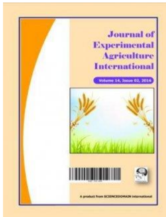

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Landscape Ecology and Geotechnologies as Tools for the Management of Biological Conservation

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Authors' contributions

This work was carried out in collaboration between all authors. Authors GLM and VSS designed the study. Author GLM managed the statistical analysis and wrote the protocol. Authors GLM, PCGC, TCS, ECGA and VSS wrote the manuscript. Authors GLM, PCGC, ECGA and TCS managed the literature searches. All authors performed the corrections and reviewed the experimental design and all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Tropical forests, such as the Atlantic Forest, are among the most relevant forest formations regarding the provision of environmental ecosystem services, however, after centuries of human expansion, most of the Atlantic Forest is reduced to forest patches. This work aimed to map and analyse the landscape structure of the Atlantic Forest remnants in the city of Goiana, PE, Brazil. For that, metric indexes of landscape ecology were used, with the description of the spatial elements that determine the existing ecological processes and their importance on biological conservation in an Atlantic Forest patch, located in the municipality of Goiana, PE, Brazil. The native vegetation remnants map was obtained through supervised classification process, using images from LANDSAT 8 sensor, in the QGIS 2.18.9 computational application, and the SCP (Semi-Automatic Classification Plugin) with the Maximum Likelihood algorithm. The landscape ecology analysis was performed in the ArcGIS 10.1 software, aided by the Vector-based Landscape Analysis Tools Extension (V-LATE) 2.0 beta. The native vegetation fragmentation was related to the size class

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which they belong, observing the landscape ecology indexes for each class to compare the vegetation patches conservation degree and size. That way, the map of the native vegetation occupied areas for the year of 2017 was obtained, with 241 patches being identified, of which approximately 45% were classified as very small patches. Therefore, it was noticed that there is a high degree of fragmentation in that region that can lead to the reduction of biodiversity. The smaller patches also presented higher edge density and greater edge effect. In relation to the proximity, when analysed together and with no size class distinction, the degree of isolation decreased dramatically, which indicates the importance of the smaller patches for the landscape and the ecological processes.

Keywords: Edge effect; fragmentation; biodiversity; metric indexes.

1. INTRODUCTION

The Atlantic Forest is one of the most diverse and endangered tropical forest biotas in the world, thus it is considered as a priority area for the biodiversity conservation worldwide (hotspot). Its geographic characteristics, allied to the wide altitude range, favors this high diversity and endemism, including more than 20,000 plants species, 270 mammals species, 850 birds species, 200 reptiles species, 370 amphibians species, 350 fish species and many other species that still requires scientific description [1].

Tropical forests, such as the Atlantic Forest, are among the most relevant forest formations regarding environmental services provision and are responsible for providing a diversity of ecosystem services, essential to the society, for instance, water regulation and supply, climate regulation, water and air purification, carbon sequestration and storage, habitat protection for fauna and flora species, slope stability, flood and erosion control, and river silting mitigation, among many others [1,2,3,4].

After five centuries of human expansion, most of the Atlantic Forest landscapes are reduced to forest patches (most of them with less than 100 hectares), surrounded by pasture lands matrices, agricultural crops, eucalyptus plantations and urban centers [2,4,5]. Isolated from each other, these patches are mostly composed of secondary forests in the early and middle stages of succession [5,6].

The importance of secondary forests patches for biodiversity conservation has been widespread in the previous decades, stimulated by the fact that these forests have been replacing mature forests in several places, and are currently the predominant type in the Atlantic Forest region and in other places.

In Brazil, the original fragmentation of the vegetation was mainly due to legalised suppression, before the establishment of environmental laws or their strengthening, as well as illegal suppression, in violation of the environmental legislation, lack of environmental and production criteria for the rational expansion of the agricultural frontier to meet the social demand, increase of cultivated areas to maximise profits, inadequate knowledge of the law and forest fires [7].

The habitats loss and fragmentation, combined with climate change at global and regional levels, are causing the collapse of the main ecosystem services, environmental disasters and a progressive loss of biodiversity [8,9].

Landscape ecology, an aspect of ecology that relates ecological processes and ecosystem characteristics, presents two conflicting approaches: a geographical one, which emphasises the influence of man on the landscape; and an ecological one, which deals with the importance of spatial context on the ecological processes. Thus, for an ecological approach, the landscape is a heterogeneous and interactive mosaic, with favourable conditions for a species or community, within an observation scale [10].

For a broader understanding of landscape structure and functions, the landscape ecology uses a set of metrics that serves as indicators of landscape quality. These metrics quantify the spatial characteristics of the forest patches together or of all landscape mosaics (considering all the land use and occupation of the landscape).

Thus, forest fragmentation can be analysed by applying landscape ecology metrics allied with geoprocessing techniques, aiming to observe the quality of the forest patches (due to the intense anthropic pressure) and how the spatial distribution of the patches interferes with the species dynamics [11], since the barriers of natural or anthropic origins also promotes the reduction of gene flow and reproductive isolation, with consequent loss of genetic diversity [12].

These metrics can also be used as support tools for the management of natural resources, such as in forested areas that are important providers of ecosystem services, aiming to assess the degree of isolation of these areas, habitat loss, biodiversity reduction and whose methodologies can be defined to assist in the recovery and conservation of these forest ecosystems.

As the pressures and fragility of tropical forests increases, it raises concerns about biodiversity sustainability and ecosystem services. In this context, the objective of this study was to map and analyse the landscape structure of Atlantic Forest remnants in the municipality of Goiana, PE, Brazil, using metric indexes of landscape ecology, describing the spatial elements that determine the existing ecological processes and their importance in biological conservation.

2. MATERIALS AND METHODS

2.1 Study Area Characterisation

The municipality of Goiana is located in the mesoregion of the Mata Norte and in the northern Mata Microregion of the state of Pernambuco (Fig. 1), being limited to the north by the state of Paraíba, to the south by the municipalities of Itaquitinga, Igarassu, Itapissuma and Itamaracá, to the east by the Atlantic Ocean and to the west by the municipalities of Condado and Itambé. The municipality has an area of 501.88 km², geographically positioned at the coordinates 7° 33' 40" S and 35° 00' 10" W and, according to Köppen classification, the region climate is Ams' type (tropical rainy of monsoon with dry summer), with average annual precipitation around 2,000 mm and average annual temperature of 24°C [13,14].

The relief of the municipality of Goiana is inserted, on its majority, in the unit of the Coastal Boards and another small area in the Coastal unit, characterised by restingas, mangroves and dunes. The municipality is found under the the Atlantic Forest domain, being the Dense Ombrophylous Forest the predominant phytophysiognomy followed by the Semidecidual Seasonal Forest [15].

2.2 Native Vegetation Patches Map

In order to obtain patches of the native vegetation map, the following steps were performed:

Stage 1. Selection of an image from the Operational Land Imager sensor (OLI), satellite LANDSAT 8: The image was available in the United States Geological Survey (USGS) catalogue, and it was selected to cover the entire territory of the Goiana municipality, presenting good atmospheric conditions and minimum cloud coverage (less than 10%). The chosen image refers to the orbit/point 214/65 and dated April 20, 2017, it presents spatial resolution of 30 meters for visible bands, near infrared and medium infrared and 15 meters for the panchromatic band.

Stage 2. Obtaining vector data: In this phase, the cartographic base referring to the municipal boundary of Goiana was obtained from the Brazilian Institute of Geography and Statistics (IBGE) website.

Stage 3. Supervised classification: In this step, geoprocessing and manipulation of matrix and vector data was performed in QGIS software 2.18.9 (QGIS 2017). After obtaining the image, a RGB - false colour composition was made with the spectral bands 6, 5 and 4. Then, to reach a spatial resolution of 15 meters, a pansharpening was performed in two steps: resampling of the low resolution raster via Superimpose sensor tool and pansharpening using the Pansharpening tool. Then, the image was cut only to the study area limit, the municipality of Goiana.

To obtain the forest patches map, an image supervised classification procedure was conducted using the Semi-Automatic Classification Plugin (SCP) and the Maximum Likelihood algorithm, whose targets recognition based on spectral responses patterns in the image is done based in training samples, which are provided to the classification system by the classifier [16,17]. The training samples of the forest patches were taken based on the photointerpretation of the satellite image in the false colour composition, as well as in the previous knowledge of the area.

Stage 4. Conversion of matrix data to vector data: After the supervised classification, the forest patches map in the matrix format was converted to the vector format polygon type, using the raster vector tool.

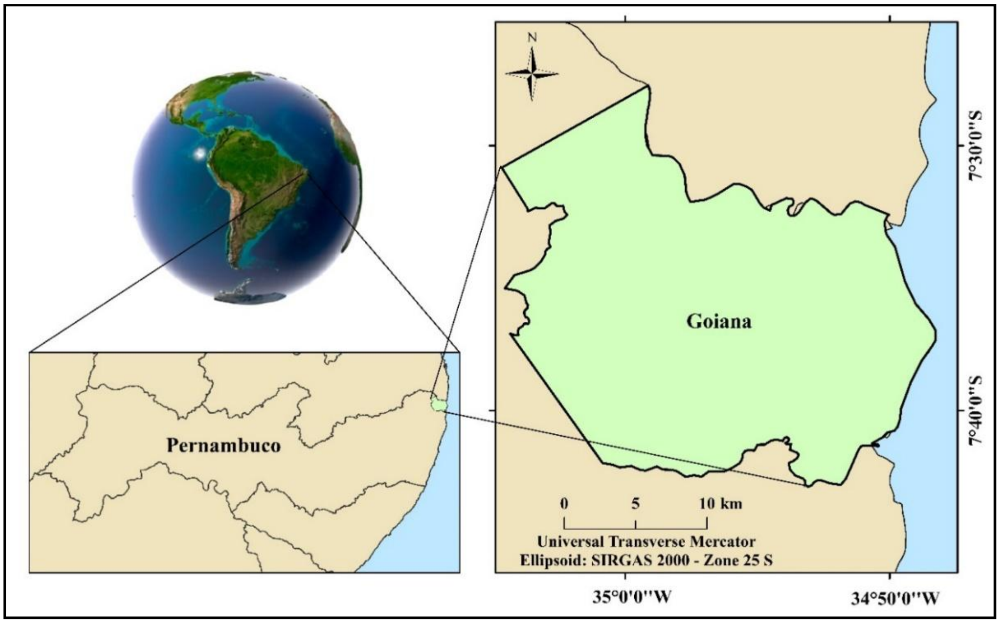

Fig. 1. Location of the study area in the municipality of Goiana, PE, Brazil, 2017

Table 1. Metric indexes of landscape ecology used for the patches of native vegetation in the municipality of Goiana, PE, Brazil

Group	Metric	Observation
Area	Class area (CA)	Sum of areas of all forest patches
Density and size	Mean Patch Size (MPS)	Sum of the size of the patches divided by the number of patches
	Number of patches (NP)	Total number of patches in the landscape or class
	Patch size standard deviation (PSSD)	Ratio of variance of patches size
	Patch Size Coefficient of Variation (PSCov)	Standard Deviation of the patch size divided by the mean patch size, multiplied by 100
Edge	Total edge (TE)	Perimeter sum of all edges within the class or landscape
	Edge density (ED)	Number of extremities relative to the class or landscape area
Shape	Mean shape index (MSI)	It is equal to one when all the patches are circular and increases with the increasing irregularity of the patch shape
	Mean Fractal Dimension (MFRACT)	Values get close to one for shapes with simple perimeter and approaches two when shapes were complex
Core area	Total class core area (TCCA)	The total size of the core patches
	Number of core areas (NCA)	Total number of core areas within the class
	Core area index (CAI)	Relative measurement of the core area
Proximity	Mean Nearest Neighbour Distance (MNN)	Mean of the distances for individual classes at the class level and the mean distance of the neighbouring class closest to the landscape level

2.3 Landscape Structure Analysis Using Landscape Ecology Metrics

The landscape ecology analysis was performed using the ArcGIS 10.1 software – student license [18], through the Vector-based Landscape Analysis Tools Extension (V-LATE) 2.0 beta [19], which provides a set of metrics for landscape ecology analysis.

The vector file of the forest patches obtained in the supervised classification process was used to obtain the metrics. Initially the area of each patch was calculated with ArcGIS "Calculate Geometry" tool from the attribute table of the vector file and then the patches were distributed in size classes [20]: very small (frag. < 5 ha), small (5 ≤ frag. ≤ 10 ha), medium (10 < frag. ≤ 100 ha) and large (frag. > 100 ha).

In order to compare the degree of conservation and the size of the forest patches mapped in this study, an analysis of landscape ecology indexes for each of the stipulated size classes (very small, small, medium and large) was carried out, as well as for all sizes together, aiming in this way, to obtain mean values of the indexes for all the patches of the study area [11].

In the landscape ecology analysis, metrics of area, density and size, edge, shape, core area and proximity, proposed by Mcgarigal et al.; [21] were used (Table 1).

For the patches core area metrics calculation, the distances of 40, 80, 100 and 140 meters of the edge were used, aiming to investigate which edge range exerts greater influence in the patches core area.

3. RESULTS

3.1 Native Vegetation Fragments Map

Through the supervised classification it was possible to obtain the native vegetation fragments spatial distribution map in the study area for the year of 2017, according to the adopted size classes (Fig. 2).

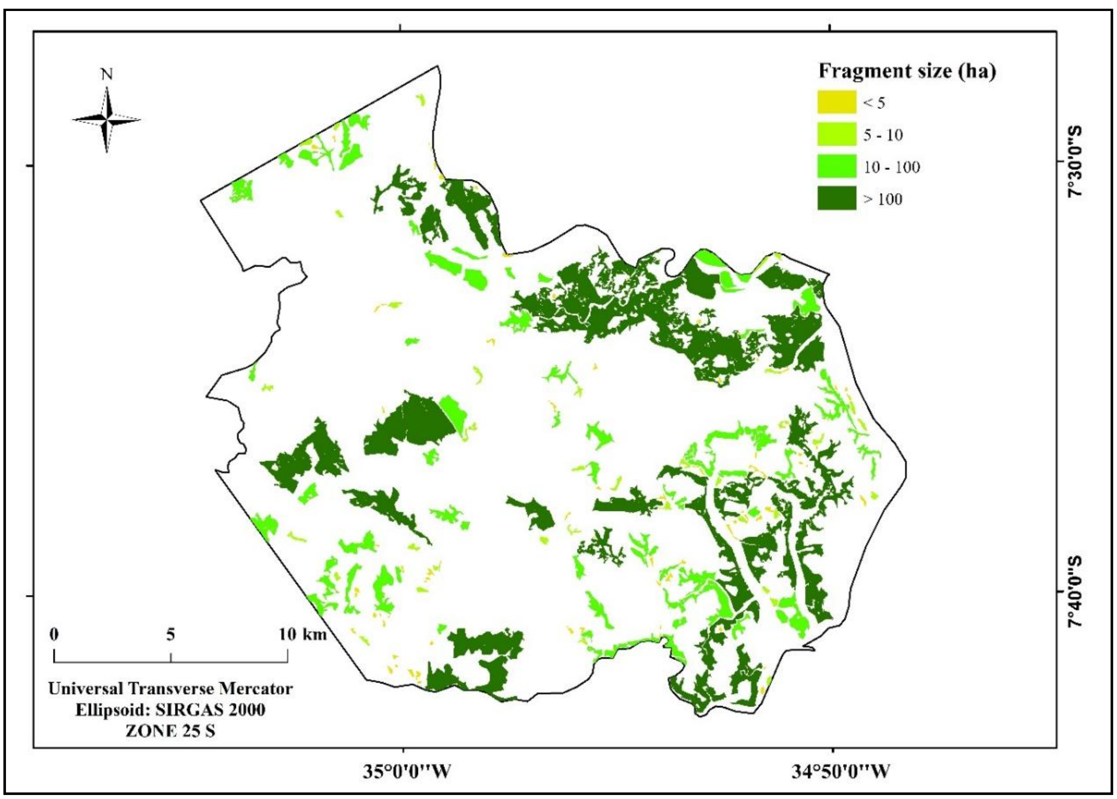

Fig. 2. Spatial distribution of the remnants of native vegetation in the municipality of Goiana, PE, Brazil, 2017

Table 2. Metric indexes of landscape ecology used for the fragments of native vegetation in the municipality of Goiana, PE

	Metric/unit	Size Classes				
		Very small (<5ha)	**Small (5≤x≤10ha)**	**Medium (10<x≤100ha)**	**Large (>100 ha)**	**All patches**
Area	CA (ha)	176.16	264.70	2450.07	7183.18	10074.10
Density and size	MPS (ha)	1.62	7.15	35.51	276.28	41.80
	NP (un)	109	37	69	26	241
	PSSD (ha)	1.36	1.32	24.18	249.66	117.26
	PSCov (%)	83.95	18.46	68.09	90.36	280.53
Edge	TE (m)	64329.99	60470.05	326238.17	623077.32	1074115.52
	ED (m/ha)	365.18	228.45	133.15	86.74	106.62
Shape	MSI (dimensionless)	1.46	1.73	2.28	3.99	2.01
	MFRACT (dimensionless)	1.37	1.32	1.33	1.35	1.35
Proximity	MNN (m)	527.86	1568.98	494.46	267.49	88.31

CA: Class area, MPS: Mean Patch Size, NP: number of patches, PSSD: patch size standard deviation, PSCov: Patch Size Coefficient of Variation, TE: Total edge, ED: Edge density, MSI: mean shape index, MFRACT: Mean Fractal Dimension, MNN: Mean Nearest Neighbor Distance.

Over the study area 241 fragments were identified, totalising 10,074.10 hectares, which corresponds to only 20.07% of the Goiana municipality total area. Within the total fragments found in the study area, 45.23% were classified as belonging to the very small class, 15.35% small, 26.63% medium and only 10.79% belong to the large fragment class.

3.2 Landscape Structure Analysis Using Landscape Ecology Metrics

The landscape ecology indexes values generated by size classes and for all the fragments of the study area can be found in Table 2.

Even though the very small size class showed the highest number of patches, it still was the class with the lowest area (CA) with only 176.16 ha. The large class, with 26 patches, presented the largest area, corresponding to 7183.18 ha.

The patch size standard deviation (PSSD) was high in the large size class, corresponding to 249.66 ha. The small size class presented the lowest standard deviation, with 1.32 ha.

The edge metrics showed that the total edge values (TE) were smaller for the very small and small size classes, with 64,329.99 and 60,470.05 m, respectively. However, the same classes presented the highest values of edge density (ED), with 365.18 and 228.45 m/ha.

As for the shape metrics, the mean shape index (MSI) values for the forest patches within the very small and small size classes presented more circular and regular formats (MSI = 1.46 and 1.73, respectively) than the medium and large patches, which had MSI values of 2.28 and 3.99, indicating the irregularity in their format.

The mean fractal patch dimension metric (MFRACT) was also used to analyse the shape of the patches in the study area. Values close to 1 represent patches with simpler forms and values closer to 2 represent patches with more complex shapes. The values obtained ranged from 1.32 to 1.35 indicating that the fragments of all size classes analysed had a simple format.

The patches degree of isolation, analysed by the mean distance of the nearest neighbor (MNN), presented results ranging from 267.49 m (large class) to 1568.98 m (small class). When all the fragments were analysed together the 88.31 m MNN was found.

The metrics values related to the core area, generated for different distances of zones under edge effect, are found in Table 3.

Table 3. Landscape ecology metric index values relative to the core area metrics calculated by the V-LATE 2.0 beta for the native vegetation patches in the municipality of Goiana, PE

Size Classes	Metrics	Edge Distance (m)			
		40	80	100	140
Very small (<5 ha)	CA (ha)	176.16	176.16	176.16	176.16
	TCCA (ha)	15.91	0.14	0.00	0.00
	NCA (un.)	119	109	0	0
	CAI (%)	9.03	0.08	0.00	0,00
Small	CA (ha)	264.70	264.70	264.70	264.70
(5 ≤ x ≤ 10 ha)	TCCA (ha)	68.13	6.43	1.24	0.00
	NCA (un.)	59	39	37	0
	CAI (%)	25.74	2.43	0.47	0.00
Medium	CA (ha)	2450.07	2450.07	2450.07	2450.07
(10 < x ≤ 100 ha)	TCCA (ha)	1275.37	590.69	397.54	181.53
	NCA (un.)	177	135	114	84
	CAI (%)	52.05	24.11	16.23	7.41
Large	CA (ha)	7183.18	7183.18	7183.18	7183.18
(>100 ha)	TCCA (ha)	4791.86	3093.86	2484.15	1601.11
	NCA (un.)	223	207	169	118
	CAI (%)	66.71	43.07	34.58	22.29

TCCA: total class core area, NCA: number of core areas, CAI: core area index.

For a minimum edge distance of 40 m, the percentage of central area (cores) of the very small and small patches, expressed by the CAI, was 15.91 and 25.74%, respectively. This means that 84.09% and 74.26% of the patches total area are under 40 m edge effect. As the distance from the edge increased, it was observed the progressive loss of the core area, reaching 0% with distances of 100 and 140 m for very small fragments and 0% with distances of 140 m for small fragments.

The CAI of patches in the medium and large classes, with a 40 m edge distance, was 66.71% and 52.05%, respectively, representing a lower edge effect than in the smaller patches. As the edge distance increased, there was a decline of CAI, with the lowest value of 7.41% for the medium class patches and 22.29% for large class patches, with a distance of 140 m.

In Fig. 3 it is possible to notice that the smaller patches suffer more with the edge effect. As the distance from the edge increases the smaller fragments lose the core area.

4. DISCUSSION

The survival of the species in fragmented landscapes may be affected by the size and connectivity of the patches.

The fragments size is related to the quality, quantity and diversity of resources, which will directly influence the size and number of the fragment resident populations. Metzger et al. [6] reports that larger fragments usually have more species and larger populations, increasing (theoretically) the balance in relation to the variations in demographic, genetic and environmental processes. However, according to Kupfer et al. [22], the matrix configuration and surrounding habitat can also have influence on the processes that occurs within fragments, regardless of their size.

In the present study, it can be extrapolated that the native vegetation covers a low percentage in relation to the total area of the evaluated municipality. Large areas with a lack of native vegetation should be considered as the main targets of action that aims at rehabilitation and conservation of these native remnants.

The mapping showed that most of the remnants found in the region are characterised by the very small class fragments (> 5 ha) and that a small percentage is characterised by the large class fragments (> 100 ha), indicating that the area has a high degree of fragmentation. A similar result was also found by Santos et al. [23] when analysing the landscape ecology in Atlantic Forest remnants of Espírito Santo state, Southeastern region of Brazil.

Under these circumstances, species richness undergoes a drastic decline as the fragment area becomes smaller than the minimum area required for the population's survival [24,25]. This high fragmentation, besides modifying the landscape structure, also has a detrimental effect on the supply and availability of several ecosystem services [26].

In turn, the landscape connectivity, considered as the landscape capacity to facilitate biological flows, has a great influence on the population permanence and on the interactions between species. The inter-fragments distance, the presence of corridors, the type of surrounding matrix and the behavior of the species are fundamental factors of the connectivity [6].

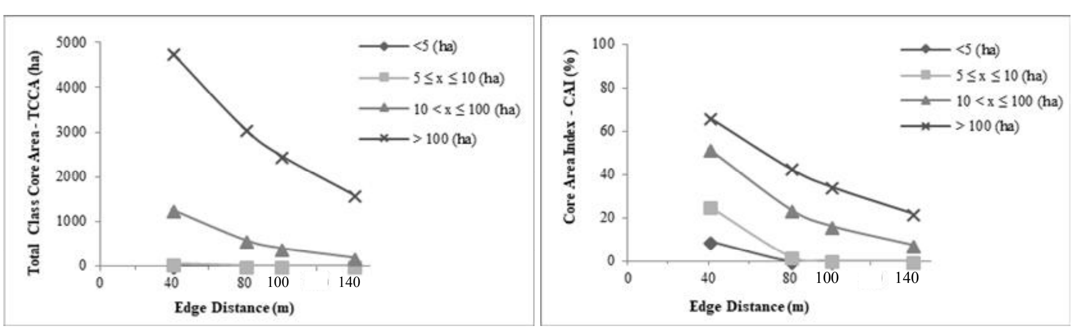

Fig. 3. Behavior of the total class core area and the core area index with the increase of edge distance in the size classes of native vegetation fragments in the municipality of Goiana, PE, Brazil

For Langevelde [27] the landscape fragmentation, besides restricting the movement of animals between habitats, also limits the fauna capacity to explore and select the ideal habitats, promoting competition for low quality fragments.

In this study, when analysing the proximity metric (MNN) it was observed that the individual size classes have a high degree of isolation. However, when analysing the proximity between all the fragments, without distinction of size class, the degree of isolation decreases expressively, reaching 88.31 m. This result demonstrates the smaller fragments importance for the landscape, possibly serving as connection elements between larger fragments. Awade and Metzger [28] when evaluating the habitat fragmentation effect on birds, observed that some bird species avoid crossing open areas with distances greater than 40 m.

Large fragments of native forest are important for the conservation of biodiversity and ecological processes; however, small remnants also play important roles throughout the landscape, and can act as ecological trampolines between large fragments, as well as serve as a refuge for several species [29,30,31].

Elevated levels of forest fragmentation, isolation and reduction of the fragments size causes several negative effects on the fauna and matter movements in the landscape. According to Saunders et al. [24], this occurs mainly if the intervening matrix prevents movement between the fragments. Seed dispersal, for example, can be highly sensitive to agriculture matrices.

The adjacent matrix to the study area is predominantly agricultural, with emphasis on sugarcane cultivation, which potentially increases the edge effect in the fragments, impairs seed dispersal and wildlife movement, and in some cases, reduces the remaining fragments.

For Eycott et al. [32], the matrices types that are most similar to the original vegetation are of better quality for the organisms because they can provide more movement between fragments.

Thus, in order to attenuate, at least partially, the impacts of loss or decrease of native habitats, the most viable alternative is to increase the quality of the matrix through land uses that provide substantial resources to the fragments, to facilitate the dispersion of fauna and flora creating low contrast in the landscape [22].

According to Pirovani et al. [11], the edge effect, understood as the differences of biotic and abiotic factors along an entire fragment edge in relation to its interior, may have several implications for the environmental balance, modifying the ecological interactions among fauna, flora and abiotic components.

About the edge metrics applied in this study, the TE values obtained for the very small and small classes were smaller than the values found for the larger fragment size classes. However, when comparing this edge value with its contribution in area, which is much smaller when compared to those of large fragments, a higher ED value was observed in the smaller fragments. These results allow inferring that a lower edge effect occurs in the large fragments, indicating a higher degree of conservation.

The high ED values found for the smaller size fragments are a worrisome factor, since the edge effect will be more prominent. According to Tabanez and Viana [33] and Juvanhol et al. [20], the problem of small fragments is the abrupt transition between the forest and adjacent areas, leaving the area susceptible to changes in landscape dynamics and microclimate. Thus, it is necessary to point out that fragments ≤10 ha should be monitored as a priority, under the risk of extinction over time, if not properly managed.

Another factor that influences the edge effect is the fragments shape. The results obtained for MSI and MFRACT indicated that the fragments of the very small and small classes have more circular and simple formats. Lang and Blaschke [34] reports that the more circular (MSI closer to 1) the shape of the fragments, the lower the influence of the edge effect will be. However, although very small and small fragments have presented more circular shapes, the edge effect is more intense in these fragments due to their sizes [35].

Based on the size of the fragments found in the study area and considering only the spatial analysis, the distance range limit under edge effect to estimate the core area of the very small fragments was 80 m, because values above that would eliminate the areas of these fragments. Mcgarigal and Marks [21] reports that the core area of a native forest fragment is a better indicator of the fragment quality than its total area and can be directly affected by the fragments edge and shape.

5. CONCLUSION

Most of the remnants found in the region are characterised by very small fragments which causes a decline in species richness, since the fragment area becomes smaller than the minimum area required for the survival of the populations.

The smaller fragments presented higher edge density and greater edge effect than the larger fragments, with progressive loss of the core area with the increase of the edge distance which causes a lower degree of conservation.

The fragments presented a high degree of isolation in all the analysed classes, however, when analyzing the degree of isolation among all the fragments, without a size class distinction, the isolation decreases notably, which indicates the importance of the smaller fragments for the landscape and its ecological processes.

The use of geotechnologies proves to be effective in the study of landscape ecology, being able to work as a guideline for structured decision-making practices in socio-environmental and economic public management, as a way to reduce the progress of natural areas degradation and forest fragmentation processes.

COMPETING INTERESTS

The authors declare no competing interests.

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