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Landscape Structure at Different Altitudes in Dry Areas

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Abstract

The objective was to analyze the forest landscape structure of fragments at different altitudes in dry region. In order to do so, RapidEye images acquired in the year of 2014 were segmented, identified the Forest and Other uses classes and classified. Categorical maps were made and inserted in raster format in the Fragstats software, and text files were generated for calculations of class-level metrics and landscape-wide and then analyzed. The results of the parameters determined that the most affected and fragmented environments are those with lower altitudes, because of the forest cover of these environments is under strong pressure, since they are surrounded mainly by the Agropecuarian class, providing more susceptibility to fragmentation and external influences. Therefore, using the metrics together it was verified that there is a high shredding and this shredding has relation with the altitudinal gradient, since the lower the altitude, the lower the connectivity and thus the lower forest cover.

Keywords: landscape ecology, metrics, remote sensing, dry forest, Brazil

1. Introduction

Anthropogenic actions to the environment transform continuous areas into fragments, impairing the quality and availability of natural resources. In the semi-arid regions, this damage is intensified, because in these areas there is an imbalance between supply and demand of these resources causing a loss of biological diversity and affecting the structure of the ecosystem.

In dry areas these exploratory actions are determinant in the aggravation of environmental issues related to the use of forest cover as a source of energy generation, resulting in the isolation and fragmentation of the landscape with predominance of extensive agricultural crops areas.

This environmental degradation has as main action the deforestation, which exploits in a predatory way to satisfy demands for charcoal and firewood for energy purposes. The energy inputs from the native vegetation of these regions meet the industrial and domestic needs, specially to supply the consumption of the poles of gypsum production.

Given this fact, the analysis and interpretation of the landscape structure are the first steps to comprehend spatially the region in a macro manner and generate information for future research and interventions. In this way, Landscape Ecology seeks to understand the structural and functional changes caused by human beings, to know and monitor the use of land and natural resources, presenting alternatives to reconcile farming and conservation (Zanella et al., 2012), considering the spatial interactions between cultural and natural units, thus including man in his system of analysis (Metzger, 2001). In order to answer questions, such as the degree of isolation between the fragments and the level of landscape shredding, it is necessary to quantify this structure, using metrics or landscape indexes, which present an analysis based on quick and objective answers.

Thus, this research sought to analyze the landscape structure of forest fragments at different altitudes in dry region.

2. Method

2.1 Location and Characterization of Study Areas

The study was developed in the region of Araripe, domain of the Brígida River Basin and located in the western part of the state of Pernambuco, Brazil.

The region has a pronounced aridity in the lower part, with precipitated annual totals varying between 400 and 500 mm and in the part corresponding to the Chapada do Araripe, rainfall increases, reaching averages between 700 and 800 mm; and the temperature ranging from 24 °C to 26 °C (Lopes, 2005).

The analyzed landscapes presented different dimensions, due to the fact they have predefined for further research. In this way, for the mapping and analysis of the landscape the buffer with distance of 2.5 km was executed, from each area, avoiding overlapping and the landscapes composed by each area and its respective buffer were analyzed. Sampling was carried out in three environments with different altitudes, being the Lowland environment with an altitude of up to 600 m, the Hill environment with heights between 600 and 750 m and the Plateau environment with altitudes above 750 m. The total sampling was in nine areas, being three in each environment and located in the municipalities of Araripina, Ipubi and Exú (Figure 1).

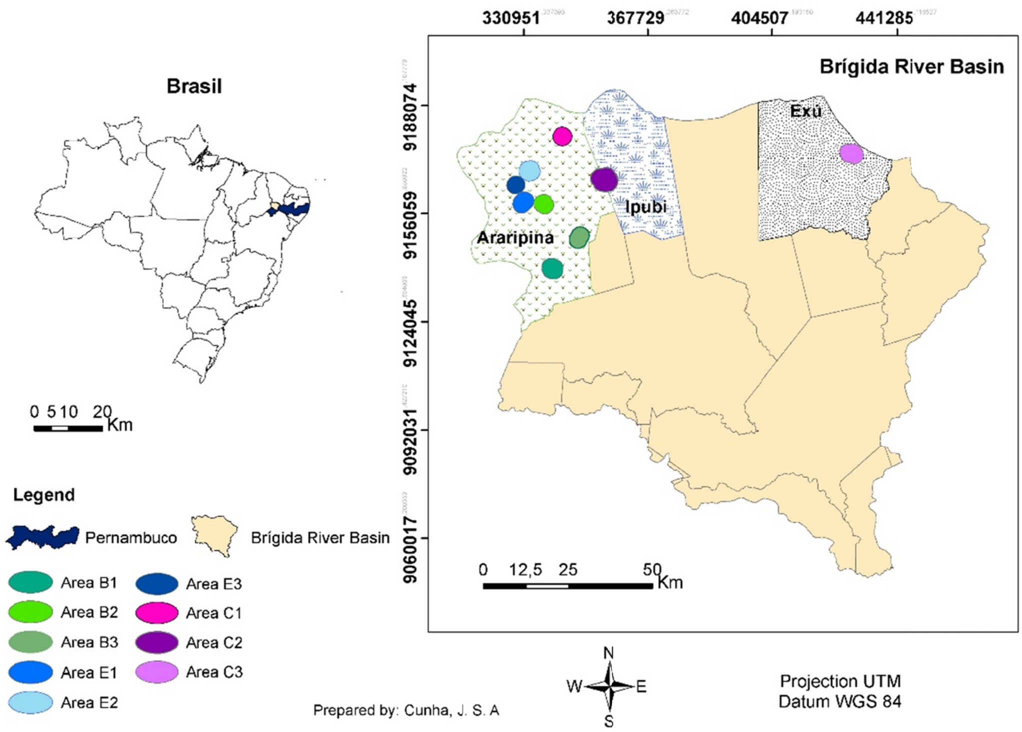

Figure 1. Location of study areas in the dry region

2.2 Data Base

Initially, RapidEye images were acquired with the characteristics and scenes covering the study dry region (Table 1). The scenes were provided by the Federal Government distributed in the GeoCatálogo of the Ministry of the Environment (MMA, 2016) and orthorectified (level 3A) with pixel size in the field of 5 (five) meters.

Table 1. Characteristics of RapidEye images obtained by MMA (Ministry of the Environment) for the Araripe region, Pernambuco, Brazil

Images	**Scene**	**Date**
	2435508	05/08/2014
	2435607	04/06/2014
	2435608	05/08/2014
RapidEye	2435609	31/07/2014
	2435611	31/07/2014
	2435612	26/05/2014
	2435507	22/07/2015

2.3 Digital Image Processing

Digital image processing, vectorization of thematic charts and visual interpretation were performed without ArcGis 10.2.1 software. They were imported as images to perform the mosaic and to cut the buffers, comprising a distance of 2.5 (two and a half) km. The images were analyzed by the color composition (R5G3B2) of the bands, along with contrast enhancement, to improve the quality under the subjective criteria of the human eye and segmented. The visual analysis and interpretation of the RapidEye images were complemented with field observations, identifying the classes Forest and Other uses. Following the training of the samples for the spectral recognition of each class and classified them by Maximum Probability. Categorical maps were prepared for the nine areas and the reliability of the digital classification of these maps was made by the confusion matrix using attribute data in ArcGis, analyzed in Microsoft Excel for Windows ™ 2016 and classified by applying The coefficient of Kappa (Cohen, 1960) ranging from -1 to 1 (Table 2).

Table 2. Quality of use classification and land cover according to Kappa coefficient intervals

Kappa Value	**Classification Quality**
< 0.00	Poor
0.0-0.20	Bad
0.20-0.40	Reasonable
0.40-0.60	Good
0.60-0.80	Very Good
0.80-1.00	Excellent

2.4 Preparation and Calculations of the Data for Landscape Analysis and Metrics Used

The analysis of the spatial patterns of the nine studied areas was performed from the categorical maps being inserted in raster format (.TIF) in the Fragstats software and generated text files for calculations of the class-level metrics and the whole landscape and then analyzed.

In order to calculate the landscape metrics, were selected indexes that quantified the elements of the landscape, estimating the area, density, shape and proximity. The metrics selected, based on McGarigal and Marks (1995):

(I) Area and density metrics: provide the dimensions of the fragments by type of land cover and the amount per unit of landscape area. At the class level were calculated the number of fragments (NP), the class area (CA) (area of all class fragments), the percentage of fragments of the same class in the landscape (PLAND) and the density of the fragment (AREA_MN) and its coefficient of variation (AREA_CV), since they are responsible for evaluating the average area of all the fragments and the variability of the Mean size of the fragments of all classes. In general, the metrics in question are the basis of landscape knowledge, discover the total area of a class exists in the landscape. These indices are key parameters of landscape composition, especially when the landscape is made up of a specific type of spot. In addition, they are appropriate for landscape comparison.

(II) Form metrics: reflect the spatial configuration of the landscape and are calculated based on the pixels of the image used as reference in the mapping of the ground cover, as a function of the perimeter/area of the fragments. At the soil cover class level (Forest and Other uses), the shape index was estimated by the mean size (SHAPE_MN) of the fragments that represent the category. It is a simpler measure and perhaps the measurement of the complexity of the form is more direct and the more trimmed and with less area, the greater the value of this index.

(III) Proximity metrics: refer to the degree of isolation and fragmentation of the remainder within a specified neighborhood (distance). The distance index of the nearest-neighbor (distance between fragments of the same vegetation type) (ENN_MN and ENN_CV) was calculated at the Forest class level and Other uses based on the Euclidean distance (in meters) between fragments edges of the same type. This metric represents the connectivity, since it measures the effort expended for between stains, and explicitly indicates the degree of stain insulation.

3. Results and Discussion

The analysis of the determination of the accuracy of the nine areas inserted in the Araripe region, the categories Forest and Other uses presented in the three environments values between the scale of 0.80-1.00, showing excellent quality for land use and coverage. The metric parameters (Table 3) evaluated show that in the Lowland environment there is a predominance of the Other uses class. This is due to the high presence of agricultural crops and pasture in this region, in addition to the disordered forest exploitation. The vegetation in the dry region suffered deforestation in disturbing areas with exposed soil patches, and the soils continue to be used by extensive livestock, mainly goats and sheep (Sousa et al., 2008; Fernandes et al., 2017b).

However, these parameters allow to affirm that in the Plateau environment, it behaves as the landscape matrix, due to the values of the occupied area (CA), the mean nearest-neighbor distance (ENN_MN) and the average size of the spots (AREA_MN). It should be understood that the matrix plays a fundamental role for the energy flow, the substances cycle and the species regime in the landscape (Lang & Blaschke, 2009).

Table 3. Values of the metric parameters selected for analysis of the landscape of the nine areas located in the semi-arid region

Environment	Area	Class	CA	PLAND	NP	PD	AREA_MN	AREA_CV	SHAPE_MN	ENN_MN	ENN_CV
Lowland	B1	Forest	1125.93	36.4	278	8.99	4.05	1046.02	1.5	61.65	0.21
		Other uses	1967.13	63.6	56	1.81	35.13	676.62	1.72	35.34	0.4
	B2	Forest	1329.06	50.61	299	11.39	4.45	1338.09	1.59	33.98	0.37
		Other uses	1296.78	49.39	87	3.31	14.91	785.04	1.83	45.37	0.34
	B3	Forest	1534.41	54.9	247	8.84	6.21	1313.93	1.56	32.26	0.39
		Other uses	1260.42	45.1	143	5.12	8.81	695.16	1.81	45.87	0.33
Hill	E1	Forest	1505.63	50.16	381	12.69	3.95	1192.7	1.64	28.02	0.45
		Other uses	1495.9	49.84	269	8.96	5.56	1222.63	1.64	29.96	0.45
	E2	Forest	2134.31	71.52	109	3.65	19.58	1018.75	1.57	29.08	0.47
		Other uses	849.96	28.48	199	6.67	4.27	627.85	1.75	45.58	0.33
	E3	Forest	1095.8	48.32	343	15.13	3.19	1162.47	1.66	27.99	0.46
		Other uses	1171.87	51.68	268	11.82	4.37	1481.47	1.5	27.88	0.4
Plateau	C1	Forest	1786.69	73.12	74	3.03	24.14	825.18	1.76	30.72	0.46
		Other uses	656.69	26.88	479	19.6	1.37	751.69	1.46	39.12	0.28
	C2	Forest	3864.18	84.19	148	3.22	26.11	1203.3	1.56	21.57	0.51
		Other uses	725.38	15.81	619	13.49	1.17	645.83	1.63	40.56	0.29
	C3	Forest	2573.88	78.17	152	4.62	16.93	1065.09	1.67	31.43	0.47
		Other uses	718.81	21.83	201	6.1	3.58	1047.22	1.78	53.34	0.22

Note. CA: total area of fragments; PLAND: Landscape percentage; NP: Number of fragments; PD: Density of fragments in 100 ha; AREA_MN: Mean fragment size; AREA_CV: Coefficient of variation of fragment sizes; SHAPE_MN: mean area of the shape index; ENN_MN: mean nearest-neighbor distance; ENN_CV: Coefficient of variation of the distance of the nearest neighbor.

In the B1 area, when evaluated the CA and PLAND metrics, it is observed that the Other uses class has a higher percentage in the landscape (63.60%) in the proportion of 36.40% of the Forest class, showing that in this area the matrix refers to class Other uses. The Forest class in B1 area showed a mean fragment size (AREA_MN) of 4.05 ha, an extremely low value for the class, especially when compared to the class of Other uses that exhibited an average of 35.13 ha.

According to the area metrics (CA and PLAND), in the B2 area, the Forest and Other uses classes virtually do not show any difference, since the Forest class has 1329.06 hectares, equivalent to 50.61%, and the class of Other uses with 1296.78 ha corresponding to 49.39%, totaling an area of 2625.85 ha. The B2 area has 386 elements, 299 of forest fragments, with mean size of fragments of 4.45 ha, showing values that according to Fernandes et al. (2017a) are more susceptible to degradation. In the other hand, the class of Other uses has an average size of 14.91 ha.

The B3 area has a total area of 2794.83 ha, formed by Forest with an area of 1534.41 ha (CA) with 55% (PLAND) of the landscape and with 1260.42 ha of Other uses corresponding to 45%, revealing that the dominant surface is the Forest, being the matrix in the landscape. The B3 area consists of 390 polygons (NP), of which 247 belong to the Forest class, with a mean size of 6.21 ha, and 143 the Other uses class, with an average size of 8.81 ha, show an increase in relation to the mean fragment size compared to areas B1 and B2.

For the Lowland environment, the average size of the spots showed lower values for the Forest class when compared to Other uses, and the coefficients of variation of this metric (AREA_CV) ranged from 1046.02% to 1338.09% for Forest class and 676.62% to 785.04% for Other uses, being considered high values, indicating polygons with average size values varied. The classes that exhibit the lowest values for this metric (AREA_MN) are the most fragmented according to McGarigal and Markus (1995).

The average size of the spots is considered a good indicator of the degree of fragmentation as a function of the number of fragments and the total area occupied by native forest (Valente, 2001; Souza et al., 2014; Mcgarigal & Marks, 2015). When associated with the density of fragments (PD), which exposes the amount of spots in an area of 100 hectares, Valente (2001) affirms that this association allows us to understand the different aspects of the structure of a landscape, including fragmentation.

In the Lowland environment, B2 area has the highest number of forest fragments per 100 hectares (11.39 frag./100 ha), followed by B1 area (8.99 frag./100 ha) and continued from B3 (8.84 frag./100 ha). The areas with the lowest values in the average size metric (AREA_MN) for fragments are those that presented the highest density (PD) of the same, alleging a more fragmented landscape (Valente, 2001; Souza et al., 2014). The B2 area is an exception, because although it reveals the highest PD (11.39 frag./100 ha), among the areas of the Lowland environment, it points out the second mean fragment size (4.45 ha).

Valente (2001) found in a sub-basin study the same exception, that even showing the highest PD had the second average size of units.

In this way, it is believed that B1 is the most fragmented. Due to its smaller value in relation to the average size of its fragments (4.05 ha), the percentage referring to Forest (36.40%) is lower than the Other uses class (63.60%) and presents the largest mean nearest-neighbor distance among the three areas of the Lowland environment, which was 61.65 m. This mean nearest-neighbor distance metric results in a medium isolation (Almeida, 2008) between native forest fragments and, as a consequence, a decrease in the species colonization capacity towards other forest fragments, causing disturbance in the migration of genes between animal and plant populations. This isolation causes clearings, which around the fragment may represent a barrier for many species of birds adapted to live inside the forests, which prevents the flow of individuals between the fragments, and over time may decrease the genetic variability of these populations (Gimenes & Anjos, 2003).

In addition to the average size of the units, the forms of the spots also influence the level of impact of the edge effect on the vegetation. This metric evaluates the complexity of the shape of a stain by comparing it with an optimized form of a circle, in which a value of 1 (Lang & Blaschke, 2009) is established. Therefore, the more the shape of the landscape element deviate from the round shape the greater the value of the metric. In this Lowland environment, Forest stains presented values for the shape metric (SHAPE_MN) between 1.50 and 1.83. Similar results were found by Calegari et al. (2010) and Souza et al. (2014) with values between 1.47 and 1.84 and described as low values, which refers to a landscape with fragments of simple form with a tendency to become irregular, indicating that the fragments are not so vulnerable to external influences.

Regarding the Hill environment, it is observed that E1 area, with a total area of 3001.53 ha, is formed by 650 units (NP) with 381 fragments referring to the Forest class and 269 units of Other uses class. By the data of the metrics (CA and PLAND), as studied classes practically did not obtain, due to the Forest class exhibit an area of 1505.63 ha equivalent to 50.16% and 1495.90 ha corresponding to 49.84% of the class of Other Uses. The Forest demonstrated a value of 3.95 ha for a mean fragment size metric, a low value for a class, which could lead to loss of habitat.

The E2 area is composed of 308 elements, of which 109 fragments are of Forest and 199 units of the class Other uses, with 2134.31 ha corresponding to 71.52% of Forest of the total area of 2984.27 ha, demonstrating that the matrix of this E2 area is, predominantly, Forest, assured by the values for the average size of the units, in which the class Forest has values of 19.58 ha and the class of Other uses a value of 4.27 ha.

In the E3 area, whose total area is 2267.66 ha, 1095.80 ha refers to Forest, equivalent to 48% of the whole landscape, and 1171.87 ha with 52% of the class Other uses. This area consists of 611 units, of which 343 are Forest fragments, with an average size (AREA_MN) of 3.19 ha and 268 units of Other uses with a size of 4.37 ha, resulting in an area with high fragmentation, since there is a high amount of units with low values for the average metric referring to Forest.

For the Hill environment, the coefficients of variation of the AREA_MN metric changed from 1018.75% to 1192.70% (Forest) and 627.85% to 1481.47% (Other uses), which shows the high amplitude in size of the units.

In general, the size of the fragments can affect the dynamics of the populations, because they do not have sufficient habitats for the permanence of certain species. This effect of decreasing habitat size is more intense in smaller fragments (Metzger et al., 2009). The mean size metrics indicated, in the areas E1 (3.95 ha) and E3 (3.19 ha), exaggeratedly lower values for the Forest class, when compared with the E2 area (19.58 ha), which, in addition to possess higher values among the fragments for AREA_MN presents smaller values when comparing with the class of Other uses (4.27 ha).

These values of the metric of average size integrated to the results of the metric of density of fragments (PD) allow understanding which area is more disturbed. In view of this, E3 area exhibits values of 15.13 frag./100 ha, followed by E1 with 12.69 frag./100 ha and continued from E2 with 3.65 frag./100 ha. These values for the environment confirm that the areas with the lowest values in the mean size metric (AREA_MN) for fragments are those that presented the highest density (PD) of the same, alleging a more fragmented landscape (VALENTE, 2001), since E3 area is the one with the smallest mean size (AREA_MN) of their forest fragments and indicates a higher density (PD) of the same, demonstrating that this area compared to others in the Hill environment is the one that exhibits the most fragmented landscape.

Taking this association (AREA_MN and PD) into account, it's noticed that the Hill environment is more troubled when compared with the Lowland environment. However, the Hill environment has less insulation between spots with almost indifferent values, obtaining a mean of 28.4 m., noting that this environment has a greater possibility of restoration. Knowing that plant populations in fragmented landscapes may be directly related to the degree of isolation as well as to the persistence, it is necessary greater connectivity of the spots, since a distinct matrix from the forest vegetation and containing isolated remnants ends up affecting that the populations receive individuals from others. Thus, a greater degree of linkage between existing populations in forest remnants allows a flow of individuals between the fragments (Metzger et al., 2009). In this Hill environment the values for the shape metric (SHAPE_MN) of Forest remnants range from 1.57 to 1.66 and are values considered as simple fragments with irregular predisposition. Moreover, the irregular shape of these fragments result in greater vulnerability to the manifestation of a border effect, especially those with smaller area, due to the greater interaction with the matrix (Vidolin et al., 2011).

As for the higher altitude environment, Plateau, it can be observed that in the three areas the mean size (AREA_MN) of the forest fragments are higher when compared to other uses. The C1 area has a total area of 2443.38 ha with 1786.69 ha (73.12%), belonging to the Forest class, and 656.69 ha (26.88%) to Other uses. The landscape is composed of 553 units (NP), of which 74 are fragments of Forest and has a mean size of 24.14 ha and 479 units with a mean size of 1.37 ha of Other uses.

In the C2 area, it is verified that 84.19% of the landscape are areas with Forest and 15.81% of other uses occupying a total area of 4589.56 ha. The area is formed by 148 fragments of Forest, which have 26.11 ha in relation to the value of the mean size metric.

The C3 area consists of 353 units, of which 152 are of the Forest class and 201 are other uses. The landscape has a total area of 3292.69 ha, in which 78.17% are of Forest and presented mean values (AREA_MN) of 16.93 ha.

In the Plateau environment the matrix is of Forest in all three areas and show high mean sizes (AREA_MN) when comparing with the class of Other uses and, mainly, when counterposing with the mean sizes of the fragments Forest of the other environments (Lowland and Hill). The coefficients of variation differ from 825.18% to 1203.30% for the Forest classes and from 645.83% to 1047.22% for other uses, indicating average size of the elements with high spatial heterogeneity.

The mean size data added to the values of the density of fragments (PD) shows that the C3 area has the smallest mean size (16.93 ha) and also a higher density of fragments (4.62 frag/100 ha), stating as a more fragmented area in the Plateau environment. For the worsening of the fragmentation factor can also be observed by the greater distance between the fragments (31.43 meters) in the C3 area.

The Plateau environment also determines units with an irregular shape tendency (SHAPE_MN), since the values of this environment are between 1.46 and 1.76.

The results of the metrics determine that the most affected and fragmented environments are the Lowland and Hill environments, because of the forest cover of these environments is under strong pressure, since it is surrounded mainly by the farming class, making it more susceptible to fragmentation and to external influences. The Plateau environment was considered to be the least fragmented, however, because of the introduction of wind farms that entail forest suppression, regardless of whether it is defended as clean energy, its introduction can disrupt several ecological processes.

Therefore, it is necessary to understand the landscape as a whole and the relationship with the phenomenon, because a single value does not show the real situation of the landscape, and the combination of results is essential for an accurate analysis.

4. Conclusions

In dry regions, native vegetation is highly fragmented, due to the rotation of land use and disorderly suppression, especially in areas with low altitudes that facilitate the process of replacing forest areas.

This process of fragmentation of the native vegetation of dry regions changes in relation to the altitudinal gradient, because the lower the altitude, the greater the degree of isolation and, consequently, the lower the forest cover.

The characterization of the landscape structure, using the metrics together, demonstrated an environment with high grinding, transforming continuous forest remnants into small and disconnected fragments. However, the high number of small fragments is essential in restoring connectivity. Thus, it is advisable to promote strategies for the union of these fragments aiming at the formation of larger fragments by means of management techniques that favor the establishment of natural regeneration, and resulting in a forest matrix in these dry areas.

The quantification of the structure parameters allowed to describe the spatial patterns of the environments in dry areas, providing preliminary data that can subsidize decisions in more sustainable strategies of action. Since the functionality of the natural areas will be compromised, due to the reduced connectivity of the fragments, if this exploration is continued. Thus, public policies are needed to stop this process, aiming at a more sustainable exploitation of wood and non-timber forest products, as well as the use of GIS in this planning, supporting with regard to real situation detection with flexible combination of different layers of data, thus facilitating sustainable actions in these semi-arid regions leading to the improvement of landscape integrity.

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