LANDSCAPE STRUCTURE IN THE UPPER COURSE OF THE BANABUIÚ RIVER, STATE OF CEARÁ, BRAZIL

ESTRUTURA DA PAISAGEM EM TERRAS DO ALTO CURSO DO RIO BANABUIÚ, ESTADO DO CEARÁ.

Clécia Cristina Barbosa Guimarães
Universidade Federal do Ceará - UFC
Fortaleza, CE, Brasil
e-mail: clecinha@gmail.com

Gustavo Souza Valladares
Professor do Programa de Mestrado e Doutorado em Agronomia
Universidade Federal do Piauí - UFPI
Teresina, PI, Brasil
e-mail: valladares@ufpi.edu.br

Claudia Miranda Martins
Professora do Departamento de Biologia
Universidade Federal do Ceará - UFC
Fortaleza, CE, Brasil
e-mail: claudia.miranda.martins@gmail.com

Veridiana Maria Sayão
Mestranda da Escola Superior de Agricultura Luiz de Queiroz- USP
Piracicaba,SP, Brasil
e-mail: veridiana.sayao@usp.br

Recebido em: 21/04/2015

Aceito em: 01/04/2016

Abstract

Current researches report that man-driven land use is directly related to the process of degradation of original vegetation cover, once natural vegetation needs to be removed in order to proceed with different land uses, leading to holistic modifications in the landscape. In the central arid region of the state of Ceará, Brazil, agriculture and pasture practices are the main drivers of vegetation fragmentation and landscape changes. Land Use and Land Cover (LULC) maps are widely used in the evaluation of natural landscape fragmentation, specially the approach of metrics that quantify the landscape structure. Therefore, these metrics, found in an extension of ArcGIS 10, were used on a land use and land cover map of a polygon located in the central arid portion of the state of Ceará, generated from MaxVer supervised classification, aiming to characterize the landscape structure and infer about how degraded vegetation is. The LULC map indicated that landscape is structured in eight classes: Urban Area, Agriculture, Water Body, Pasture, Bare Soil, Riparian Vegetation, Caatinga Open Shrublands, and Caatinga Dense Shrublands. The region has a significant amount of native vegetation cover (65%), however it is highly fragmented in ecologically unstable regions that present small areas and large perimeters (giving them many entrances), vulnerable to the edge effect and susceptible to extinction in a short scale.

Keywords: Fragmentation; Caatinga; Metrics; Semi-arid.

Resumo

O uso e ocupação antrópica das terras são atividades diretamente relacionadas ao processo de degradação da cobertura vegetal original, uma vez que a vegetação natural precisa ser retirada para que essas atividades possam tomar o lugar, causando modificação na paisagem como um todo. No Sertão Central do Estado do Ceará, percebe-se que as práticas de agricultura e pastagem são as principais responsáveis pelo processo de fragmentação da vegetação e modificação da paisagem. Mapas de uso e cobertura das terras são bastante utilizados na avaliação da fragmentação da paisagem natural, usando sobre eles métricas que quantificam a estrutura de uma paisagem. Assim, essas métricas foram utilizadas sobre o mapa de uso e cobertura de um polígono localizado no Sertão Central do Estado do Ceará com o intuito de caracterizar a estrutura da paisagem e inferir o quanto de sua vegetação natural apresenta-se degradada. Percebe-se, pelo mapa de uso e cobertura das terras, que a paisagem está estruturada em oito classes, sendo elas: Área Urbana, Agricultura, Corpo Hídrico, Pastagem, Solo Exposto, Vegetação Ripária, Caatinga Arbustiva Aberta e Caatinga Arbustiva Densa; e que a região tem uma porcentagem significativa de cobertura natural (65%), mas ela está bastante fragmentada em manchas ecologicamente instáveis que apresentam pequenas áreas e grandes perímetros (que lhes assegura muitas reentrâncias), vulneráveis ao efeito de borda e suscetíveis a desaparecerem em pouco tempo.

Palavras-chave: Fragmentação; Caatinga; Métricas; Semiárido.

1. INTRODUCTION

In the ecogeographical region of Caatinga there is a set of physical and climatic contrasts that, coupled with anthropic activity, determine the emergence of different types of landscape mosaics (FREITAS, 2007). With technological advances, the great landscape domain diversity has been modified, with the natural landscape being replaced by the urban landscape and the farm landscape, this last one characterized by agricultural activities (FERRAZ; VETTORAZZI, 2003; SANTOS et al., 2008).

In the state of Ceará, Brazil, approximately 60% of native vegetation cover was already degraded (COSTA et al., 2012) due to logging activities, cattle, goat and sheep ranching or shifting cultivation, generating an enormous mosaic of areas in different regeneration conditions (SAMPAIO, 2010). As a consequence, the flora and the vegetation physiognomy are being markedly altered and reduced to small landscape fragments (CASTELLETTI et al., 2004; MACHADO et al., 2006).

According to Termorshuizen and Opdam (2009), the knowledge of landscapes physical characteristics, including the identification and quantification of its structure, is necessary for a good sustainable development (balance among landscape patterns, ecological processes and human needs). Thus, knowing which services can be obtained from each specific landscape is important, once Landscape Ecology needs to focus not only in preserving actual landscapes and projecting future ones that maintain landscape patterns and processes, but in ensuring that ecosystem services, from which people actually need, are maintained and not exhausted (PEARSON; GORMAN, 2010).

Considering landscape characterization, indices have been used that quantify its composition and spatial configuration (TURNER; GARDNER, 1990; McGARIGAL; MARKS, 1995) such as the index of shape, area and perimeter of fragments; proportion perimeter/area; Euclidean distance and others. In order to calculate a wide variety of existent metrics, a few programs were developed, like FRAGSTATS (McGARIGAL; MARKS, 1995) and extensions developed and integrated to Geographic Information Systems (GISs) such as V-LATE (TIEDE, 2004) in ArcGIS.

The present study is directed to the quantification of the landscape structure from an area located in the ecogeographical Caatinga domain, once the ecological and economical importance of Caatinga and the high level of alteration the landscape is undergoing justify the realization of planning, looking forward conservation purposes and rational use of its natural resources. In this manner, land use and environmental, social and economical sustainability can be achieved (METZGER, 2001).

Using Land Use and Land Cover (LULC) maps of the region, generated from RapidEye system of sensors and Landscape Ecology metrics as well, it was possible to characterize the landscape structure and infer how much of its vegetation is fragmented; through Principal Component Analysis (PCA), it was possible to improve the understanding of similarities between LULC classes.

2. MATERIALS AND METHODS

2.1 Characterization of the study area

The study region has an area of approximately 1.490 km and is located in the arid central portion of the state of Ceará, in the microregion of Senador Pompeu, in the Banabuiú watershed. It is placed in 24S zone, referenced to the projection system Universal Transverse Mercator (UTM) (FIGURE 1); it features hot semiarid climate, with rainfall concentrated from January to April, having an average rainfall of 800-1500 $mm.ano^{-1}$ and average temperature of 25º C (IPECE, 2007a; IPECE, 2010; VIANA, 2010).

Extensive livestock farming and traditional slash and burn agriculture are the main activities that occur in the region and are essentially responsible for the current degradation level of natural vegetation. The region encompasses portions of Open and Dense Caatinga Shrublands, Caatinga Forest (Thorny Deciduous Forest), Dry Forest (Semi-deciduous Tropical Rainforest) (IPECE, 2007b) and Riparian Vegetation.

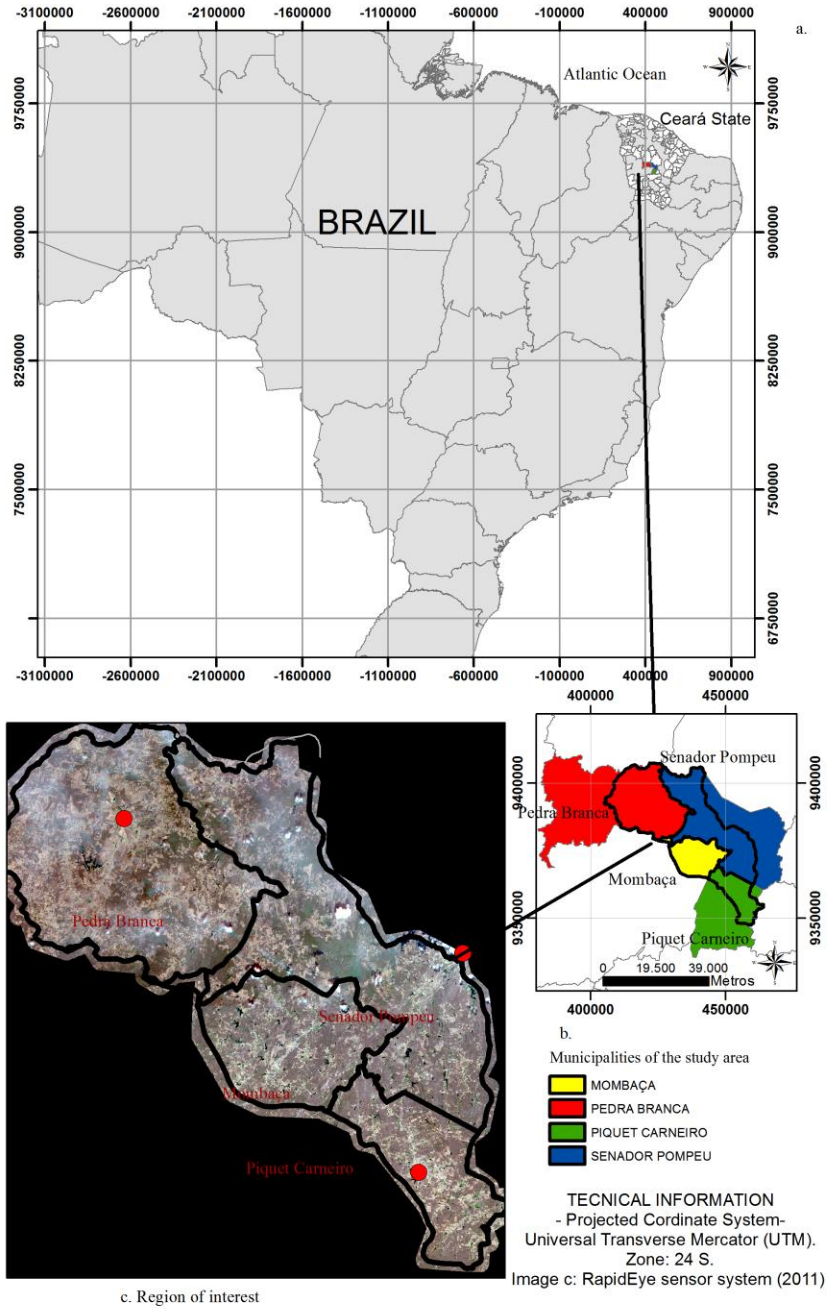

Figure 1. Location of the study area in the state of Ceará, Brazil. (Letter "a" represents the state of Ceará (Brazil), with contour lines in the four municipalities that integrate the study area. Letter "b"

represents the expansion of the municipalities that integrate the region of interest; it is delimited by thick black lines. Letter "c" represents the satellite image of the study area, area delimitation (thick black lines) and the municipal seats (dots)).

The relief provides the landscape a unique feature, as it is very diverse, ranging from flat to mountainous. The prevailing altitude in the study area ranges from 200 to 300 m, in the region characterized by dissected pediplanes, although there is also elevation higher than 700 m (VALERIANO; ROSSETTI, 2011) in areas characterized by mountain ranges and residual ridges. According to Jacomine et al. (1973) and EMBRAPA (2006), the main soils that occur in the region are Chernosols, Luvisols, Ultisols, Leptosols and Planosols. Soils are originated from Precambrian rocks, predominantly metamorphic rocks.

2.2 Analysis of landscape structure

The LULC map was elaborated through the supervised classification (pixel by pixel) of satellite images of the study site obtained by the RapidEye system of sensors, from September and December of 2011, with spatial resolution of five meters. The types of land use and land cover were visually interpreted from bands 3, 2 and 1, through the true-color composite, and the Maximum Likelihood classification algorithm, available in GvSIG 1:11 software was used.

Before classification, 20 sample points of each one of the LULC classes identified during field visits that occurred in February and April of 2012 were collected. The sampling points were located in the satellite image in order to proceed with the automatic classification processing. The used vegetation classes were obtained from the IPECE map (2007b) plus the Riparian Vegetation information, identified in the area during the field visits.

The raster output of the LULC map resulting from classification was transferred to the ArcGIS 10.1 software and homogenized. Some mistaken classes were corrected after transformation of the raster format in a vector one; neighboring polygons of the same class were incorporated, forming a single polygon; and polygons smaller than 1000 m² were eliminated to facilitate the interpretation of classes. All of these methods were intended to improve the quality of the map, which was assessed by the Kappa index (LANDIS; KOCH, 1977). This index allows to determine from the error matrix (or ground truth) the agreement between the data obtained by satellite image, updated with information acquired in the field, and the data resulting from the automatic classification. This index is an indicative of the accuracy of the mapping process.

The metrics available in the V-LATE 2.0 beta, which is an extension of ArcGIS that uses seven different metrics categories (area, shape, core area, edge, proximity, diversity and analysis subdivision) (TIEDE, 2004), were applied in the LULC map shapefile. The use of landscape metrics of fragment and class enabled the quantification of fragment patterns within each class (TABLE 1).

TABLE 1 - Metrics of vegetation fragments used in the landscape structure analysis

Metrics	Symbol	Formula	Variation
Area	A	aij (m²)	A>0 unlimited
Perimeter	P	Pij (m)	P>0, unlimited
Shape	I	25pij/ √aij	I≥ 1, unlimited. I= 1 when the fragment increases without limits, the shape becomes more irregular
Proportion Perimeter/Area	PARA	pij/aij	PARA > 0, unlimited.
Euclidean Distance	NNDist	Hij	NNDist > 0, unlimited.
Total number of fragments in a class	NP	Ni	NP≥ 1, unlimited.

Source: Mcgarigal; Cushman; Ene (2012). Legend: aij= fragment area ij in a landscape location; pij= fragment perimeter; ij in a landscape location; hij= distance (m) from fragment ij to the nearest neighbor from the same class, based on the edge-to-edge distance; ni= number of fragments from landscape class i; eik= total length of the edge of a class i in the landscape.

The analysis based on the values found in the fragments metrics contributes to a consistent understanding of the landscape spatial pattern, since the fragments are the main elements that define the structure thereof (BATISTELLA, 2001). These metrics were used in order to quantify the landscape composition and configuration, to identify the dominant classes and to assess the fragmentation process.

The perimeter and the perimeter-area relationship are metrics that quantify and qualify the fragments in relation to the edge effect, which is an important aspect studied by ecological researchers because it may not guarantee the ecological stability of the fragment (VOLOTÃO, 1998). According to Metzger and Dècamps (1997), the edge effect is one of the main processes associated with fragmentation as it promotes deep changes in vegetation structure and in biological dynamics.

The perimeter metric indicates the number of entrances present in the fragment. For fragments of the same area within the same class, which have high perimeter variability (with a few ones having higher values than others do), those with larger perimeters have a high number of entrances or edges, and consequently, present high fragmentation.

According to Volotão (1998), the shape index will have value equal to one when the fragment presents the simplest shape (square) in the landscape. This form is effective for the conservation of internal resources, since the perimeter exposed to external effects is minimized (HARRIR; KANGAS, 1979 apud FORMAN, 1995). For Volotão (1998), the nearest neighbor metric is defined as the distance from one fragment to the fragment that is around it, from the same class. The author indicates that this metric quantifies the landscape configuration and is based on the edge-to-edge distance. When fragments are more isolated, the index has high values, and this values increase as the isolation gets more critical.

The other metrics of classes used in this study (total area, mean of total area, standard deviation of the total area, total perimeter, mean of shape index, mean of perimeter-area ratio) are a more generalized representation of fragments metrics and were utilized more specifically in this study for statistical analysis.

2.3 Principal component analysis

Because this study has many variables that may be correlated with the analyzed LULC classes, Principal Component Analysis (PCA) was performed, having as variables the following class metrics: number of fragments (NP), Total Area (CA), Average Area (MPS), Standard Deviation of Mean (PSSD), Total Perimeter (TE), Perimeter Mean (MPE), Mean of Shape Index (MSI) and Mean of perimeter-area ratio (MPAR).

The class metrics represent the totality of which was measured for fragments belonging to each class, and ACP was used in order to evaluate which of them best correlate with the found classes (best explain the variability), and to know how many factors are necessary to explain the used metrics and which classes best correlate with each other. The fragments metrics were not used because they form a number of variables significantly high in quantity that makes correlation analysis unfeasible, and at the class level, the specific patterns within the landscape become clearer (BATISTELLA, 2001).

The correlation matrix was made according to the Pearson linear correlation analysis, which measures the degree of correlation between variables, two by two, and the closer to one (positive or negative) they are, more correlated the selected variables are.

In PCA analysis, data were standardized in order to have mean equal to zero and variance equal to one; the analyses were performed in the standardized data array. The factors that relate to information of all surveyed metrics were calculated. Each LULC, which was defined before by the average values of the landscape metrics, was redefined by the new variables (factors), which enables its location as a point in a two-dimensional graph and the closer the major points are, greater their similarities will be. This can be used as a tool in the grouping of LULCs and thus assist in explaining the dynamic of use and coverage of lands.

3. RESULTS AND DISCUSSION

3.1 Landscape structure

The classes found in the LULC map are: Urban Area (AU), Agriculture (A), Water Body (CH), Pasture (P), Exposed Soil (SE), Riparian Vegetation (VR), Open Shrub Savanna (CAtA) and Dense Shrub Savanna (CAtD) (FIGURE 2). The map was classified as good quality as it presented the Kappa accuracy index value of 0.9.The total area of each class is shown in FIGURE 3 and the largest class was CAtD, occupying approximately 37% of the area.

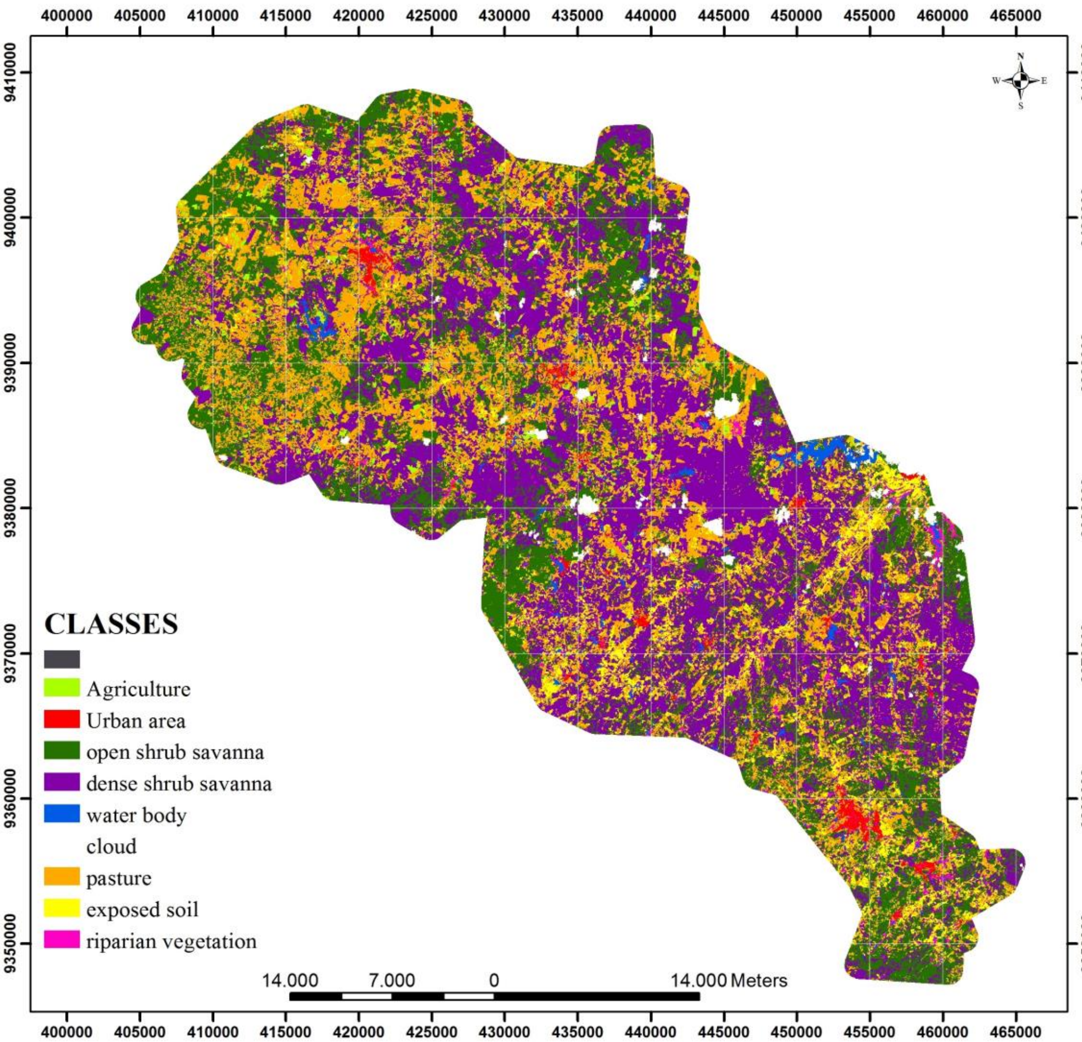

Figure 2 - LULC map from the region of interest.

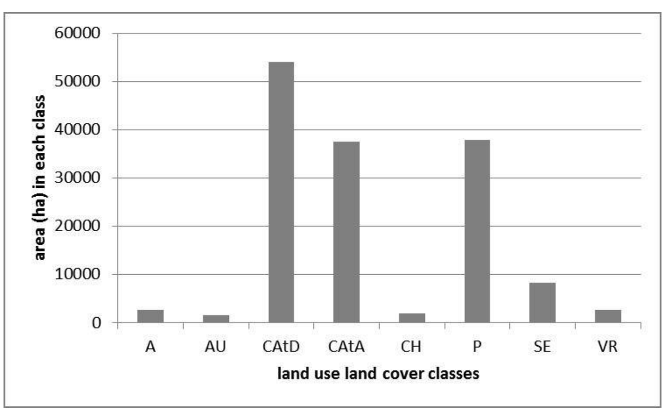

Figure 3 - Total area (in hectares) of each LULC class in the region of interest.

Source: Clécia Cristina Barbosa Guimarães (2012). Legend: A – Agriculture; AU – Urban Area; CAtD – Dense Shrub Savanna; CAtA – Open Shrub Savanna; CH – Water Body; P – Pasture; SE – Exposed Soil; VR – Riparian Vegetation.

The percentage of landscape modification, which characterizes man-driven actions in the region, can be calculated by the sum of the classes Agriculture, Pasture, Exposed Soil and Urban Area, which constitute 35% of the area, while the classes Dense Shrub Savanna, Open Shrub Savanna, Water Body and Riparian Vegetation, representing the natural landscape, constitute 65% of the area.

The presence of Open Shrub Savanna in the region is a consequence of human activity coupled with environmental factors, which hinder and delay the regeneration of natural vegetation (ALVES et al., 2009). There are lentic water bodies in the area that are originated from anthropogenic modification of dense native vegetation into open vegetation and due to dam construction.

A total of 70,897 fragments were found, predominantly in the classes Open Shrub Savanna, Pasture and Dense Shrub Savanna (TABLE 2). The highest proportions of large fragments were also found in the same classes (TABLE 3) but including Urban Area, which has fragments larger than 100 hectares due to central locations of each municipality.

TABLE 2 - Number of Fragments (NP) of each class.

Classes	NP	% NP
AU	488	1
CH	1339	2
A	2425	3
VR	3455	5
SE	10061	14
CAtD	15289	22
P	15764	22
CAtA	22076	31

Source: Clécia Cristina Barbosa Guimarães (2012). Legend: A – Agriculture; AU – Urban Area; CAtD – Dense Shrub Savanna; CAtA – Open Shrub Savanna; CH – Water Body; P – Pasture; SE – Exposed Soil; VR – Riparian Vegetation.

These data should indicate a good preservation of the landscape, but in all classes small fragments predominate (TABLE 3), which, for the natural vegetation fragments, indicates that larger fragments are subdivided. According to Lovejoy (1997), there is a significant fragmentation of the landscape since it is restricted to small fragments surrounded by many fragments of human activity.

TABLE 3 - Percentage of small, medium and large fragments in each LULC class.

Classes	Small fragments (0-10 ha)	Medium fragments (>10-100 ha)	Large fragments (> 100 ha)
AU	96.1	3.3	0.6
CH	98.4	1.5	0.1
A	98.7	1.3	0.0
VR	99.2	0.8	0.0
SE	99.0	0.9	0.1
CAtD	97.7	2.0	0.3
P	96.3	3.3	0.4
CAtA	98.0	1.7	0.3

Source: Clécia Cristina Barbosa Guimarães (2012). Legend: A – Agriculture; AU – Urban Area; CAtD – Dense Shrub Savanna; CAtA – Open Shrub Savanna; CH – Water Body; P – Pasture; SE – Exposed Soil; VR – Riparian Vegetation.

The cause of this process is in agreement with Tabarelli et al. (2004). According to these authors, the natural landscape fragmentation of neotropical regions is usually associated with human settlement and their livelihoods. Although the authors cite as examples only the Amazon and the Atlantic Rainforest regions, the analyzed Caatinga region clearly fits within the same context, because small fragments of natural vegetation emerge due to the inclusion of other unnatural fragments resultant from the human needs of property and livelihood.

Andrade-Lima (1981) divided the Caatinga in two strata, tree stratum and shrub stratum, in which predominates, in almost all species, the deciduousness of the leaves on other forms of resistance to water stress; and a plant community moderately rich in cactuses and bromeliads added to other thorny species and several endemic ones. The variations found in Caatinga strata are considered by the author not only as the result of climatic and edaphic variations, but also as resultant from human activities that cause the reduction of large patches of natural vegetation.

The consequence of this predominance of small patches in the landscape is the loss of many environmental services, since the large natural vegetation patches are the only structures in a landscape that protect aquifers and interconnect river networks, maintain and protect viable populations of many species and provide natural disturbances events that are essential for the maintenance of population’s heterogeneity. Besides this, the species extinction rate tends to be high in small and low-quality patches (FORMAN, 1995).

Despite this, small patches are also important for the landscape, because according to the same author, they can serve as wildlife corridors that aid in dispersing species and in protecting scattered small animals; or even serve as occasional habitat for species restricted to small fragments and offer diversity to the landscape. However, these small patches do not replace in value and function large patches, as in fact they complement them. A greater amount of large natural vegetation patches supplemented by small ones is necessary in order to improve the structure of the study site landscape.

The next presented metrics were performed only for the following classes: Riparian Vegetation, Open Shrub Savanna and Dense Shrub Savanna, given that fragmentation occurs in the intact natural vegetation and this study is focused in the degradation of these natural areas in the landscape.

3.2 Perimeter and Perimeter-Area Relationship

As shown in FIGURE 4 (a, b and c), there is a greater variability of the perimeter data for small and medium-sized fragments, indicating that these groups are growing in edge.

Smaller fragments are more degraded as a result of environmental damage that the edge effect leads to plant species. Laurance et al. (2000), studying the landscape fragmentation consequences for large trees located on the edges of Amazon Rainforest fragments, found that plant species located on fragments edges, in addition to man-made damages, had many ecological damages such as uprooting and breakage of larger individuals and increased competition for smaller species with invasive and opportunistic ones. Thus, the mortality for native smaller individuals became higher, reducing further the fragment size and increasing its edge.

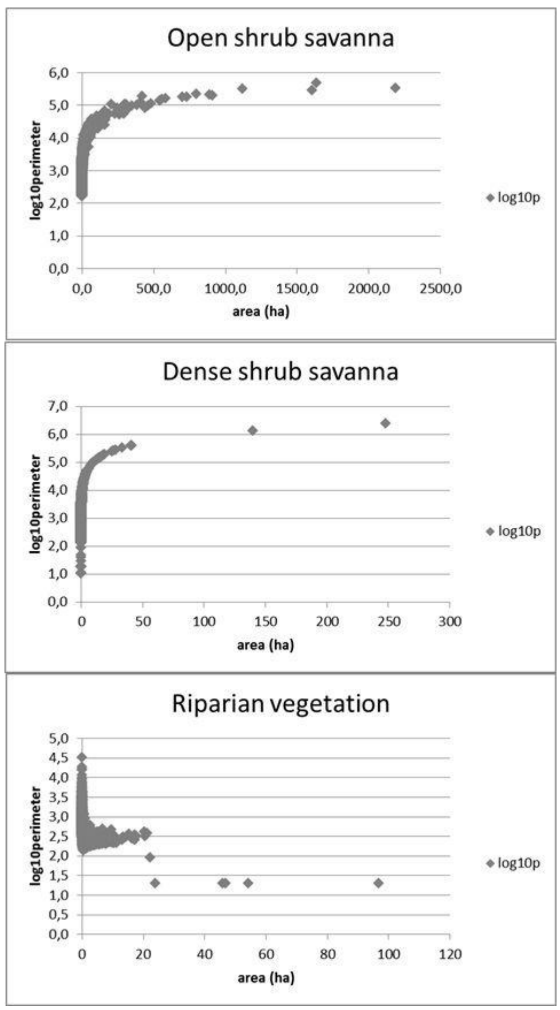

Figure 4 - Perimeter Variability for fragments from Open Shrub Savanna (a), Dense Shrub Savanna (b) and Riparian Vegetation (c).
Source: Clécia Cristina Barbosa Guimarães, 2012.

The fragments of Dense and Open Shrub Savanna over 30 hectares, and Riparian Vegetation over 12 hectares presented little or inexistent perimeter variation between fragments of the same area. These larger patches, after the edge is established and no growth thereof is observed, remain as more stable fragments regarding the fragmentation process. The increased stability of these fragments may be due to the large core area they present in comparison to its lower edge area. Thus, the species located inside them undergo much less ecological damage (LAURANCE et al., 2000) stabilizing the fragmentation process therein.

The perimeter-area relationship qualifies the edge effect: the higher the value of this metric, the greater the edge effect in the fragment. As the fragments increase in size, the edge effect on them decreases (FIGURE 5 – a, b and c).

Thus, the entrances of large fragments attribute to them a lower edge effect, showing in all three classes a lower metric value, being the lowest (0.01) value attributed to a Dense Shrub Savanna fragment of 119 ha in area and 8,438 m in perimeter. The highest value of the metric (0.8) was found in all small fragments of the three classes that have 0.0025 ha in area and 20 m in perimeter.

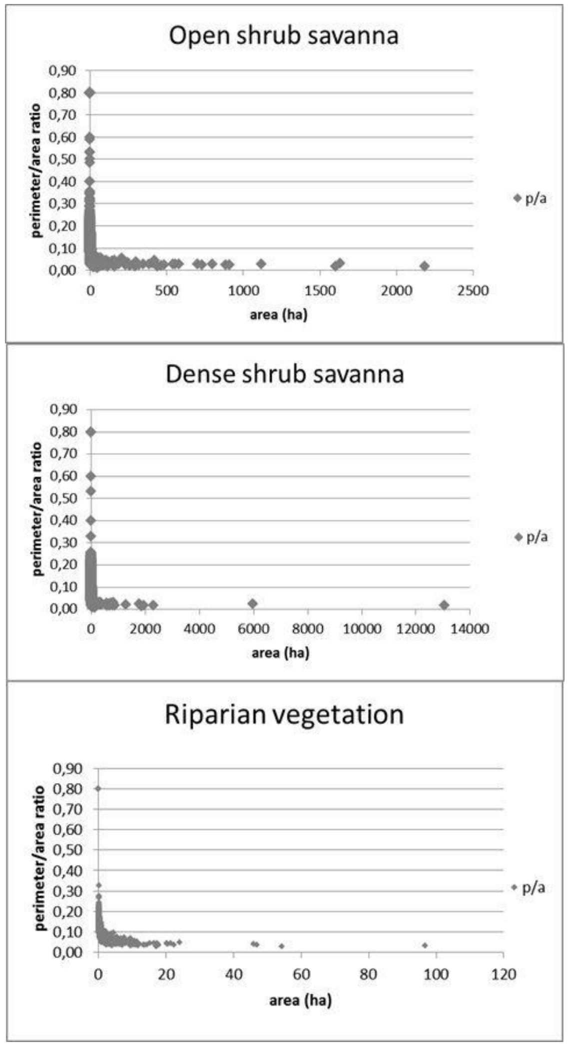

Figure 5. Edge effect relative to the size of the Open Shrub Savanna (a), Dense Shrub Savanna (b) and Riparian Vegetation (c) fragments.
Source: Gustavo Souza Valladares (2012).

3.3 Shape Index

The value of the shape index ranged from 1 (one) to 61, with 21.25% of fragments from the three classes presenting the lowest value. Approximately 65% of the fragments from the three classes showed shape two (TABLE 4). Almost all of the fragments that have the shape index equal to one and two (99.92%) have up to 10 hectares area, indicating that these fragments are very unstable, since they have very low shape and are small in area. Fragments that have large areas and fewer cuttings are less susceptible to external disturbances, since the edge effect is minimized by the core area (MILAN; MORO, 2012).

According to Forman (1995), in order to perform various key functions, the ecologically optimal fragment shape generally has a large internal area with some curvilinear limits and narrow lobes. However, each species will respond differently to a particular fragment shape. Fragments that have small area and very irregular shape are certainly unstable. Only one fragment of Dense Shrub Savanna, with approximately 13,056 hectares, had the highest index value, which is the most stable fragment in the landscape.

The amount of edge and the shape of the fragments dictate the interactions between the different types of fragments and the flow of species through the landscape (BATISTELLA, 2001). In this sense, the present study provides a preliminary analysis of edges and shapes of fragments that can be the basis for studies involving the different species that live in these fragments and their gene flows.

3.4 Distance between nearest neighbors

The proximity between natural forest fragments is important for ecological processes and its results reflect the degree of isolation of fragments, since the movement or flow of species among fragments decreases when farther they are (FORMAN, 1995).

The classes Dense Shrub Savanna, Open Shrub Savanna and Riparian Vegetation had fragments very close to each other, with Euclidean distance of 60 and 67 m. These three classes presented singly 65%, 68% and 44%, respectively, of its fragments with these distances. Only Riparian Vegetation presented 42 fragments with a distance greater than 1000 m. This higher isolation is probably explained by the standard location of the streams rather than by the anthropism, since the inclusion of this class is dependent on the location of streams. The classes Dense Shrub Savanna and Open Shrub Savanna presented 13 and 15 fragments (all with an area smaller than two hectares and extensive borders), respectively, more isolated, with 500 to 1000 meters between them. These fragments, as a consequence of being very small, are more susceptible to edge effects and have a physical barrier (distance) to gene flow. For these reasons, they may be considered as the most unstable fragments in the landscape.

Each species in nature responds to a certain distance between fragments so that their populations do not become genetically isolated (VIANA; PINHEIRO, 1998). Thus, studies are needed to evaluate the distances that each species from the region responds in order to maintain their gene flows.

During field visits, it was possible to observe areas that were already disturbed in the past that have been abandoned, and today are in recovery, characterized by the presence of Open Shrub Savanna with well aligned bushes and the same size, indicating that the process of fragmentation of natural landscape has been occurring in the region since ancient times. By the sum of the analyzed metrics results, it is concluded that the agricultural activities performed in the region, mainly pasture, are accelerating even further this fragmentation process and that small fragments may soon be extinct, as they are becoming increasingly degraded. These results are in agreement with those found by Castelletti et al. (2004). These authors worked with the broad Caatinga area and proved that it is totally fragmented.

Natural areas in the region that remain conserved need to be prioritized for maintenance of plant and animal species. The choice of these areas have to consider how connected they are, particularly considering the distance between them; which barriers they present to the flow of matter and energy; and which habitat characteristics (considering quality and quantity) they have to maintain certain species (FORMAN, 1995).

3.5 Principal Component Analysis Applied to Landscape Metrics

In order to cluster and characterize LULC classes, landscape metrics PCA was chosen. This is one of the most commonly used statistical methods when analyzing multivariate data.

The first three principal components (F1, F2 and F3 factors) were sufficient to explain the variability of the metrics obtained in this work, since they explained together 95% of the data variance (TABLE 4).

TABLE 4 - Eigenvalues and variance of the first three factors calculated by the Principal Component Analysis.

	F1	F2	F3
Eigenvalues	4.675	1.620	1.306
% variance	58.444	20.252	16.321
cumulative %	58.444	78.695	95.016

Source: Clécia Cristina Barbosa Guimarães (2012).

Table 5 shows the correlation matrix of the analyzed metrics. A few metrics presented high correlation with others, which can also be seen in Table 6. Only MPAR is not highly correlated with any other metric; it has a low correlation with MSI.

Regarding the variance data, F1 (TABLE 6) explains the variance of almost all metrics (NP, CA, MPS, PSSD, TE, and MPE), showing high positive values. Thus, it indicates a high correlation between these metrics that consider the fragment size. The correlation matrix presented in TABLE 5 corroborates this result.

The MSI metric showed ambiguity in the three factors. In the correlation matrix, this metric had a high correlation value only with MPE; regarding scores, it had the second highest value in F2, indicating that the correlation between these two metrics is weaker than the correlation MPE had with other metrics. The F3 explained only the MPAR metric, indicating that this metric has no correlation with the others.

TABLE 5 - Correlation matrix between metrics.

	NP	CA	MPS	PSSD	TE	MPE	MSI	MPAR
NP	1	0.894	0.296	0.479	0.971	0.268	0.244	0.540
CA	0.894	1	0.615	0.794	0.968	0.495	0.229	0.349

MPS	0.296	0.615	1	0.801	0.478	0.938	0.547	0.088
PSSD	0.479	0.794	0.801	1	0.625	0.589	0.141	0.180
TE	0.971	0.968	0.478	0.625	1	0.418	0.276	0.432
MPE	0.268	0.495	0.938	0.589	0.418	1	0.793	0.234
MSI	0.244	0.229	0.547	0.141	0.276	0.793	1	0.593
MPAR	0.540	0.349	0.088	0.180	0.432	0.234	0.593	1

Source: Clécia Cristina Barbosa Guimarães (2012). In bold: significant positive correlation (except the diagonal line), for a significance level alpha = 0.05 (two-tailed test). Legend: NP – Number of fragments of each class; CA –Total area of each class; MPS – Average of total area of each class; DSSP – standard deviation of mean of the total area of each class; TE – Total perimeter of each class; MPE – mean of total perimeter of each class; MSI – mean of shape index of each class; MPAR – mean of perimeter-area ratio of each class.

TABLE 6 - Scores of metrics calculated by the Principal Component Analysis for factors F1, F2 and F3.

	F1	F2	F3
NP	0.791	-0.561	0.165
CA	0.916	-0.349	-0.184
MPS	0.797	0.498	-0.336
PSSD	0.794	0.010	-0.469
TE	0.879	-0.440	-0.003
MPE	0.767	0.629	-0.039
MSI	0.572	0.574	0.564
MPAR	0.506	-0.130	0.769

Source: Clécia Cristina Barbosa Guimarães (2012). The highest values are highlighted in red. Legend: NP – Number of fragments of each class; CA –Total area of each class; MPS – Average of total area of each class; DSSP – standard deviation of mean of the total area of each class; TE – Total perimeter of each class; MPE – mean of total perimeter of each class; MSI – mean of shape index of each class; MPAR – mean of perimeter-area ratio of each class.

The grouping of LULC classes in relation to the analyzed metrics resulting from the factors one and two, which explained 78.7% of the data, is shown in FIGURE 6. One of the groups includes Agriculture (A), Water Body (CH), Riparian Vegetation (VR) and Exposed Soil (SE); the other one, more discreet, consists of Pasture (P), Open Shrub Savanna (CAtA) and Dense Shrub Savanna (CAtD), even though the latter is a little distant in the group; and Urban Area (AU) is isolated from the other groups. The association of metrics can be considered as poorly efficient in separating the grouped classes, or, on other standpoint, it is considered that there is an intrinsic relationship between these classes, as in the work of Turetta et al. (2013). These authors studied 16 landscape metrics and

LULC maps of a region of Rio de Janeiro, and the Principal Component Analysis was efficient to characterize a few classes from the map, but other classes were characterized by their intrinsic association in the landscape, as for example, the proximity of pasture and annual crops metrics, associated with the rotation of crops occurring in that region.

Regarding the first three classes of the first group (Agriculture, Water Body and Riparian Vegetation), there is no intrinsic association between the Agriculture class and the other two, since they are different and independent considering their use and coverage. Agriculture is a class of intensive use, as Water Body and Riparian Vegetation are natural coverage classes closely associated, since Riparian Vegetation from the region is formed by hydrophilic plant growing in or close to natural water bodies. Exposed soil is not very far from this group, because it is associated with water bodies and agriculture.

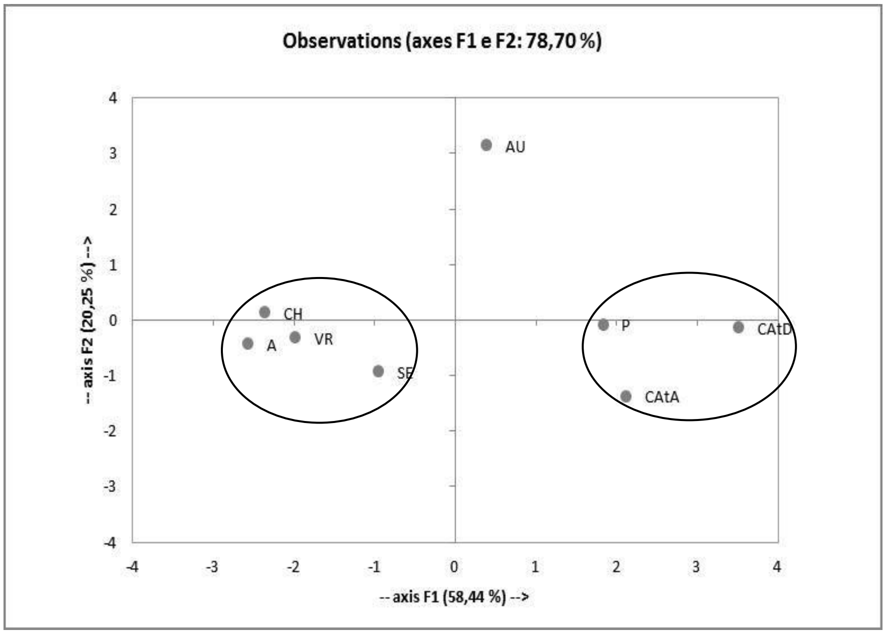

FIGURE 6 - Grouping of classes associated with metrics of Principal Component Analysis for the factors F1 and F2.
Source: Clécia Cristina Barbosa Guimarães (2012). Legend: A – Agriculture; CH – Water Body; VR – Riparian Vegetation; SE – Exposed Soil; AU – Urban Area; P – Pasture; CAtA – Open Shrub Savanna; CAtD – Dense Shrub Savanna.

Thus, in addition to the association of Exposed Soil with Water Body and Agriculture, the best grouping of these three classes (A, CH and VR) is explained by the similarities in size, shape and quantity of fragments. These are classes that had smaller amount and size of fragments and, associated with the similar shape in all classes, were separated in a distinct group. Urban area was not included in this group, because even though it also had small sizes and amounts of fragments, this class had a different shape. Urban Area presented more entrances and sinuosity; it had highest values for the MPE and MSI metrics. As these metrics are best explained (mainly MSI) by the F2 factor, the Urban Area class had the highest positive value for this factor that separated it from the others (FIGURE 8 a, b, c, d, e, f).

The mean of MPAR perimeter-area ratio, which was best explained by F3 factor (FIGURE 7), distanced the Exposed Soil class from the others in its group. The metric assumes higher values when the perimeter is larger than the fragment area, and this result was found for Exposed Soil, since elongated fragments with small areas and large perimeters, such as unpaved roads and trails, were included in this class.

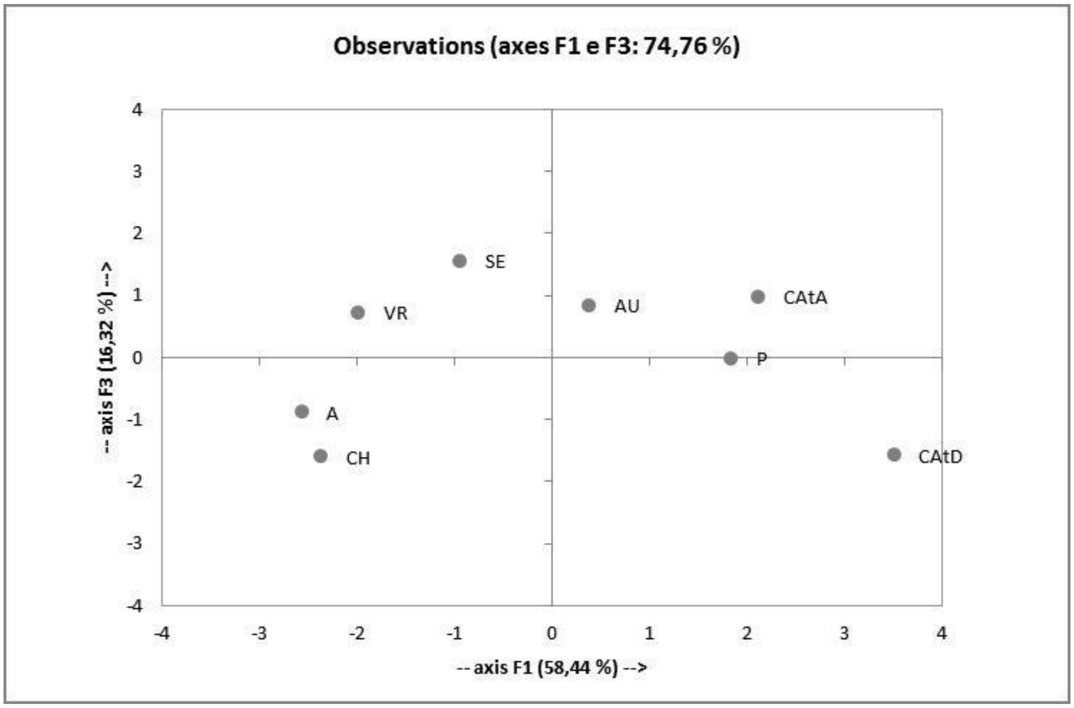

FIGURE 7 - Grouping of classes associated with metrics of Principal Component Analysis for the factors F1 and F3.
Source: Clécia Cristina Barbosa Guimarães (2012). Legend: A – Agriculture; CH – Water Body; VR – Riparian Vegetation; SE – Exposed Soil; AU – Urban Area; P – Pasture; CAtA – Open Shrub Savanna; CAtD – Dense Shrub Savanna.

Classes such as Pasture, Open Shrub Savanna and Dense Shrub Savanna had the highest F1 values (FIGURES 6 and 7), represented in Table 6 by NP, CA, MPS, PSSD, TE and MPE metrics, which are related to the amount and size of the fragments. These classes were present in greater number and with larger sizes of area and edge in the landscape (FIGURE 8 a, b, d, e, f, g). Thus, these classes are characterized in the same group, even though there is a separation between them, caused by the LULC characteristics.

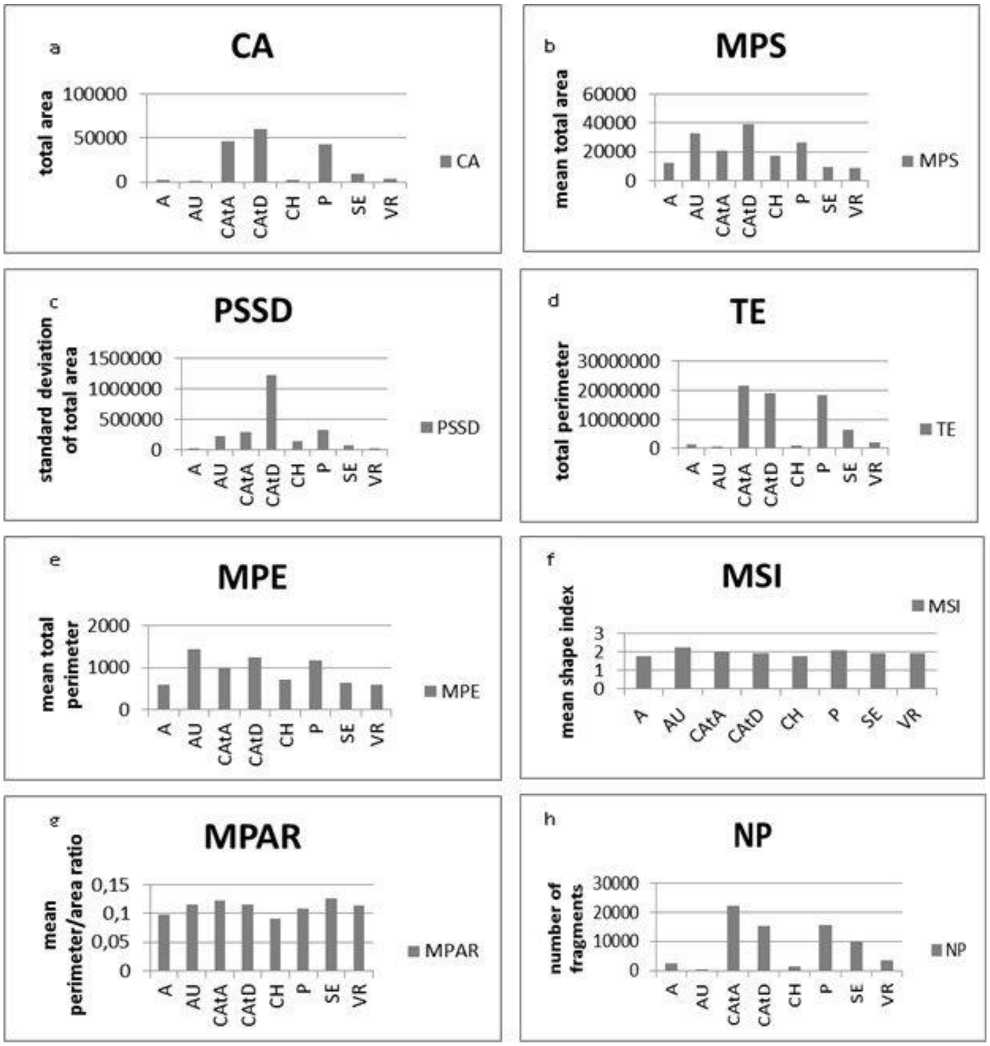

FIGURE 8 - LULC classes regarding the selected metrics.
Source: Clécia Cristina Barbosa Guimarães (2012).

Pasture and Open Shrub Savanna had a high association with the agricultural management, since after the abandonment of a pasture area and the consequent establishment of initial vegetation, small shrubs dominate the region for a while, leading to a process known as ecological succession. In addition, Open Shrub Savanna areas can serve for pasture, though its coverage is different from grazing fields, the use of land is the same. The sequence between classes continues until the establishment of more stable vegetation, in this case represented by Dense Shrub Savanna. Thus, this class is clustered with the other two in a more discreet way, as it is a less degraded form of vegetation.

4. CONCLUSIONS

1. The landscape of the study area was reduced to small fragments of natural coverage that threaten the maintenance of flora and fauna species and the heterogeneity of the landscape.
2. The smaller fragments undergo further fragmentation due to the edge effect.
3. The region had most of its natural vegetation fragments with simple shape, (near the square one), which is important for the maintenance of internal resources of each fragment, but affect the flow of species, causing some instability in the landscape.
4. Most natural vegetation fragments had a distance from others of its class of less than 1000 m. Their classification as distant or close for the matter and energy flows depends on its species composition.
5. The LULC classes Agriculture, Exposed Soil, Riparian Vegetation and Water Body had similar landscape configuration metrics.
6. Pasture, Open Shrub Savanna and Dense Shrub Savanna were classes intrinsically associated regarding the ecological succession process, considering the stages of degradation, abandonment, and reestablishment that characterized each class, respectively.
7. The method used in the study was effective in landscape fragmentation analysis, indicating that the region has a significant percentage of natural vegetation. However, it is represented almost entirely by small fragments resultant from the degradation of large natural vegetation fragments and insertion of agriculture and pasture areas.

5. ACKNOWLEDGEMENTS

We wish to thank PETROBRAS for funding the research and FUNCAPE for the first author's scholarship.

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