UNDERSTANDING THE PATTERN OF ATLANTIC FOREST FRAGMENTATION: PRELIMINARY RESULTS OF EXPLORATORY DATA ANALYSIS FOR AN AREA OF THE SOUTH EAST OF BAHIA, BRAZIL

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ABSTRACT

Since the first European colonisation, the exploitation of the *Mata Atlantica* (Brazilian Atlantic forest) has been so strong that nowadays only 7% of the original extent is left. The forest land cover is highly fragmented and the further process of forest fragmentation would seriously threaten the biological diversity of *Mata Atlantica*. This paper presents the first results of the application of a flexible integrated information monitoring system designated to control the forest fragmentation of *Mata Atlantica*. The application is done with data of an area of South Bahia (Brazil), that was very important for the cocoa breeding (Rio Cachoeira catchment), in order to show how to detect the relationships between the changes of forest land cover fragmentation and the changes of some socio-economic data from 1988 to 2001. The results show that in these last decades the landscape pattern of forest did not change significantly, correlation analysis based on fuzzy set theory proved that the forested area was expanding with new patches near the urban areas however the forested areas decreased in the poorest rural municipalities were the population and the gross domestic product were decreasing too.

Keywords: Atlantic Forest, forest fragmentation, fuzzy sets, GIS, remote sensing.

INTRODUCTION

Fragmentation is a process involving the simultaneous reduction of the habitat area and the increased isolation of the remaining habitat patches (Saunders et al. 1991).Fragmentation has a negative influence on many species of plants and animals, and on ecological processes (Farina 2000). In fact, apart from causing immediate extinctions, fragmentation may have long-term effects on ecological populations through changes in ecological processes such as pollination, predation, territorial behaviour and feeding habits (Ranta et al. 1998). Although fragmentation is a world-wide phenomenon, tropical forests are particularly threatened from this process (Wilcove et al., 1986; Skole and Tucker, 1993).

The patterns of fragmentation are affected by many natural and socio-economic variables. In particular, during the last century, the rates of forest fragmentation in tropical areas were strongly increasing as consequence of human activities (Farina 2000). The Brazilian Atlantic rain forest (*Mata Atlantica*) represents one of the clearest examples of sensitive areas where the effects of the increasing anthropogenic pressures had a strong negative impact on its extension. *Mata Atlantica* is an example of threatened tropical forest being reduced to only 7% of its original area (Quintela 1990, SOS *Mata Atlantica* and INPE, 2002).

When Europeans started to explore Brazil in the 16th century, *Mata Atlantica* covered about 1.350.000 km^2 with a longitudinal extension from north-east to south-east of some 4.000 km. Since the first Portuguese colonisation, the exploitation of *Mata Atlantica* was considerable. After a period of intensive logging (mainly of Brazilian wood, *Caesalpina echinata*), the forest

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was cleared to introduce sugar cane, cocoa and coffee plantations and later to produce pastures. In the last century, new economic cycles based mainly on industrialization process led to a strong urbanization growth that heavily contributed to fragment the forest systems. Today, about 108 millions inhabitants, 60% of the Brazilian population, live in the area that was occupied by *Mata Atlantica* (Netto, 1997).
To preserve the forest and the related biological diversity, conservation efforts must focus on the remaining forest fragments. Many studies have been developed to understand the pattern of forest fragmentation (Trani and Giles 1999, Cumming and Vernier 2002) from them it is clear that further information is needed and a monitoring system has to be developed in order to control the phenomenon and its consequences in setting management plans (Schelhas and Greenberg 1996).
In this paper we present some of results of the application of an information system based on the integration of geographic information system (GIS) technology with remote sensing, spatial statistics and multivariate analysis that is able to offer, when needed, the spatial pattern of the forest in the landscape and to evaluate the spatial changes during the time.
We do not want to describe the system, we want just to present with a simple application to *Mata Atlantic* how useful can be the application of software tools that today are available at low cost even in the smallest administrative units of Developing Countries to measuring, monitoring and understanding changes in landscape spatial pattern.

THE STUDY AREA

The framework was developed during a study conducted in the Rio Cachoeira Catchment in the South East of Bahia that was one of the most important area of Cocoa plantation in Bahia. Today the percentage of remaining Atlantic forest in the state of Bahia covers about 16% of the territory (the highest among the states of Brazil), with the lowest rate of deforestation.
The conservation of Mata Atlantica in Bahia is mainly due to the local cultivation model established for the Cocoa (*Theobroma cacao L.*) more than 200 years ago that is traditionally known as Cacau-cabruca (De Carvalho, 1997). Cacau-Cabruca is a low-density cocoa plantation under the shade of native canopy trees. In general, this particular agro-forestry system creates habitat for a wide array of plant and animal species preserving biological diversity of the Atlantic forest biome. Although until the 80’s, the South East of Bahia, known as Cocoa Region (“Regiao Cacaueira”), was the world’s second largest producer of cocoa this region suffered a serious economic crisis. Between 1986 and 1992 the international price of cocoa fallen down from 2500 US$ to 1000 USD$ per ton throwing the economy region in the worst crisis of its history. The farmers, in order to minimize the loss, dismissed the workers and started to exploit the Atlantic forest in other ways. Since 1989 the crisis became even worse as a consequence of the infestation of the fungus *Crinipellis perniciosa* leading the disease known as witches’ broom (“vassoura-de-bruxa”) (Alger and Caldas, 1996).
The effects of this crisis was a big emigration of cocoa‘s workers to urban areas and the further deforestation to get land for pastures. As a matter of fact about 50% of cocoa plantations are now partially or totally abandoned.

DATA AND METHODS

The data about the spatial distribution of forested areas of the Rio Cachoeira Catchment have been collected by remote sensing and GIS technology (in this case IDRISI, Eastman 2001, but any kind of GIS with similar performance can be applied).
Two different LANDSAT satellite images have been processed to produce two land cover maps: one for 1988 (the beginning of the worst period of cocoa crisis) and the other for 2001 (more or less corresponding to a renaissance of interest for the cocoa plantation). The study was

conducted by keeping into consideration the 12 municipalities included in the Rio Cachoeira Catchment as operational geographic units (OGUs, Crovello, 1981, Feoli and Zuccarello, 1996). This was a decision dictated by the fact that the socio-economic data were available only at the municipality level. The analysis of forest land cover pattern was done by the free software FRAGSTATS (McGarigal et Al., 2002).

Given a landscape mosaic image, FRAGSTATS computes, several metrics for: (1) each patch in the mosaic; (2) each patch type in the mosaic; and (3) the landscape mosaic as a whole. So we can obtain 3 groups of metrics: patch, class and landscape. In this preliminary study we consider only the forest patches, larger than 1ha.

Three indices are considered here: patch density (n° of forest patches/km^2), patches isolation (average Euclidean distance between the closest forest patches) and shape complexity (area-weighted mean shape index) (McGarigal, K et al., 2002). These are calculated for each municipality for the land cover maps of 1988 and 2001. The socio-economic data of IBGE census (e.g IBGE, 2002) have been organized in an ACCESS data base. In this way there is an easy access to the data from many type of GIS that are used today. Only two socio-economic indicators out of 345 available are here considered. They are the gross domestic product (GDP) and the population growth rate (PGR) for municipality.

The differences between the values obtained with FRAGSTATS for the 1988 and 2001 have been correlated with the differences of percentage of forest land cover (% forest), the difference of percentage of urban areas (% urban), the difference of percentage of area covered by pastures (% pastures) and the difference of gross domestic product and with percentage of total land cover change (% land cover change) and the population growth rate (for the period 1988-2001). The differences and the percentage of total land cover change have been coded with 0 if less than 20%, 1 if between 20% and 30%, 2 if between 30% and 50% and 3 if more than 50%. The population growth rate as given by the census data maintains its original values. The data are presented in Table 1.

The values in each column of the table represents the changes (increment + or decrement -) of each selected variable in the two periods for the 12 considered municipalities. Thus the matrix in Table 1 represents dynamic variables that have been used to classify the municipalities in order to identify similar pattern of changes. The programs of multivariate data analysis used in this paper were SYNTAX (Podani 2000) and the free software tools developed by the Department of Biology of University of Trieste (Feoli and Orloci, 1991), however any other software can be applied. The correlation coefficient is used to measure of the link between the variables. Several methods of clustering have been applied to the matrix in Table 1.

The method suggested by Carranza et . Al (1998) was applied to select the sharpest classification. The clusters have been characterized by the average values of the variables in Table 1. The degrees of belonging (fuzzy membership) of municipalities to the clusters, calculated as suggested by Feoli and Zuccarello (1986,1988), are used to quantify the links between the municipalities and the situations represented by the clusters.

RESULTS

The data in Table 1 is suggesting that the forested area from 1988 to 2001 was increasing in 50% of the municipalities, while it was decreasing in about 30% of the municipalities and it was stable in about 20% of them. The correlation matrix between the variables is presented in Table 2. The correlation coefficients in Table 2 are over the 0.50 only in few cases, they are suggesting the following general hypothesis:

1) The forested area increased mainly with new forest patches (correlation between Patch –D and % forested-land = 0.51), however the increment is also due to the expansion of the existing patches since there is also a high correlation between % forested-land and shape complexity (r= 0.84).

2) Pasture and the general process of total land cover change have produced new patches of forest since the correlations between Patch-D and pastures and %total change is 0.77 for both.
3) The increasing population growth rate had not direct negative influence on the forest expansion since the correlation coefficient between % forested-land and PGR is 0.55.
4) The establishment of pastures has not damaged the forest expansion since the correlation between pastures and % forested-land is 0.51.

Table 3 presents the degrees of belonging of municipalities to the three main clusters obtained with cluster analysis (similarity ratio and complete linkage) and also shows the average values of the variables in each cluster. The table shows also the percentages of area covered by pastures. From Table 3 the evolution of the municipalities during the considered period results clear. There is a group of municipalities in which the forested areas increased with increasing patch density, also the area covered by pastures increased, however the GDP decreased and the PGR was slightly negative. These are the municipalities including the most important urban areas (Ilheus and Itabuna) and those more close to the coast where the cocoa *cabruca* was a very important economic resource. It is remarkable that only in one of these municipalities the area covered by pasture reaches the 60%.

In the municipalities of the other two clusters the area covered by pastures is always more than 60%. The second cluster includes municipalities where the GPD slightly increased and the GPR is slightly positive. In these municipalities the forested area slightly increased notwithstanding the urban areas was also increasing.

It looks that the economy of these municipalities including and near the urban area of Itapetinga is benefiting from the new industrial development related to food production however this has to be confirmed by further analysis.

The third cluster includes municipalities where the GPD was decreasing the GPR was the most negative and where the forested area decreased, also the patch density and the shape complex were decreasing. This cluster represents the most rural area of the catchments and it proves that the economic problems are pushing the people to use still the forest resources.

DISCUSSION AND CONCLUSION

This paper presents the application of an integrated way to use different information systems such as GIS, data management and analytical software to analyze the changes of forest land cover pattern in a tropical area where the forest is fragmented and highly threatened. It presents and discusses just three tables obtained with the use of several methods in an integrated way. The first one is showing the changes of some spatial variables related to forest land cover and of some socio-economic variables from 1988 to 2001 (Table 1).

It is obtained with the application of GIS and remote sensing technology and data base management techniques. It is a table based on few variables however the system would allow obtaining tables more rich in variables. This will be done in a next future in order to understand more clearly what is going from a socio-economic point of view. The second table (Table 2) is presenting the correlation between the changes of the variables.

It is obtained with the use of the linear correlation coefficient that is the cosine between the vectors representing the variables. In this case this coefficient is used just to investigate on the mutual position of the variables in the multidimensional space generated by the matrix in Table 1 and not for statistical testing.

It could be used to cluster the variables according to their proximity in the multidimensional space however since the variables used are just 9 we have not thought necessary to group them in clusters. Any other coefficient measuring the link between the variables could be used, the software tool for these coefficients is generally belonging to the software of multivariate analysis as that used for obtaining Table 3. This last table (Table 3) is presenting the results of a

classification procedure based on the changes occurring in the variables from 1988 to 2001 (Table 1) and fuzzy set theory. A table like this can be obtained by the many software for multivariate data analysis or more general software capable to perform simple data transformations (normalization and standardization) and matrix algebra operations (matrix multiplication, matrix inversion, singular value and spectral matrix decomposition et.).
All the software can be available free of charge from the net, notwithstanding we have used for GIS the IDRISI software and for the classification the SYNTAX software. From these simple tables, that are the results of a first and simple exploratory data analysis, we are able to describe in a very clear way what was happening in the area in terms of forest fragmentation and forest land cover changes and we can formulate some hypothesis that should be tested by further statistical analysis.
For the moment it is clear that the landscape pattern of forested area is strongly determined by the economy and that socio-economic plans have to be directed towards the forest protection. A monitoring system based on the tools we have used in this paper can offer to the planners the instruments to identify the areas where such plans have to be most urgently addressed.

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Table 1. The 9 variables used to classify the municipalities in order to identify similar pattern of changes

	PGR	GDP	% forest	Patch density	Patch isolation	Patch shape	% land cover change	% pastures	% urban area
1.Barro Preto	-2.29	-1	1	1	-2	1	2	1	1
2.Firmino Alves	-0.73	1	-1	-1	0	0	0	0	2
3.Floresta Azul	-2.01	-1	0	0	0	0	1	0	1
4.Ibicarai	-0.63	-1	2	1	-1	1	2	1	2
5.Ilheus	-0.08	-1	1	1	1	1	2	1	0
6.Itabuna	0.67	0	2	1	0	1	3	1	0
7.Itaju do colonia	-1.44	-1	-1	0	0	0	1	0	0
8.Itape	-0.74	-1	1	0	0	1	2	0	1
9.Itapetinga	0.89	1	1	0	-1	0	1	0	0
10.Itororo	-0.39	1	0	1	0	0	1	0	1
11.Jussari	-1.26	0	-1	1	0	-1	2	1	0
12.SantaCruz	-3.76	-1	-1	0	1	-1	1	0	0

The differences of the indicators for the period 1988-2001 have been coded with 0 if less than 20%, 1 if between 20% and 30%, 2 if between 30% and 50% and 3 if more than 50%.

Table 2. Correlation coefficients between the variables; coefficients higher than 0.50 are marked in bold

	PGR	GDP	% forest	Patch density	Patch isolation	Patch shape	% land cover change	% pastures	% urban area
TPGR	1	**0.54**	**0.55**	0.17	-0.12	0.46	0.26	0.18	-0.03
GDP	**0.54**	1	-0.15	-0.20	-0.08	-0.27	-0.38	-0.26	0.09
% forest	**0.55**	-0.15	1	**0.51**	-0.40	**0.84**	**0.69**	**0.51**	0.13
Patch density	0.17	-0.20	**0.51**	1	-0.19	0.32	**0.77**	**0.77**	-0.23
Patch isolation	-0.12	-0.08	-0.40	-0.19	1	-0.36	-0.14	-0.25	-0.37
Patch shape	0.46	-0.27	**0.84**	0.32	-0.36	1	**0.53**	0.41	0.31
% land cover change	0.26	-0.38	**0.69**	**0.77**	-0.14	**0.53**	1	**0.77**	-0.29
% pastures	0.18	-0.26	**0.51**	**0.77**	-0.25	0.41	0.77	1	-0.08
% urban area	-0.03	0.09	0.13	-0.23	-0.37	0.31	-0.29	-0.08	1

Table 3. Degrees of belonging of the municipalities to three clusters; the table shows also the percentages of pastures in 2001 and the average values of the variables for each cluster

	Cluster 1	Cluster 2	Cluster 3	% pastures
1.Barro Preto	**0.77**	0.41	0.24	17.88%
4.Ibicarai	**0.78**	0.48	0.24	41.86%
5.Ilheus	**0.81**	0.49	0.42	14.05%
6.Itabuna	**0.81**	0.51	0.31	36.25%
11.Jussari	**0.65**	0.39	0.42	60.01%
2.Firmino Alves	0.25	**0.60**	0.24	87.84%
8.Itape	0.60	**0.67**	0.47	74.10%
9.Itapetinga	0.46	**0.66**	0.30	72.97%
10.Itororo	0.52	**0.72**	0.42	66.85%
3.Floresta Azul	0.46	0.65	**0.66**	73.00%
7.Itaju do colonia	0.40	0.52	**0.81**	73.79%
12.SantaCruz	0.26	0.31	**0.81**	81.28%
PGR	-0.72	-0.60	**-2.6**	
GDP	-0.6	**0.2**	**-1.0**	
% forest	**1.0**	0.2	**-1.0**	
Patch density	**1**	0	0	
Patch isolation	-0.4	-0.2	**0.5**	
Patch shape	**0.6**	0.2	**-0.5**	
% land cover change	**2.2**	1	1	
% pastures	**1**	0	0	
% urban area	0.6	**1**	0	