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Temporal variability of the cover of the dry forest (caatinga) in the state of Rio Grande do Norte

The objective of this work was to understand the temporal dynamics of land use and occupation in the microregions of the state of Rio Grande do Norte in the period 1985 to 2018. The methodology was based on the application of the homogeneity test, to verify the tendency of grouping the microregions as to homogeneous patterns of gain or loss of forest cover. The annual data on land cover and land use were obtained from the Project for Annual Mapping of Land Cover and Land Use in Brazil (MapBiomas), for the analyses the type of cover associated with the Savanna Formation (Caatinga) was chosen and of the 167 municipalities 19 microregions were selected, annual time series of the forest cover were used, so that the temporal variability of the cover and the tendency of loss of the Caatinga type forest cover could be verified. The results showed that the Caatinga biome over the years, suffered changes during the period studied, evidencing a variability in forest cover with a significant reduction in forest cover and a high degree of change in its landscape. The decrease in the original forest cover is remarkable. Thus, we can infer that this decrease is associated with the advances of anthropic actions, such as agriculture and cattle-raising. However, some microregions stood out in relation to the variability of forest cover, with significant losses of cover if compared to others. These were: Mossoró, Midwest, Borborema Potiguar and Pau dos Ferros.

Palavras-chave: Land use and land cover; Temporal analysis; MapBiomas; Caatinga; Northeast Brazil.

Variabilidade temporal da cobertura da mata seca (caatinga) no estado do Rio Grande do Norte

O objetivo deste trabalho foi compreender a dinâmica temporal do uso e ocupação do solo nas microrregiões do estado do Rio Grande do Norte no período de 1985 a 2018. A metodologia tomou por base a aplicação do teste de homogeneidade, para verificar a tendência de agrupamento das microrregiões quanto aos padrões homogêneos de ganho ou perda da cobertura florestal. Os dados anuais de cobertura e uso da terra foram obtidos do Projeto de Mapeamento Anual da Cobertura e Uso do Solo do Brasil (MapBiomas), para as análises foram escolhidos o tipo de cobertura associada a Formação Savânica (Caatinga) e dos 167 municípios selecionou-se 19 microrregiões, utilizou-se séries temporais anuais da cobertura florestal, para que se pudesse verificar a variabilidade temporal da cobertura e tendência de perda da cobertura florestal do tipo Caatinga. Os resultados mostraram que o bioma Caatinga ao longo dos anos, sofreram alterações durante o período estudado, evidenciando uma variabilidade na cobertura florestal com significativa redução da cobertura florestal e alto grau de alteração de sua paisagem. É notável o decréscimo da cobertura florestal original. Assim, podemos inferir que este decréscimo está associado aos avanços das ações antrópicas, assim como agricultura e pecuária. Porém algumas microrregiões se destacaram em relação à variabilidade da cobertura florestal, com perdas de cobertura significativas se comparada a outras. Foram elas: Mossoró, Médio Oeste, Borborema Potiguar e Pau dos Ferros.

Keywords: Uso e cobertura da terra; Análise temporal; MapBiomas; Caatinga; Nordeste do Brasil.

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INTRODUCTION

Degradation processes produce consequences on different environmental components, as for example eliminating the original vegetation cover and inserting invasive species, besides causing the partial or total loss of the soil due to physical (erosion) or chemical (salinization and alkalinization) phenomena (ROSS, 2001). Such factors cause environmental degradation problems in the semiarid region of Northeast Brazil, and the degraded areas can significantly increase due to anthropic actions.

According to Oliveira et al. (2012), the Caatinga, 84 million hectares (Mha), or 10% of the country, located in the Northeast region of the country, is considered the Brazilian biome that has been most altered by land use and land cover change, and is now composed of secondary forests (AIDE et al., 2013; SOBRINHO et al., 2016). Spatially explicit information on the historical trajectories of land use and land cover in Brazil is critical for sustainable natural resource planning and management, policy formulation, and other social applications (ALMEIDA et al., 2005).

According to Carvalho et al. (2016), environmental studies with remote sensing support allow the analysis of land cover and land use changes over a given period of time. This technique coupled with the geographic information system provides basis for a reflection on the transformations and aspects that influence the intensity and type of changes, such as factors of origin.

According to Santos et al. (2015) and Silva et al. (2015), remote sensing represents a fundamental tool for monitoring semiarid regions, since orbital sensors can cover an extensive surface area with a satisfactory temporal scale, providing data on parameters that could only be estimated with specific environmental applications in field experiments. According to Santos et al. (2015), using orbital remote sensing for identifying land use alterations and consequent climate change has many advantages.

Optical earth observation data present limitations to assess deforestation, regeneration, or reforestation processes in semiarid areas due to the high spatio-temporal variability of the vegetation. According to Mayes et al. (2015), this limitation stems from the complex regional ecology of the vegetation associated with factors such as land use practices and disturbance regimes. Tomasella et al. (2018) also added that the wide variety of trees, shrubs, and grasslands irregularly distributed in the biome coupled with the high degree of fragmentation diversify the spectral responses in these landscapes.

Araújo et al. (2018) evaluated the changes occurring in Northeast Brazil through the spatio-temporal analysis of albedo, Normalized Difference Vegetation Index (NDVI), and surface temperature (Ts) obtained from the MODIS sensor in the period from 2002 to 2011. The data obtained by remote sensing were associated with precipitation data obtained by reanalysis techniques to evaluate the areas of interest and their respective selected sample points. On the same theme, Cunha et al. (2020) investigated spatio-temporal patterns of vegetation cover removal in a Caatinga area located in the state of Paraíba. The authors used Landsat data (TM, ETM+ and OLI) over a 31-year interval (1985-2015) and compared the spectral indices Enhanced Vegetation Index (EVI), NDVI, and surface albedo, with the latter presenting the best accuracy.

Soares (2019) sought to understand the dynamics of land use and occupation through the quantification of spatial patterns of the Atlantic Forest biome in the Northern Coast and Agreste Baiano using methods of landscape ecology and geoprocessing techniques, identifying changes of vegetation cover in a multitemporal series (2000-2016). Through the Google Earth Engine platform and access to the MapBiomas Collection 2.3, the studies indicated a gradual decrease of 20% in the area corresponding to forest formations as well as an increase of 29% in agropastoral areas and significant increase in urban infrastructure during the annual period 2000 to 2016. The largest forest fragment occupied 22.7% of the total area of the studied region.

One of the national projects aimed at land cover classification is the Annual Mapping of Land Cover and Land Use in Brazil - MapBiomas, including the five biomes of Brazil. The MapBiomas initiative is a tool for understanding forest dynamics using medium resolution remote sensing data with detailed land use classification[1]. The present study sought to understand the temporal dynamics of land use and land cover in the microregions of the state of Rio Grande do Norte in the period from 1985 to 2018.

MATERIALS AND METHODS

Study area

The object of study is the state of Rio Grande do Norte (Figure 1), which is located in the eastern sector of the Northeast region of Brazil, between latitudes 05°47'42" and 6°58'57" S and longitudes 35°12'34" and 38°36'12" W, bordering the states of Ceará and Paraíba. Rio Grande do Norte has a territorial extension of 52,811.126 km^2 divided into 167 municipalities.

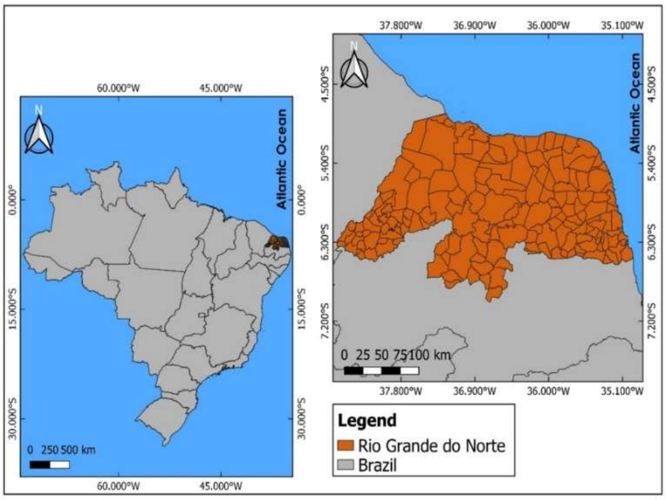

Figure 1: Location map of Rio Grande do Norte State.

The rainfall in the semiarid region of Brazil is marked by interannual variability, which associated with low total annual rainfall values contributes as one of the main factors to the occurrence of drought events. According to Marengo (2006), this region has always been affected by great droughts or great floods. Beuchle et al. (2015) point out that precipitation has an extremely irregular temporal and geographical distribution,

[1] https://mapbiomas.org/downloads_collections-1-2?cama_set_language=pt-BR

and Leal et al. (2005) report that annual variations in precipitation are large and droughts can last for years. Despite its importance, the Caatinga biome has been undergoing a process of rapid deforestation, especially in recent years, due to the consumption of native firewood. The vegetation of the region is 'caatinga', characterized by "low to medium sized woody vegetation, formed by xerophytic plants" (Nunes, 2006). The vegetation in the Caatinga, which is a tropical dry forest, ranges from low deciduous shrubs to small patches of tall dry forests, reaching up to 20 m, mainly distributed in fragmented landscapes[2].

Data

Annual land cover and land use data for the state of Rio Grande do Norte from 1985 to 2018 were obtained from the MapBiomas Project (mapbiomas.org/statistics). The main goal of the project is to produce land cover and land use data in an automated and up-to-date manner "so as to make it possible to recover the history of the last decades" (MAPBIOMAS, 2017). The type of cover associated with the formation Savanna (Caatinga) was chosen for the analyses. Among the 167 municipalities, 19 geopolitical microregions of the state were selected to analyze the dynamics of land use and land cover. Annual time series (1985 to 2018) of the forest cover were used to verify the temporal variability of the cover and the trend of loss of the forest cover type corresponding to Caatinga.

Methodology

A cluster analysis was done based on the amplitude (2018-1985) of forest cover and the homogeneity was tested to verify the clustering trends of the microregions regarding homogeneous patterns of gain or loss in the state of Rio Grande do Norte from 1985 to 2018.

Ward's hierarchical clustering method

The Ward's hierarchical clustering method was applied to group individuals (points) based on their characteristics along with a measure of dissimilarity called the square Euclidean distance. Ward's method interconnects the samples by their associations and, for the initial formation of clusters, considers the individuals that provide the lowest sum of squares of the deviations. The method was applied to the entire 34-year historical series. The grouping was made by means of the sums of squares of the deviations between accesses or from the square Euclidean distance, in the relationship as shown in Equations 1 and 2.

$$SQD_{ii'} = \frac{1}{2} d^{2}{}_{ii'} \tag{1}$$

$$SQD_{ii'} = \sum_{j=1}^{n} SDQ_{j(ii')} \tag{2}$$

Where: SQDj(ii') is the sum of squares of the deviations for the j-th variable, considering ranks i and i'; $d^2_{ii'}$ is the square of the Euclidean distance between ranks i and i', and n is the number of variables evaluated. The sum of squares of the total deviations can be determined using Equation (3):

[2] https://www.mma.gov.br/biomas/monitoramento-ambiental.html.

$$SQDT = \frac{1}{g}\sum_{i<}^{g}\sum_{i'}^{g} d_{ii'}^{2} \quad (3)$$

Silhouette index

Of the existing approaches to assist in the decision of the number of clusters, the silhouette method proposed by Rousseeuw (1987) was used in this study. This method subsidizes the choice of an optimal number of clusters, evaluating the partitions found, and allows the graphical visualization of the clusters. The silhouette is a graph of the cluster C composed of a silhouette value s(i), i = 1, ..., n, which reflects the quality of the allocation of objects in the clusters. Each object (individual) in the cluster is represented by i. And a value s(i) is calculated for each object i.

The silhouette method was proposed by Rousseeuw (1987) for obtaining clusters by partitioning. The idea is to help the researcher to choose the optimal number of clusters and, at the same time, to allow him to build a graphical representation of the clustering found.

The quality of the clusters formed was evaluated using the Silhouette Index (SI) developed by Rousseeuw (1987) which assesses how similar an observation is to other observations in its cluster compared to observations in other clusters. Each observation has an SI and the overall mean of all observations allows us to evaluate the overall performance of the cluster. The values of this index vary in the range -1 to 1. Values close to 1 indicate that the object is in the correct cluster, and close to -1 indicate that the observation was probably allocated to an inappropriate cluster. Values near zero indicate that the object is near the boundary between two clusters and does not belong to any of them. The SI (n) is calculated according to the following equation (Rousseeuw, 1987):

$$\mathrm{SI}(n) = \frac{b(n) - a(n)}{\max\ \{a(n)\ ,\ b(n)\}} \quad (4)$$

With the observation being evaluated, a(n) is the mean distance from the n^{th} observation to all others within the same cluster and b(n) is the mean distance from the n^{th} observation to all others allocated in the nearest cluster. The overall cluster quality can be measured by the mean SI (n), according to Equation (5):

$$\overline{\mathrm{SI}} = \frac{\sum_{n=1}^{N} \mathrm{SI}_n}{N} \quad (5)$$

Where: N the total number of observations.

TIME SERIES ANALYSIS

Pettitt test

Pettitt's nonparametric statistical test checks two samples $Y_1, Y_2, ..., Y_t$ and Y_{t+1}, Y_{t+2}, Y_T, from equal populations. This methodology is able to locate the point where there was a sudden change in the mean of the time series, besides providing information about the homogeneity of the data in the analyzed series (PETTITT, 1979). The statistical term $U_{t,T}$ counts the number of times a member of the first sample is greater than a member of the second, and can be written through the Equation(6):

$$U_{t,T} = U_{t-1,T} + \sum_{j=1}^{T} sgn(Y_t - Y_j) \text{ para t = 2,.,T} \quad (6)$$

Where: sgn(x) = 1 to x > 0; sgn (x) = 0 to x = 0; sgn (x)= -1 to x < 0. The $U_{t,T\ statistic\ is}$ then calculated for the values of 1≤ t ≤ T and the k(t) statistic of the Pettitt test is the maximum absolute value of $U_{t,T}$. This statistic locates the point where the time series broke and its significance can be calculated approximately by Equation (7):

$$p \cong 2\exp\left\{{-6k(t^2)}/{t^{3+}t^2}\right\} \tag{7}$$

Mann-Kendall test

The Mann-Kendall test (MK) is a non-parametric test used to evaluate trends in time series (YUE et al., 2002). This test was developed by Mann (1945) and Kendall (1975), can be obtained through Equations (8 and 9):

$$S = \sum_{t=1}^{n=1} \sum_{j=i+1}^{n} sgn(X_{j-}X_i) \tag{8}$$

Where: the signal (X_j- X_i) is obtained by Equation (9):

$$sgn(X_j - X_i) = \begin{cases} +1\ if(X_j - X_i) > 0 \\ 0\ if(X_j - X_i) = 0 \\ -1\ if(X_j - X_i) < 0 \end{cases} \tag{9}$$

Mann (1945) and Kendall (1975) showed that the S statistic is usually distributed with mean and variance given by equations (10 and 11), respectively:

$$E[S] = 0 \tag{10}$$

$$Var[S] = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} ti(ti-1)(2t_i+5)}{18} \tag{11}$$

The value of the Z statistic is given by Equation (12):

$$Z_{MK} \left\{ \frac{S-1}{\sqrt{Var(S)}} if\ S > 0 \right. \tag{12}$$

The null hypothesis of absence of trend ($H_{0)}$, is rejected whenever-Z-> Z5/2, where α is the adopted significance level and Zα/2 is the critical value of Z from the normal standard table. For the significance level of 5% the value of Zα / 2 is 1.96. Positive Z values indicate increasing trends, while negative values indicate decreasing trends.

RESULTS AND DISCUSSION

Figure 2 shows the hierarchical clustering analysis of the microregions according to differences of forest cover in the years 2018-1986. Based on that, the microregions were classified as to the homogeneous patterns of gain or loss over the period analyzed. The distribution of elements (microregions) that are in each homogeneous region (HR) is shown in Figure 2B. The same information portrayed in a different way can be seen in the map with each micro-region (Figure 2A).

The Silhouette width (SI) (Figure 2B) indicates the level of clustering: a large SI (close to 1.0) means that the observations are well clustered; a small SI (around 0) means that the observation is between two clusters; and observations with a negative SI are probably placed in the wrong cluster (BROCK et al., 2008; LEWIS, 2017). Silhouette is the adherence of the element to the group, so that there are some elements that are in the group but do not have much adherence to it like the other elements have. It was noted that most of the elements in each cluster were, on average, well grouped. Of the 19 elements, only 7 microregions had SI below 0.61. The microregion Umarizal was in the HR, but had little adherence; among all the microregions, Umarizal had the lowest adherence. On the other hand, Agreste Potiguar, Serra de São Miguel, Litoral Sul, Natal, and Macaíba presented large SI values, close to 1. The results obtained with the application of the SI were satisfactory, since the mean Silhouette width was 0.61.

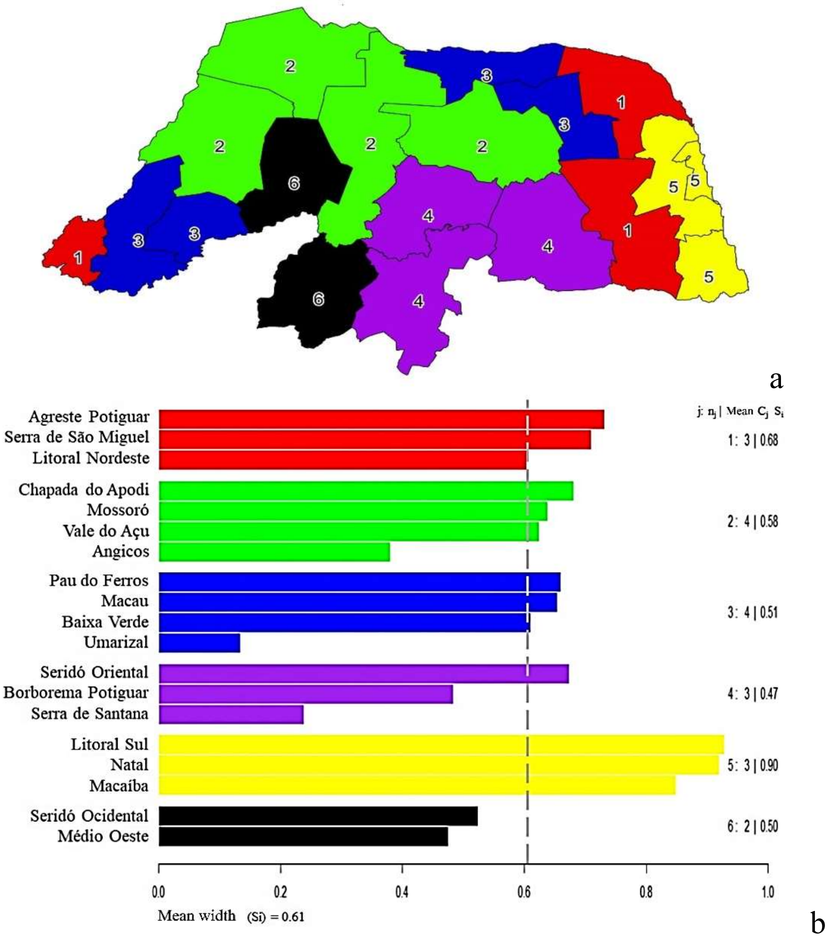

Figure 2: Delimitation of homogeneous regions of forest cover loss/gain (A) and Silhouette Index (B) in the period from 1985 to 2018.

According to Beuchle et al. (2015), the Caatinga has been under increasing anthropic pressure for many years, but the study of land use and land cover changes in these seasonal ecosystems has been largely neglected until now, especially when compared to the attention given to the Amazon region. This limitation has resulted in insufficient knowledge about the historical transformations and current state of forest cover in the area. Regardless of the changes in land cover and the unsustainable use of its land resources, Caatinga has been considered one of the least known and most neglected biomes in Brazil (SANTOS et al., 2011).

The process of land cover change was evaluated by means of a hierarchical cluster analysis based on the homogeneous patterns of the microregions of the state of Rio Grande do Norte. We sought to classify the microregions as to the annual pattern of gain/loss of forest cover in each group. The loss of forest cover grouped by similarity for the microregions of Rio Grande do Norte in the period 1985-2018 was observed (Figure 3).

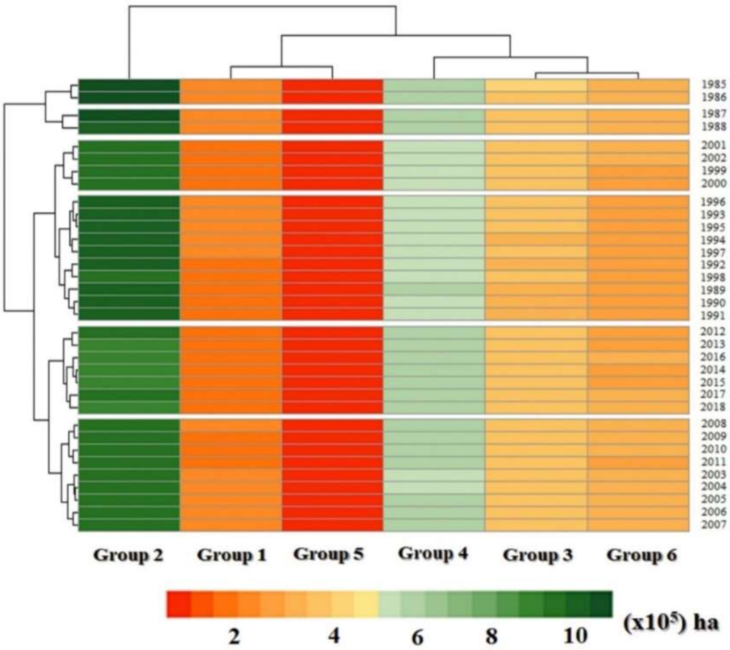

Figure 3: Temporal variability of annual forest cover (ha) in the state of Rio Grande do Norte.

The analysis with three temporal clusters (Figure 3) indicated that the annual variability of forest cover during the analyzed period was similar in the microregions that make up the group 2 (Angicos, Chapada do Apodi, Mossoró, and Vale do Açu). This group presented a mean behavior from 221,444 to 271,507 ha. The groups 1 (Agreste Potiguar, Litoral Nordeste, and Serra de São Miguel) and 5 (Litoral Sul, Macaíba, and Natal) presented a variability of forest cover of 41,964 to 72,067 ha and 1,059 to 6,696 ha, respectively.

The groups 3 (Baixa Verde, Macau, and Pau dos Ferros), 4 (Borborema Potiguar, Seridó Oriental, and Serra de Santana) and 6 (Médio Oeste and Seridó Ocidental) showed a growing trend in the temporal variability of forest cover, especially the group 4, which showed a mean behavior between 181,660 to 203,533 ha.

The temporal analysis also showed that in the 90's, there were annual losses of forest cover in the microregions, which persisted throughout the entire period from 1990 to 1999, especially in the years 1997 and 1998. This must have been directly associated with the decrease in accumulated rainfall resulting from the strong action of the phenomenon El Niño. These conditions were also observed by Araújo et al. (2012) who found that El Niño events can reduce precipitation levels by 50%. Sampaio and Satyamurty (1998) observed in their study a rainfall deficit in the Northeast of Brazil during the rainy season (February-May 98), estimated at 400 billion cubic meters. The microregions that presented the greatest reductions when comparing the forest cover areas in the years 1985 and 2018 (difference) were Mossoró -87,410 ha, Médio Oeste -38,321 ha, Borborema Potiguar -32,846 ha, and Pau dos Ferros -30,339 ha.

There are recovery areas in Seridó. That does not necessarily indicate that there was no cover loss or soil degradation, but it may indicate a spectral response due to the recovery of moisture in the environment, especially soil moisture as a result of rainfall. Thus, the observation of recomposition does not necessarily indicate that after 2 years or more of minimum return of rainfall and soil moisture recomposition, the vegetation will have returned to the initial state. Thus, it can be inferred that this reduction in Caatinga areas has in part the participation of the climatic component, because it was observed that in some way the rain had an important role in the recomposition of vegetation.

Albuquerque (1999) stated that the degradation of the Caatinga is not always directly of anthropic origin, and that the climate should also be taken into consideration. Climate plays a fundamental role in the dynamics of land use and on the evolution of the landscape of the biome (MALDONADO et al., 2002). Still in this context, Marengo et al. (2018) highlight that, in Brazil, several extreme events have been recorded in the last 15 years, such as the El Niño in 1997-1998, causing droughts in the semiarid regions of the Northeast.

Records of previous El Niño events indicate that the 1982/83 and 1997/98 episodes were among the most intense since the beginning of measurements, with sea surface temperature (SST) anomalies reaching up to 4 °C and causing effects of catastrophic proportions in the semiarid region of the Northeast (MARENGO et al., 2011). Still on this scenario, Pereira et al. (2011) evaluated the influence of El Niño and La Ninã phenomena on rainfall in the city of Mossoró (RN) and observed that 52% of rainfall data showed values below the historical mean for the years that were under the influence of the El Niño.

According to Silva (2013), in Northeast Brazil, the losses observed in El Niño years involved sectors of the economy, agriculture, livestock, energy, and others, as well as the water supply for society. The Northeast of Brazil is recognized as highly vulnerable to climatic factors, especially in its semiarid region.

It was observed that in the group 3 (Figure 4C) and 4 (Figure 4D) from the MK test, there was a trend of loss of forest cover from 2001 to 2017 (p-value < 0.05). The groups 1 (Figure 4A), 2 (Figure 4B) and 5 (Figure 4E) showed a negative trend in the period from 1978 until mid-2018. In turn, the group 6 (Figure 4F) oscillated: it showed first a negative trend - a decrease in forest cover - for 10 years, but after the year 2000, there was an increase in forest cover which lasted for approximately nine years (2001 to 2009), that is, during the 9 years (2010 to 2017) remaining of the period in question, there was a decreasing and increasing trend, respectively. There was a break in the series of the group 1 (A) and another in the series before in the group 2 (B) in the beginning of the decade of 2000; in the group 3 (C) this break was a little ahead; in the group 4 (D), it was equivalent and in close years; in the group 5 (E), it occurred around 2009; and in the group 6 (F), around the year 2000. There was a break in the series for the groups 4 and 6 in 2005 and 2001, respectively.

In 1990, the percentage of tree cover and other wooded land in the Caatinga was 18.8% and 48.6% respectively, or a total of 67.4% of natural vegetation cover. By 2010, the percentage of tree cover and other forested land in the Caatinga was reduced to 16.9% and 46.3%, respectively (BEUCHLE et al., 2015).

According to Silva (2020), based on data from MapBiomas (2019), there was a decrease of 8% - from 4,770,088.29 ha to 4,400,992.65 ha - in the natural vegetation cover of the territory of the state of Rio Grande do Norte between the years 1989 and 1992. This decrease occurred more intensely in the West of the state: in all municipalities the arboreal vegetation of the forest type occupied 1,273,666 ha in 1985 and was reduced to 1,125,756.11 ha in 1989, being Mossoró and the neighboring municipalities Upanema, Apodi, and

Caraúbas the ones that presented greater reductions.

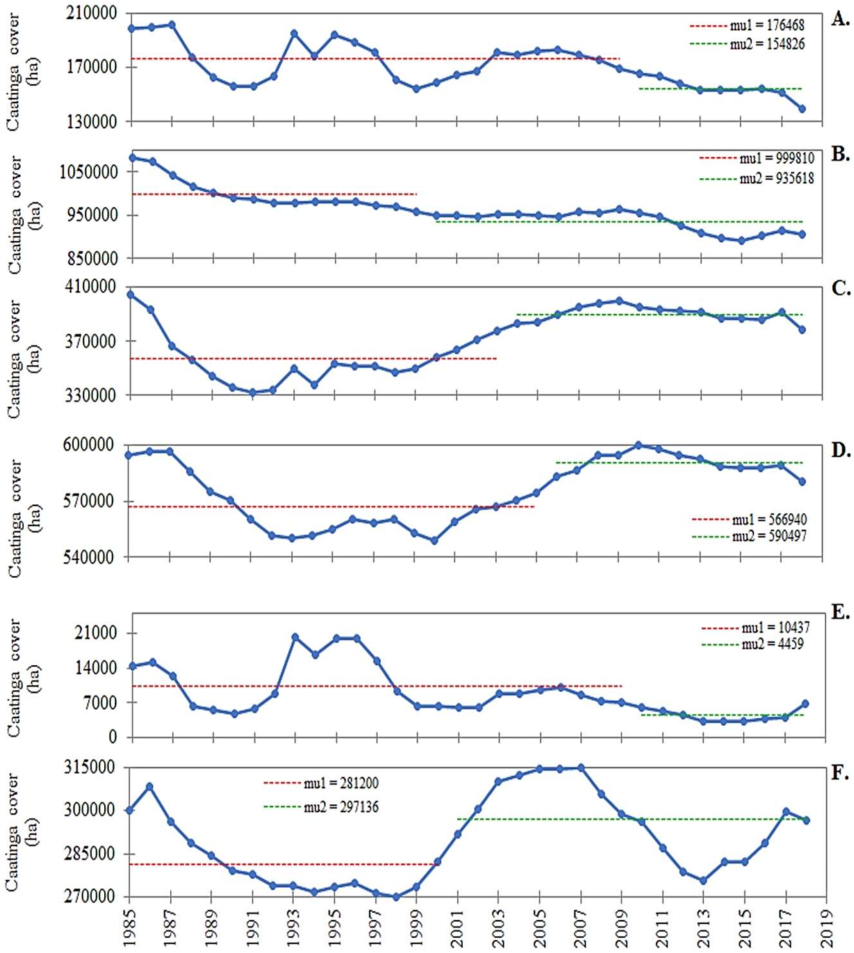

Figure 4: Forest cover variability in Group 1 (A), Group 2 (B), Group 3 (C), Group 4 (D), Group5 (E), Group 6 (F) in the period from 1985 to 2018.

CONCLUSION

The results of the present study made it possible to identify that the Caatinga biome has undergone changes during the period studied, showing variability in forest cover over the years with a significant reduction of forest cover and marked changes in the landscape. Thus, the decrease of the original forest cover is remarkable in the area studied. Therefore, we can infer that this decrease is associated with the advance of anthropic actions such as agriculture and livestock production.

However, some microregions stood out in relation to the variability of forest cover, with significant losses of cover when compared to the others. They were Mossoró, Médio Oeste, Borborema Potiguar, and Pau dos Ferros. It is necessary to create protection and recovery policies for these microregions that have undergone intense processes of land use and land cover change in recent years.

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