Effect of Land Cover Change on Atlantic Forest Fragmentation in Rio Largo, Al, Brazil

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Authors’ contributions

This work was carried out in collaboration among all authors. Authors LGS, ACFT, JPSV and JFSN made the data collection. Authors LGS, ACFT, JPSV and CFLESB identified the landscape parameters. Authors LGS, ACSV, REC, ACFT and CFLESB managed the literature search. Authors LGS, ACFT, CFLESB and JPSV performed the study analyzes. Authors LGS, ACFT, CFLESB, NLS, AALS, REC and JPSV wrote the first version of the article. Authors LGS, ACFT and CFLESB made the statistical analysis. Authors ACFT, CFLESB and MDL reviewed the work. Authors LGS, ACFT, JPSV and CFLESB planned the study. Author ACFT determined the protocol. Authors LGS, ACFT, CFLESB, NLS, AALS and REC managed the analyzes, All authors read and approved the final manuscript.

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ABSTRACT

This study's objective was to analyze the effect of land cover change, between 1965 and 2018, using statistical metrics and geoprocessing tools. And consequently, to provide information of area (ha) and spatial fragmentation of the Atlantic Forest in the municipality of Rio Largo/AL, Brazil. The

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1. INTRODUCTION

Over the years, natural environments all over the world, including Brazil, are being modified due to pressure imposed by human activities [1], noting a significant transformation of areas covered by native forests into other types of cover and land use, such as agriculture and urbanization [2]. The influences on the ecological scenario end up summarizing dense and continuous areas in small fragments sprayed and with their environmental functions threatened. Atlantic Forest had a larger occurrence in Brazil territory, making up north to south along the entire tropical coast of the country to Rio Grande do Norte state; and reaching territorial limits in the interior of Argentina and south of Paraguay. With most of its vegetation suppressed in Brazil, the research data show only a residual tropical forest presence in Brazil varying from 1% to 12% [3]. The human modification of land cover has a high impact on local, regional and global environments, demonstrated by how environments occupation has occurred [4]. From there, it is possible to differentiate anthropic and natural impacts or how can be restored an environment that went through processes of deforestation, loss biodiversity, increased temperature rates and natural floods, in large scale [5].

Forest fragmentation refers to a continuous forest area that become in vegetative patches with high and low interaction levels with forest matrices because of area loss [6], causing deleterious effects on biodiversity, carbon cycle and other ecosystem processes [7-9]. Forest loss leads to adverse effects in tropical forests, causing ecological collapse and increasing tree mortality and accentuation of anthropic problems [10]. In addition, the emergence of smaller and distant forest patches from matrices propitiates extinction comparing to larger fragments that are closer to matrices [7,11].

The fragmentation of the Atlantic Forest causes the decrease of natural habitats and severe biodiversity losses, such as the extinction of living organisms. Besides, the isolation between forest remnants causes blockage in the flow of individuals who tend to move around the landscape in order not to affect their survival. Thus, the higher the isolation, the higher the probability of extinction [12].

Forest landscape estimation provides support for analysis of current problems and allows anticipating panoramas and planning best practices for maintaining ecological equality [13]. However, it should be highlighted the distributions of landscapes as models of preservation and conservation of biodiversity, establishing the level of the environmental value of the studied area [14].

Still, forest-scale research is limited to the study of small landscapes. The study of landscapes using space technologies allows the understanding of ecological relationships at the temporal level, given the constant change in the coverage of the Earth's surface. In this context, computational applications such as Geographic
Information Systems (GIS) and remote sensing data have an essential role in the analysis of environments, where they contribute to the description of spatial patterns of forest fragments [15].

The objective of this study was to analyze the effect of land cover change, between 1965 and 2018, for forest fragmentation using landscape metrics with geoprocessing tools. And consequently, provide information on the dynamics of distance (m) and area (ha) values and spatial dispersion of the Atlantic Forest’s remnants a delimited area in the municipality of Rio Largo/AL, Brazil.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in the municipality of Rio Largo/AL, which has 293.816 km², 75,120 inhabitants, and a demographic density of 223.56 inhabitants per km². Rio Largo is located at 44 meters above sea level and between the geographical coordinates Latitude: 9°28’49” south, Longitude: 35°51’29” west [16] (Fig.1). Treating a region with exclusive predominance of Dense Ombrophilous Forest [17].

2.2 Methodology

Digital and georeferenced data sources were accessed via the internet, as well as in fieldwork, data in photographic and non-georeferenced paper format. The first one was organized in a 2018 vector archive, obtained from the Brazilian Institute of Geography and Statistics (IBGE) Map Portal [18] and the others were organized in raster archives from 1985 to 2018, accessed from the Mapbiomas Project Platform [19]. The photographic paper and non-georeferenced data refer to the collection of aerophotogrametric surveys of 1965, accessed by the MAPOTEC of the Engineering and Agrarian Sciences Campus (CECA), belonging to the Federal University of Alagoas (UFAL).

In addition to the data sources, QGIS software (version 3.4.1) and LibreOffice (version 6.4.3) were used, as well as Regeemy (version 0.2.43) and Google Earth Engine, all of them free.

Initially, the research was carried out to obtain a vector file representing the official limit of the municipality of Rio Largo. For this purpose, the Map Portal of Brazilian Institute of Geography and Statistics - IBGE was used, from which

![Fig. 1. Location Map of the study area of the municipality of Rio Largo, AL, Brazil](Source: Authors (2020))
the al_municipios.zip archive was downloaded, with the shapefile archive (SHP) referring to the municipal mesh 2018 of Alagoas.

Within QGIS, this file was used to select, separate, and create the vector file only from the municipality of Rio Largo. Also, in the QGIS, it was found that only two aerial photos from the 1965 aerophotogrametric survey with scale 1: 60,000, belonging to the CECA’s collection, represented the territory of Rio Largo. These aerial photos, still in photographic paper format, were scanned in the A3 scanner, with a resolution of 1,200 DPI (Dots per Inch). This high resolution minimized the difficulties of photo-interpret the territorial elements, caused by the wear of the film and the little detailed scale of the photos.

These aerial photos already in digital format were georeferenced from the Datum SIRGAS 2000, the official of Brazil. In this process, was used QGIS, specifically the GDAL georeferencing plugin, also allowing the insertion of UTM coordinates in the images.

The georeferenced images were transformed in mosaic using the Regeemy software, which maintained the original georeferencing of the photos, in the final mosaic.

Back to QGIS, the mosaic was cut using the vector file of the Rio Largo boundary. The cut mosaic was used to create a vector file of the study area, which was slightly smaller than the total area of Rio Largo, and of the fragments of Atlantic Forest in 1965. And from the same mosaic the forest fragments map was created by using the classical photo interpretation technique.

Then the Mapbiomas Project data were downloaded, i.e., raster files referring to the Atlantic Forest fragments from 1985 to 2018 (mapbiomas-mataatlantica-alagoas-riolargo-1985.tif; mapbiomas-mataatlantica-alagoas-riolargo-1986.tif; .. mapbiomas-mataatlantica-alagoas-riolargo-2018.tif). The technology of the Google Earth Engine platform was used to download the data on the project website.

Returning to QGIS, the batch processing tool was applied to crop the raster data (1985 to 2018) by the vector file of the desktop. So, for each year was made the separation of pixels with values of numerical identification 3, referring to forest formation. Then, it was calculated the areas (hectare/ha) encompassed by this pixel value from the plugin r.report (Grass).

Landscape ecology Statistics (LecoS), a QGIS plugin, was used to calculate ecological variables such as middle distance, number of fragments, middle area, ground covering and scenery division.

The statistical analysis and measurement of the data were made with the data of areas and quantity of forest fragments. The following functions of Libre office were applied: the sum of areas (ha), the quantity of fragments (nº), and average values of the area of the fragments (between 1965 and 2018). For the determination of areas with values below 10 ha, i.e., at risk of extinction, [20] was applied the function CONT.SE, assigning logical functions for determining areas (Equation 1):

\[
Area \leq 10 = \text{cont.se}(\text{fragments values} \leq 10) \quad (1)
\]

The percentages of the areas were defined from the division of the total area of forests in each year by the total area of the municipality. The loss values were estimated (%) by dividing the values from the years 1985 to 2018 by the value of the base year (1965), this being a fixed denominator (Equation 2).

\[
\text{Number of fragments} = \text{cont.num} (n^\circ) \quad (2)
\]

The analysis of the behavior of two variables that influence forest dynamics over time: comparison and correlation analysis between the variables of average areas and fragment numbers, aiming to cross two data series and their respective changes. The graph was assembled based on the timeline of years analyzed in this study.

3. RESULTS AND DISCUSSION

The values obtained the forest coverage indicated an important fragmentation and area decrease of Forest, between 1965 and 2018. In 1965, the forest covered 32.17% of the total area of Rio Largo municipality. In 2018, with the decrease, this value reached 12.04% of territory occupation, which means a decrease of 20.13% in forest cover (Fig. 2).

According to the same figure, the most significant loss of forest cover (native vegetation) occurred between 1965 and 1985. In 1965, there were 9855.7 ha of forest, being reduced to 3620.25 ha in 1985, representing a loss of 63.27% of forest cover (6235.45 ha) converted into sugar
cane monoculture. The Proalcool program aggressively deforested the natural forests belonging to the Atlantic Forest between the 60s and 80s for sugar cane cultivation, transforming the rural landscapes into continuous fields [21]. Linked to this, it caused the decrease of the original forest cover, besides not protecting stretches of rivers and their natural boundaries.

Between the years 1985 and 2018, there was no significant variation in the loss of forest areas, and, if it occurred, the natural resilience of the vegetation managed to supply this decrease and maintain it between 11 and 12% of forest cover. These percentages remained with little variation due to these areas being in regions of difficult access to be explored more sharply. That situation is verified by analyzing the small increase of 67.84 ha, which is noticeable when considering, separately, the comparative years of 1986 and 2018. Another factor that coherently corroborates with these data is the insertion and application of current legislation in the forest area, which establishes, among several others, the measures of containment and restriction of access and the improper exploitation of native cover.

Regarding the comparison of the number of forest remnants with the mean area of forests between 1965 and 2018, the increase in the number of fragments and the decrease in their mean areas induced that the most conserved forest remnants in that year lost area, fragmented and, consequently, become more susceptible to irreversible ecological impacts, due to the loss of resilience of this landscape.

According to Fig. 3, the highest value for deforestation occurred in 1989, where it was observed the lowest remaining value of mean forest area (10.87 ha) and the highest number of forest fragments (327). Still, in the same figure, perceive a decrease in the number of fragments (200) in the period from 1989 to 1996, but without a gradual increase in the forest area, thus demonstrating the transformation of forest remnants to other types of uses of anthropic nature. Between 1996 and 1997 there was an increase to 250 fragments with a slight increase in forest areas [22].

In 1965 the average forest area was 201.13 ha, but with the advanced fragmentation process, after 1985, the medium value of the fragments decreased to 11.94 ha. After this period, it is observed that the average forest area undergoes an increase, as in 2003, with 24.72 ha, and 2011, with 24.95 ha (Fig. 3). It is evident that even with this increase in the average forest area, the loss compared to what it had in 1965 is quite significant. The implementation of sugarcane is mainly one of the leading causes of the excessive fragmentation of this ecosystem [23].
Also, the rural market favored the conversion of forest into lots, favoring urban growth and, therefore, decreasing forested areas and the loss of ecological services essences as water and soil resources to this region [24].

In 1965, the three main forest matrices had 2017.16 ha, 1562.83 ha, and 1291.90 ha, presenting extensive and continuous areas. In 1988, after the most considerable period of deforestation, the size was 594.90 ha, 544.4 ha, and 191.074 ha, respectively, demonstrating a forest cover loss of 70%. Only after 33 years, in 2015, these matrices showed a recomposition of their areas, reaching 928.91 ha, 599.65 ha, and 300.33 ha, respectively. However, representing an average gain value of 18.40%, far below the decrease occurred in 1988.

It is important to emphasize that the decrease in vegetation cover can directly influence the flow of genes and the difficulty of having the transit of pollinators and seed dispersers, due to the low permeability of the matrix being associated with the increase of cane monoculture and expansion of urbanization in the municipality [25].

The values of gain in forest cover can be explained through unproductive areas that were abandoned and converted into forests via passive regeneration. This situation shows that only the isolation of degradation factors (monoculture and pasture) can favor spontaneous forest restoration [26]. Thus, increasing this low-cost method in the recovery of degraded areas was favorable in the municipality under study. Besides, the evolution of legal tools related to the protection of the natural resources, such as Article 225 of the Brazilian Federal Constitution (1988) and the Brazilian New Forest Code (2012), and its supervision, has been trying to ensure the protection and restoration of these resources, so that they are maintained for future generations [27,28].

The spatial analysis of forest fragmentation shows that the number of remnants less than 10 ha in 1965 was 14, rising to 260 in 1985, 285 in 1989, and 206 in 1997. The year 2003 presented 99 fragments, the lower value after the beginning of agricultural expansion in the 60s, indicating the disappearance of 65.26% compared to 1989,
the year with more significant fragmentation. After 2011 there was a new increase in the number of fragments, reaching 132 in 2018. This increase is explained by the application of the new forest legislation and the reinsertion of new areas (Table 1). The loss of area in smaller fragments is higher than in matrix areas or poorly disturbed forests [29]. This behavior indicates that these remnants suffer a higher effect in isolation, disturbance by edge effects, and the chances of extinction [30], causing losses in the environmental services provided by these formations.

It is also noteworthy the extinction of smaller fragments that were more distant from the matrix habitats, as it is noted the decrease of the areas. The results show a greater distance of forest fragments between the years 1965 and 1989, and disappearance by 2018, configuring that isolation may have been a decisive factor in the maintenance of some areas (Fig. 4). Some matrices serve as supply and shelter, while others, such as sugar cane monocultures, play a negative role, acting as a barrier and dynamizing the maintenance of forest remnants in the landscape [25].

The result of Pearson's correlation coefficient for the period between 1965 and 2018 presented a value of $r = -0.525$, indicating a negative correlation, but moderate between the variables: average value of areas (ha) of forest fragments and the number of forest fragments.

### Table 1. Table of fragmentation in total quantities, quantity of fragments less than 10 hectares and average areas

<table>
<thead>
<tr>
<th>Years</th>
<th>Fragment quantity</th>
<th>Quantity fragments ≤ 10 ha</th>
<th>Average forest area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>49</td>
<td>14</td>
<td>201,137</td>
</tr>
<tr>
<td>1985</td>
<td>303</td>
<td>260</td>
<td>11,948</td>
</tr>
<tr>
<td>1986</td>
<td>300</td>
<td>258</td>
<td>11,852</td>
</tr>
<tr>
<td>1987</td>
<td>318</td>
<td>276</td>
<td>11,181</td>
</tr>
<tr>
<td>1988</td>
<td>310</td>
<td>268</td>
<td>11,199</td>
</tr>
<tr>
<td>1989</td>
<td>327</td>
<td>285</td>
<td>10,87</td>
</tr>
<tr>
<td>1990</td>
<td>292</td>
<td>248</td>
<td>12,491</td>
</tr>
<tr>
<td>1991</td>
<td>291</td>
<td>252</td>
<td>12,752</td>
</tr>
<tr>
<td>1992</td>
<td>272</td>
<td>232</td>
<td>13,821</td>
</tr>
<tr>
<td>1993</td>
<td>248</td>
<td>209</td>
<td>14,642</td>
</tr>
<tr>
<td>1994</td>
<td>226</td>
<td>188</td>
<td>15,794</td>
</tr>
<tr>
<td>1995</td>
<td>215</td>
<td>177</td>
<td>16,389</td>
</tr>
<tr>
<td>1996</td>
<td>200</td>
<td>159</td>
<td>17,125</td>
</tr>
<tr>
<td>1997</td>
<td>250</td>
<td>206</td>
<td>14,142</td>
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<tr>
<td>1998</td>
<td>179</td>
<td>137</td>
<td>19,222</td>
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<tr>
<td>1999</td>
<td>159</td>
<td>118</td>
<td>21,335</td>
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<tr>
<td>2000</td>
<td>169</td>
<td>128</td>
<td>20,602</td>
</tr>
<tr>
<td>2001</td>
<td>147</td>
<td>106</td>
<td>23,411</td>
</tr>
<tr>
<td>2002</td>
<td>143</td>
<td>103</td>
<td>24,305</td>
</tr>
<tr>
<td>2003</td>
<td>140</td>
<td>99</td>
<td>24,728</td>
</tr>
<tr>
<td>2004</td>
<td>149</td>
<td>108</td>
<td>23,512</td>
</tr>
<tr>
<td>2005</td>
<td>142</td>
<td>101</td>
<td>24,783</td>
</tr>
<tr>
<td>2006</td>
<td>154</td>
<td>116</td>
<td>23,313</td>
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<tr>
<td>2007</td>
<td>151</td>
<td>112</td>
<td>23,622</td>
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<tr>
<td>2008</td>
<td>166</td>
<td>127</td>
<td>21,559</td>
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<td>2009</td>
<td>188</td>
<td>149</td>
<td>19,252</td>
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<td>2010</td>
<td>178</td>
<td>138</td>
<td>20,202</td>
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<tr>
<td>2011</td>
<td>143</td>
<td>104</td>
<td>24,951</td>
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<tr>
<td>2012</td>
<td>149</td>
<td>110</td>
<td>24,252</td>
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<tr>
<td>2013</td>
<td>151</td>
<td>111</td>
<td>24,046</td>
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<tr>
<td>2014</td>
<td>161</td>
<td>120</td>
<td>22,649</td>
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<td>2015</td>
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<td>128</td>
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<td>2016</td>
<td>186</td>
<td>143</td>
<td>19,933</td>
</tr>
<tr>
<td>2017</td>
<td>168</td>
<td>126</td>
<td>21,875</td>
</tr>
<tr>
<td>2018</td>
<td>175</td>
<td>132</td>
<td>21,075</td>
</tr>
</tbody>
</table>

*Source: Authors, 2020*
Fig. 4. Comparative maps of forest fragmentation in the most influential years (1965, 1989, 2018)
Source: Authors (2020)
The correlation can also be explained by the abrupt change in deforestation levels between the 60s and 80s (higher degree of deforestation) compared to the later decades, which showed less variation in forest cover. The 1965 values analyze showed an outlier point, in other words, an abnormality that influenced directly the results obtained after 1965 and indicated a very high increase in deforestation from that year compared to the other analyzed years (Fig. 5). For the same variables, between 1965 and 1985, the correlation was perfect and negative \( r = -1 \). That is, with the increase in the number of fragments, there was a reduction in the same proportion of the forest fragments sizes.

Using only the years between 1985 and 2018, the correlation found a negative and almost perfect value \( r = -0.98 \) with proportional behavior between the values of the variables over time. This means that the growth in the values of one variable influenced the decrease in the other variable. Despite the reductions and increases in forested areas found in the years studied, this value \(-0.98\) indicates a strong influence among the variables from 1985 onwards.

The correlations analyzed between the two variables allows to assess a relationship in which deforestation induces an increase in fragmentation and, consequently, a reduction in the forest area.

Landscape change from 1965 to 2020 could be easily viewed using images such as aerial and local photo, and satellite image. These images show the high level of disparity in coverage and land use, and it is possible to understand the dynamics of fragmentation process caused by anthropic actions carried out over decades. Finally, these images allow us to understand the outlier occurrence in the statistical analysis (Fig. 6).
4. CONCLUSION

The most worrying situation regarding the maintenance of native forests occurred in 1989. There was a substantial decrease in continuous forest areas reaching an average value of 10.87 ha of forest area, being distributed in 327 fragments.

Between 1986 and 1996, the number of fragments fell from 300 to 200, demonstrating a considerable slowdown in the fragmentation process. However, in the bienniums 1996 and 1997, there was a new imbalance in forest maintenance, with an increase in the number of fragments, from 200 to 250. The loosening of environmental control explains this increase for deforestation that occurred in previous years.

Therefore, deforestation was highly detrimental to the size of forest matrices, which went out of values between 2017.16 and 1291.90 ha, in
1965, reaching alarming values between 648.72 and 242.46 ha, in 1985. This dynamic of abrupt change in the Atlantic Forest Ecosystem causes imbalance and decreased survival of native forest individuals. In 33 years, only 18.40% of the original vegetation (1965) was restored, indicating the need for actions to enable compliance with international treaties, such as Agenda 21 promulgated during Eco-92, for nature conservation and ecological rebalancing.

The smallest forest fragments were observed in 1988, indicating a year with a high degree of modification in the forest cover area of the local Atlantic Forest biome. The year 2003 presented 99 fragments, the lower value after the beginning of agricultural expansion in the 60s, indicating the disappearance of 65.26% compared to 1989, the year with more significant fragmentation.

According to the statistical correlation analysis of the data between 1965 and 2018, carried out in this work, deforestation directly influenced the process of forest degradation, and when linked to the loss of ideal ecological conditions, led to the reduction of natural forest areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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