Eucalyptus PLANTATION BENEFITS TO PATCH SIZE AND SHAPE OF FORESTED AREAS IN SOUTHEAST ATLANTIC FOREST

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ABSTRACT – The adoption of mixed plantation systems (exotic and native species) is viable and represents an important alternative in the context of forest and landscape restoration. This study evaluated whether *Eucalyptus* cultivation is associated with changes in native forest cover and fragment connectivity in the region from 1987 to 2017. The study region (Southeast Atlantic Forest) has been undergoing a forest transition process. Based on land use/land cover maps obtained from satellite images and a pair-wise comparison, it was detected that the dynamics in one land cover were not necessarily associated with the other one. It was verified an increase in *Eucalyptus* cover since 2007, possibly related to the New Forest Code that allows the use of exotic species in reforestation, provided it does not exceed 50% of the total area. An increase in the native vegetation cover was also observed, highlighting the importance of restoration actions and national regulations. In addition, forest patches were larger and less complex with *Eucalyptus* presence, indicating that this land cover is potentially beneficial for the landscape connectivity.

Keywords: Connectivity; Silviculture; Tropical forest.

BENEFÍCIOS DO PLANTIO DE Eucalyptus *PARA O TAMANHO E FORMA DE FRAGMENTOS DE ÁREAS FLORESTAIS NA MATA ATLÂNTICA DO SUDESTE*

RESUMO – A adoção de sistemas de plantios mistos (espécies exóticas e nativas) é viável e representa uma importante alternativa no contexto da restauração florestal e paisagística. Este estudo avaliou se o cultivo de **Eucalyptus** *está associado a mudanças na cobertura florestal nativa e conectividade de fragmentos na região de 1987 a 2017. A região de estudo (Mata Atlântica do Sudeste) vem passando por um processo de transição florestal. Com base em imagens de satélite, mapas de uso e cobertura da terra e uma comparação pareada, verificamos que a dinâmica em uma cobertura da terra não estava necessariamente associada à outra. A partir de 2007 verificamos um aumento da cobertura de* **Eucalyptus***, possivelmente relacionado às regras do Novo Código Florestal, que permite o uso de plantios de espécies exóticas para recomposição da vegetação, não ultrapassando 50% da área total, e aumento da cobertura vegetal nativa, destacando o importante papel de várias ações de restauração que ocorrem na região e algumas regulamentações nacionais. Além disso, remanescentes florestais foram maiores e menos complexos com a presença de* **Eucalyptus***, indicando que essa cobertura do solo é potencialmente benéfica para a conectividade dessa paisagem.*

Palavras-Chave: Conectividade; Silvicultura; Floresta tropical.

1. INTRODUCTION

The Atlantic Forest biome, a biodiversity hotspot (Myers et al., 2000; Lima et al., 2020), has less than 26% of its native vegetation cover remaining in Brazil (Rezende et al., 2018) due to intense deforestation and human disturbance that occurred mostly in the first half of the 19th century (Dean, 1996; Joly et al., 2014). Nature reserves protect only 9% of the native forest left (Ribeiro et al., 2009). Lately, demographic and market shifts resulted in land abandonment on portions of cattle ranches and farms that are less suitable for agriculture, which in turn have regenerated back to forest (Silva et al., 2017, Piffer et al., 2022), although regenerated forests may not persist longer. At the same time, the Atlantic Forest biome has become an important global conservation and restoration focus (Brancalion et al., 2019), with efforts of nongovernmental organizations to recover native Brazilian ecosystems (WRI, 2018) and local restoration initiatives. In addition, the Convention for Biodiversity has determined restoration of degraded ecosystems as an important strategy for biological conservation (CBD, 1992).

Habitat fragmentation implies the isolation and distancing of native vegetation compartments, influencing seed dispersal and vegetation regeneration processes (Jordano et al., 2006). The landscape of the Atlantic Forest biome consists of many islands (mostly less than 50 ha) of old-growth forests and secondary forest undergoing regeneration (Ribeiro et al., 2009; Rosa et al., 2021). According to a recent study, natural regeneration might bring back 35% of native vegetation cover in this biome (Rezende et al., 2018). The presence of natural regenerating areas or other forested sites may connect isolated areas. The connectivity concept stands for the landscape's ability to facilitate or prevent biological flows of organisms between habitat patches (Tischendorf and Fahrig, 2000), as observed for pollination flows in the Atlantic Forest (Varassin et al., 2021). In order to favor effective connectivity through vegetation fragments in the Atlantic Forest some strategies may be adopted, such as corridors, stepping stones and matrix permeability (Tambosi et al., 2014; Rocha et al., 2021).

Although controversial, some studies have been showing that forest plantations (using exotic or native species) might promote connectivity (Nogués and Cabarga-Varona, 2014), specially for generalist species (Pliscoff et al., 2020), and to enhance natural restoration of native tropical forests (Amazonas et al., 2018). The adoption of mixed plantations systems, which intercrops exotic species (such as *Eucalyptus*) with a high diversity of native tree species, is viable and represents an important alternative in the context of forest and landscape restoration (Amazonas et al., 2018). The Brazilian Forest Code (Lei 12651/2012: Brasil, 2012) and a São Paulo state resolution (Resolução SMA 32/2014: São Paulo, 2014) allow using exotic species plantations for vegetation recomposition, if not exceeding 50% of total area. In Brazil, and in the Southeast Atlantic Forest biome, *Eucalyptus* plantations grew exponentially mainly due to tax incentives established by the Brazilian government for reforestation projects in 1966 and 1974. In Paraíba do Sul River Valley, Brazil, *Eucalyptus* species have been used to increase environmental quality of degraded pastures and to agroforestry systems, in small-scale projects, and in farms of pulp and paper companies, in large-scale.

Despite *Eucalyptus* is a short time harvest species which might restrict forest restoration opportunities and long term conservation through landscape connectivity, planted forest-related ecosystem services, as soil conservation, pollination and carbon stock, also need to be considered (Brockerhoff et al., 2008). Beyond *Eucalyptus* crops, this region historically placed a forest transition process, migrating from a period of constant reduction of native vegetation to another of passive restoration, after land abandonment due to the regional geomorphology (hilly), and demographic and economic aspects (Silva et al., 2017). In order to analyze possible beneficial effects of *Eucalyptus* crops on forest restoration and connectivity of the Southeast Atlantic Forest in Paraíba do Sul River Valley this study aimed to evaluate: (i) variation in native and *Eucalyptus* vegetation cover in the region from 1987 to 2017; and (ii) the relationship between *Eucalyptus* cultivation and native forest cover and connectivity. We expected to find an increase in native vegetation and *Eucalyptus* planting cover and in connectivity, through increases in both land covers.

2. MATERIAL AND METHODS

2.1. Study site

The study area comprises the Paraíba do Sul river basin, located between two mountain ranges “Serra da Mantiqueira" and "Serra do Mar", in southeast Atlantic Forest biome, Brazil. It covers 14,236 km², comprises 35 municipalities and a population of almost 2 million inhabitants (IBGE, 2010). The vegetation is Atlantic forest (transition between evergreen and semi-deciduous forest) and disjoint savanna areas (São Paulo, 2020), with several federal, state and municipal protected areas (of full protection and sustainable use), sometimes overlapping.

The region has passed through some important economic cycles, where coffee cultivation was the most important one. In the 50's, urban and industrial expansion lead to the predominance of extensive pastures (Alves et al., 2011a). The crash of stock markets in the 30s, loss of pasture productivity coupled with urbanization forced an intense rural exodus to large urban centers and consequently, the abandonment of lands, while establishment and expansion of *Eucalyptus* cultivation and secondary forest regeneration took place (Devide et al., 2014; Silva et al., 2017).

2.2. Remote sensing data

We investigated the influence of *Eucalyptus* plantations on native forest connectivity from 1987 to 2017. In order to perform this, a temporal series of data was obtained by TM and OLI sensors (Landsat) for 1987, 1997, 2007 and 2017. We used TM sensor (Landsat-5) for 1987 to 2007, and OLI sensor (Landsat-8) for 2017. Such images have spatial resolution of 30 meters and spectral bands limited to the wavelength range from blue till short-wave infrared. Data were acquired at United States Geological Survey (earthexplorer.usgs.gov) and are expressed in reflectance after atmospheric correction by the LEDAPS (USGS, 2017) and LaSRC (USGS, 2019) algorithms.

Due to the size of study area, we generated mosaics (Figure 1) for each of the four years that constitute a multitemporal series. In this case, each mosaic was composed of four scenes of close dates between August and September of each year, which

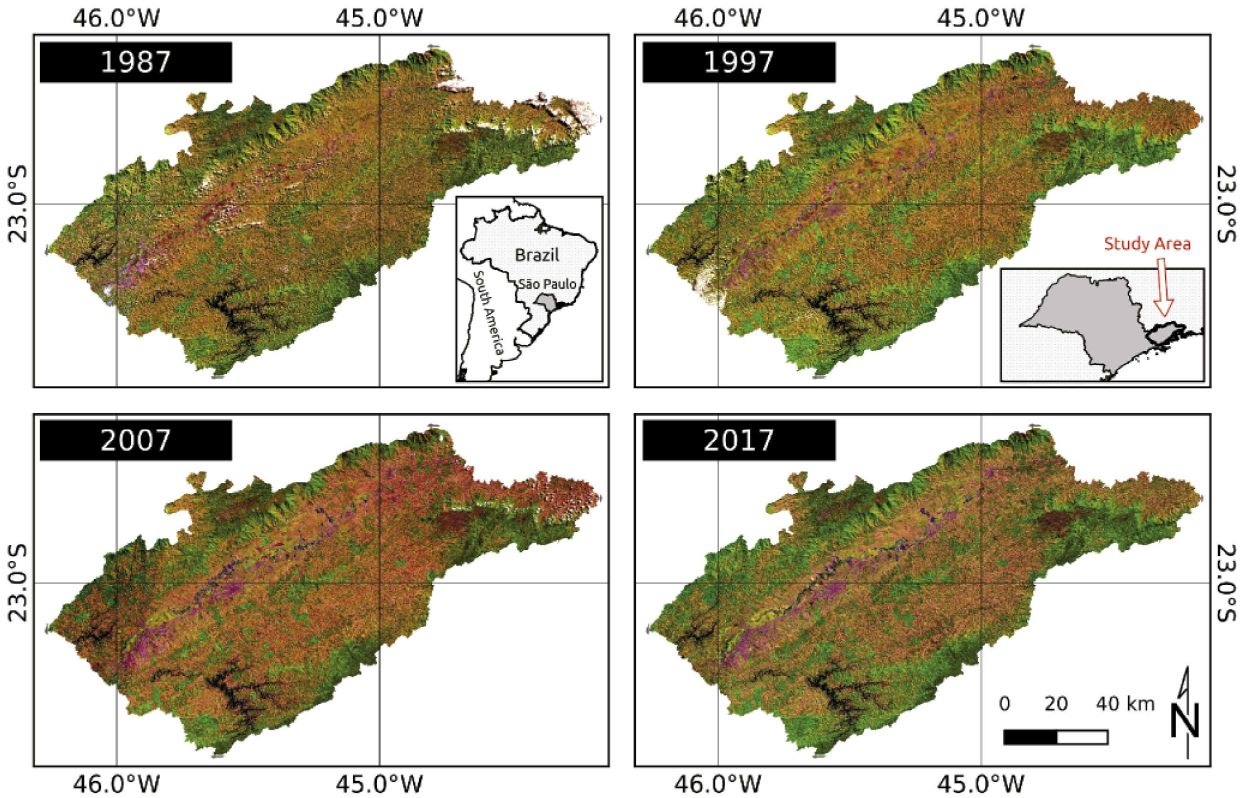

Figure 1 – Study area time-series mosaics.
Figura 1 – *Mosaico das series temporais da área de estudo.*

reduces the chance of cloud occurrence and imposes the same seasonal period for all-time series. These mosaics are defined on a wide support of 7800×4650 pixels.

Since we intend to produce LULC maps from each study area mosaics employing supervised classification, reference samples are necessary for training and accuracy assessment purposes. In the scope of this study, we consider the following LULC classes: native forest, *Eucalyptus* plantation, water body, urban area, bare soil, and agriculture. The collection of such samples was conducted from visual inspection of targets (*Eucalyptus* plantation identification was aided by forestry inventories). Once sample dimensions are much smaller than the entire region, we cannot illustrate in details sample spatial distribution. The complete dataset used in this research is available at github.com/anonymous/project/.

2.3. Image classification and landscape metrics

LULC maps rises as a convenient alternative on the analysis of spatial elements of a geospatial domain as well as highlight the properties shown by such elements. Remote sensing image classification is an efficient and automated process to obtain LULC maps. The image classification comprehends applying a function $f:X \rightarrow \Omega$ on the attribute vector x of each pixel in the image in order to assign it to one class in $\Omega=\{\omega_1,\omega_2,\ldots,\omega_c\}$. Furthermore, supervised classification methods perform the modeling of f through a training set $D=\{(x_i,\omega):i=1,\ldots,m;\omega\in\Omega\}$, where (x_i,ω) denotes an assignment between x_i and the class ω.

Despite several proposals in the literature (Li et al., 2014), the Maximum Likelihood Classifier (MLC) and the Support Vector Machine (SVM) are examples of supervised methods with demonstrated potential on the classification of remote sensing data.

Concerning the MLC method, the function f comprises to the decision rule $\omega_i = \arg\max_{j=1,\ldots,c} p(x \mathrm{V} \omega_j)$, where $p(x\mathrm{V}\omega_j)$ is a probability distribution function regarding the class ω_j. The multivariate Gaussian distribution is the usual choice in this purpose. Such distribution is modelled through the estimation of respective parameters with basis on observations in D assigned to ω_j class. More details about the multivariate Gaussian distribution and its parameter estimation are found in Mood et al. (1973).

Regarding the SVM method, $f(x)=k(x,w)+b$ expresses the distance between x and a decision surface whose separation margin is maximized, where $k(.,.)$ is a kernel function, and both w and b are decision surface parameters. As a consequence of its binary classification nature, in order to apply the SVM on classification problems with more than two classes it makes necessary use multi-class strategies. Further details concerning the w and b parameters computing, kernel functions and multi-class strategies are found in Theodoridis and Koutroumbas (2009) and Webb and Copsey (2011).

When there is special attention to evaluate the arrangement and the spatial relations among the patches (i.e., regions of a particular class) of a LULC map, the landscape metrics reveal as an important tool. Several metrics have been proposed in the literature (Uuemaa et al., 2009). In particular, the landscape configuration metrics focus on quantify geometric features of patches.

Formally, let S a spatial domain (i.e., a limited region on the geographic space) where is defined a landscape composed by patches P_{jk}, for $j=1,\ldots,c$ and $k=1,\ldots,l_j$. Equivalently, we may write that $S_{i=1} \mathrm{U}^{l_j}_{k=1} P_{jk}$. In the context of a landscape analysis through LULC maps obtained by image classification, P_{jk} stands for a region of spatially connected pixels.

Distinct features may be computed for a specific P_{jk}, for example, its area a_{jk}, perimeter p_{jk} and the shortest edge-to-edge straight line length to any other patch P_{jz} of similar class, denoted as $d_{j(kz)}$. Three useful metrics on the geometric evaluation of multi-temporal landscape analysis are: patch size; shape index; and the nearest-neighbour. While the patch size of P_{jz} stands for the a_{jk} feature scaled in hectares and the nearest-neighbour refers to the minimum value found for $d_{j(kz)}$; the shape index is expressed by $p_{jk}/(4\sqrt{a_{jk}})$. As a general interpretation regarding such metrics, the increase of patch size points to larger extensions of relative LULC class. On the other hand, larger values of nearest-neighbor and shape index imply more isolation and patches' irregularity, respectively.

2.4. Experimental design

Figure 2 depicts the experiment design, basically structured into three stages: data acquisition and

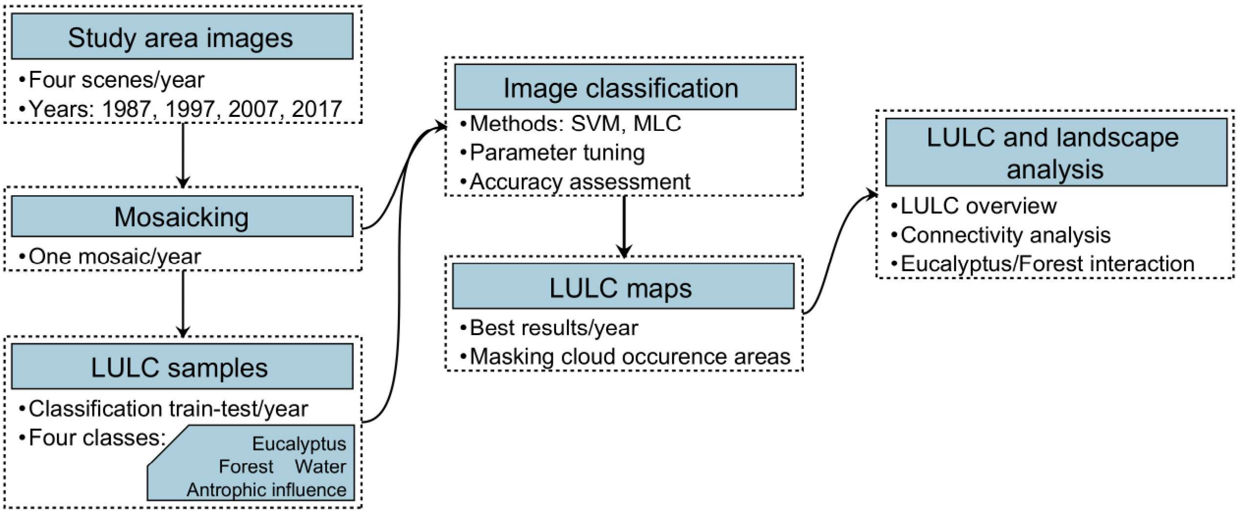

Figure 2 – Experiment design flowchart.
Figura 2 – *Fluxograma do desenho experimental.*

pre-processing; LULC mapping; and respective landscape analysis.

The first stage comprehends the study area images acquisition, mosaicking composition and LULC samples selection, as previously discussed in Section 2.2. Regarding the study area LULC mapping, we employed the MLC and SVM classification methods addressed in Section 2.3. Different parameter configurations are tested for the SVM method to reduce the influence of parameter values on the accuracy of classification results. Precisely, are observed the penalty parameters *C* in $\{10^{-1},10^{0},\ldots,10^{4}\}$, kernel gamma values for RBF kernel in $\{10^{-4},10^{-3},\ldots,10^{0}\}$, and one-against-all multi-class strategy. Concerning the MLC method, no further parameters are adjusted beyond those related to the classes probability distributions fitting.

Each classification result, concerning a year, classification method and parameter configuration, is submitted to an accuracy assessment process using kappa coefficient (Congalton and Green, 2002) and the respective LULC testing samples as reference data. The classification result with the highest kappa value for each instant is adopted in the next stage of landscape analysis.

Additionally, given possible interference of clouds, masks were constructed, so that such areas could be disregarded in each year analysis. Information provided by LEDAPS and LaSRC algorithms was employed to define these masks. Finally, we quantify the LULC classes frequency as well as compute landscape metrics discussed in Section 2.3, which comprises the patch size, shape index and shortest distance (i.e., nearest-neighbour) between fragments. The mean value and standard deviation of these metrics were used in the analyses. As computational tools, the LULC maps and cloud masks were built using ENVI 5.7 (Exelis, 2019). The landscape metrics were computed using FRAGSTAT (McGarigal et al., 2012) software.

3. RESULTS

According to the experimental design (Section 2.4), several LULC maps were computed using the MLC and SVM methods with distinct parameter configurations. SVM's higher accuracy values are similar to those resulting from the MLC method with a kappa value of 0.98. Thus, LULC classification results from MLC were adopted in the following discussions to computing patch area, shape index and nearest-neighbor landscape metrics.

From 1987 to 2017, we found an inverse relationship between urban infrastructure (cities and pastures) and silviculture (*Eucalyptus* forest) and native forest areas (Figure 3a) and Table 1). Looking over decades, we noticed a decrease in forest cover between 1987 and 2007 and an increase in 2007-17 decade; while *Eucalyptus* plantations expanded,

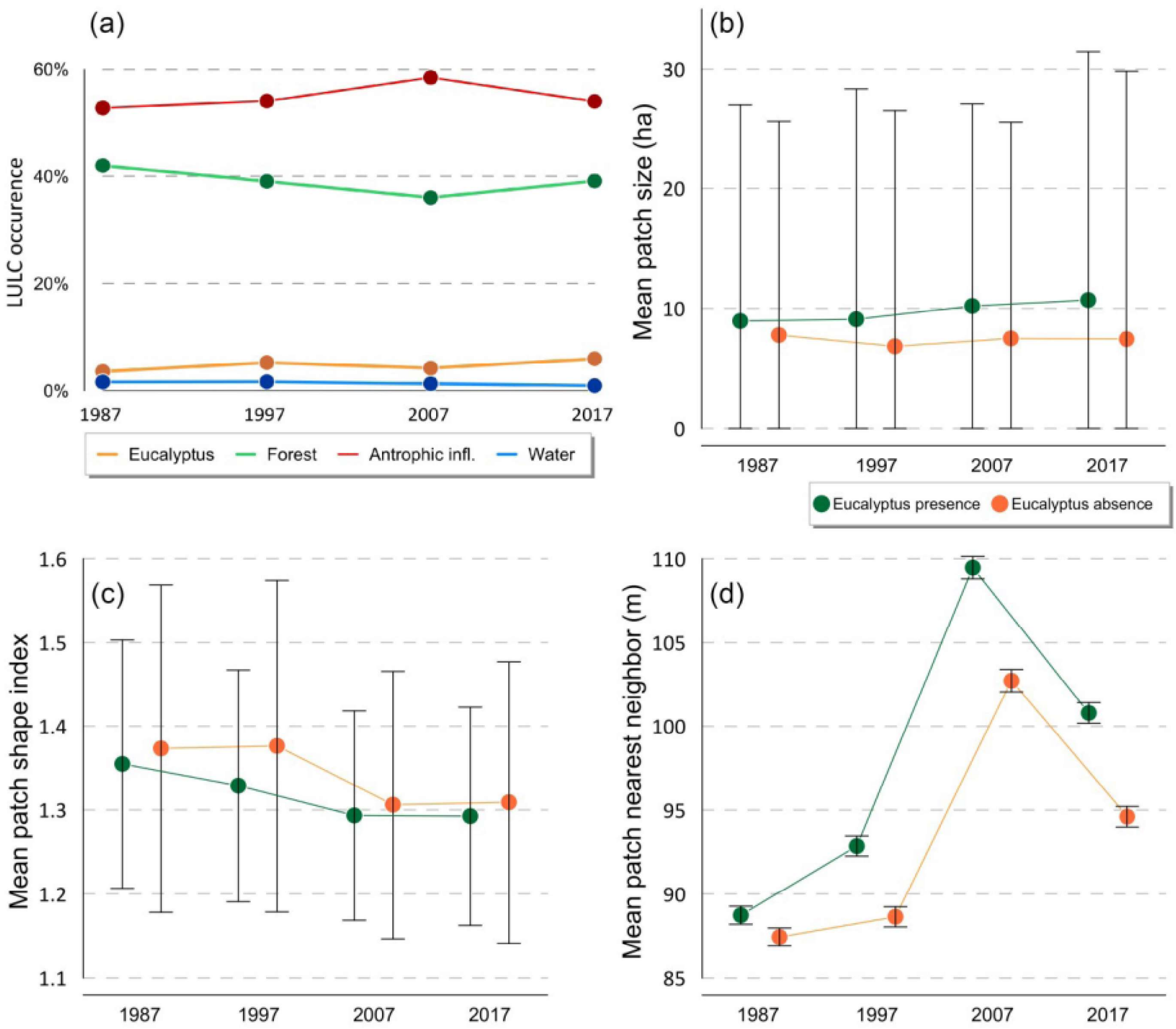

Figure 3 – Landscape metrics. (a) LULC class occurrences, (b) patch size, (c) shape index, (d) nearest neighbor. Error bars at (a) and (c) are 25% of variation coefficient; for (b) and (d) are the variation coefficient. The error bars are purposely low-bounded by zero.
Figura 3 *– Métricas da paisagem. (a) Ocorrências de classe de uso e cobertura do solo, (b) tamanho do fragmento, (c) índice de forma, (d) vizinho mais próximo. As barras de erro em (a) e (c) são 25% do coeficiente de variação; para (b) e (d) são o coeficiente de variação. As barras de erro são propositalmente limitadas por zero.*

Table 1 – Variation in forest and *Eucalyptus* cover from 1987 to 2017.
Tabela 1 *– Variação na cobertura de floresta nativa e* ***Eucalyptus*** *de 1987 a 2017.*

Period	Land cover characteristics				Cloud coverage
	Forest cover		Eucalyptus cover		
	ha×10³	%	ha×10³	%	ha×10⁵
1987-1997	-42.097	-2,98	23.364	1,66	Absence
1997-2007	-42.615	-3,02	-14.589	-1,03	14.112
2007-2017	43.549	3,09	24.834	1,76	Presence
1987-2017	-41.164	-2,92	33.609	2,38	1.427

contracted and expanded again, respectively from 1987-97, 97-2007 and 07-17 (Figure 3a) and Table 1). In general, the presence of *Eucalyptus* brought some positive aspects to the landscape. While forest patch size became larger through the analyzed period (Figure 3(b)), the shape index decreased (Figure 3(c)). Regarding the average distance to the nearest neighbor patch, we noticed that distance increased 41% with *Eucalyptus* presence (Figure 3(d)).

4. DISCUSSION

In general (from 1987-2017), we found an increase in urban infrastructure and silviculture (*Eucalyptus* forest) and a decrease in native forest areas. Looking over decades, we noticed a decrease in forest cover between 1987 and 2007 and an increase in 2007-17 decade; while *Eucalyptus* plantations expanded, contracted and expanded again. The dynamics in one land cover were not necessarily associated to the other one; *Eucalyptus* subtle changes along 1987-2007 might be explained by its harvest cycle and the increase in *Eucalyptus* cover from 2007-2017, higher than in the previous decades, might be related to the New Forest Cover (from 2012), which allowed exotic species plantations for vegetation recomposition, if only up to 50% of total area. Regarding native forest, despite two decades of decrease, there has been an increase verified in the Paraíba do Sul river valley region since 2007, which confirms other studies (Ronquim et al., 2017; Silva et al., 2017; São Paulo, 2020). This increase may highlight the important role of several restoration actions taking place in the region (by non-governmental organizations and governments, specially payment for ecosystem services programs) and some national regulations (specially the New Forest Code and the Atlantic Forest Law: Lei 11428/2006: Brasil, 2006).

In general, the presence of *Eucalyptus* brought some positive aspects to the landscape: forest patch size increased, the shape index decreased, indicating that forest patches are bigger and less complex with *Eucalyptus* presence, and with higher distance to the nearest neighbor patch. As showed in Figure 4, small areas of *Eucalyptus* plantations in small rural properties of the region fill empty spaces previously occupied by pastures. Then, when *Eucalyptus* was present, small fragments become larger and consequently more distant to each other. Some data have identified native

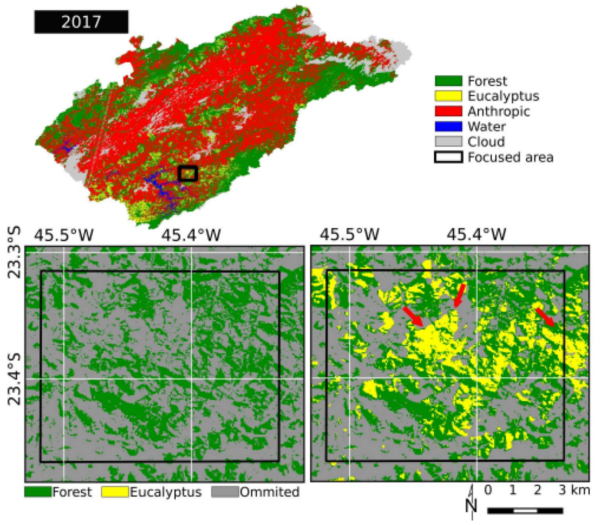

Figure 4 – *Eucalyptus* influence on patch size and distance to the nearest neighbor.
Figura 4 *– Influência do* ***Eucalyptus*** *sobre o tamanho dos fragmentos e distância do vizinho mais próximo.*

fauna transit along Paraíba do Sul landscape, using native and *Eucalyptus* planted forests, indicating a functional connectivity for animals (Oliveira, 2002). Again, despite *Eucalyptus* is a short time harvest species which might restrict long term conservation and restoration through landscape connectivity, planted forest-related ecosystem services need to be considered (Brockerhoff et al., 2008).

Since 1960, *Eucalyptus* plantations have been located in the studied region for cellulose production purposes (SMA, 2011). Many paper and pulp industries have environmental certification, especially the ones who trade internationally, and measures such as fire breaks, protection of native vegetation and restoration of riparian areas are required, increasing forest cover (Alves et al., 2011b). Guedes et al. (2020) have showed that fire probability is smaller in silviculture sites of Paraíba do Sul river valley region, attributed to a zero-fire policy of *Eucalyptus* stands of pulp and paper companies, consequently protecting native forest patches nearby. The same protection against fire might promote forest regeneration in some sites.

Given the history of the Paraíba do Sul river basin, which led to a scenario of few extensive conserved areas and the predominance of abandoned and/or degraded areas, *Eucalyptus* cultivation has the potential to be beneficial for connectivity of this and other regions. A recent technical report (SMA, 2018) addressed the importance of sustainable pastures (with *Eucalyptus*) to landscape restoration of Paraíba do Sul River Valley.

5. CONCLUSION

In order to analyze possible beneficial effects of *Eucalyptus* crops on forest restoration and connectivity of the Southeast Atlantic Forest in Paraíba do Sul River Valley, we expected an increase in native vegetation and *Eucalyptus* planting cover and in connectivity, through increase in both land covers. From 1987-2007 we found that the dynamics in one land cover were not necessarily associated to the other one. Since 2007 we verified an increase in *Eucalyptus* cover and an increase in native vegetation cover, highlighting the important role of several restoration actions taking place in the region and some national regulations. In addition, forest patches were bigger and less complex with *Eucalyptus* presence, indicating this land cover to be potentially beneficial for this landscape connectivity. However, mid- to long-term impact of this increase in patch size with *Eucalyptus* presence requires further examination, due to temporary aspect of this cultivation and due to other potential effects of silviculture to biodiversity (as fauna flow).

AUTHOR CONTRIBUTIONS

Conceptualization: G.R.S., R.G.N., K.G.M and E.H.A; Funding acquisition: G.R.S. and R.G.N. Investigation: G.R.S., R.G.N., K.G.M and E.H.A; Methodology: G.R.S., R.G.N., K.G.M Validation: G.R.S., R.G.N., K.G.M and E.H.A; Writing original draft: G.R.S. and R.G.N.

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