

Spatial Analysis of Forest Fragmentation in the Atlantic Forest Bioma Areas

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Abstract

The goal of this work was to calculate landscape ecology metrics using the R language, allowing the analysis of forest fragments under the Atlantic Forest domain located in the sub-basin of Arroio Jaquirana, Rio Grande do Sul, Brazil. For the mapping of the forest fragments, we used images from the REIS/RapidEye sensor dated 2016, and the classification was supervised through the Bhattacharya algorithm. The fragments were analyzed in seven size classes, to separate them and to calculate the landscape metrics it was used R language. The results attained demonstrated that the native forest occupied 34.01% of the study area, covering a total of 1,995 fragments, of which 93.43% were less than 5 ha. The highest values of edge and perimeter-area ratio were found in the small fragments indicating a greater edge effect, with the central areas of these remnants being exposed to the external matrix effects. Thus, it is concluded that the Atlantic Forest is highly fragmented and is extremely important to establish measures to minimize the effects and/or increase the connectivity between the fragments through ecological corridors using the smaller fragments, in addition, it makes necessary the development of public policies and research for the management of the region in order to preserve the remnants.

Keywords: landscape ecology metrics, deforestation, remote sensing, R language

1. Introduction

For decades the deforestation resulting from the process of anthropization of the landscape, has caused the destruction of natural resources. Native forests gave way mainly to agriculture, livestock and urbanization, with the formation of fragments, often isolated from one another. The loss of areas, the increasing of the isolation and the greater exposure of the borders of the fragments to human actions cause changes in the structure and function of these fragments (Lindenmayer & Fischer, 2006).

The process of forest fragmentation and loss of areas are present in the different biomes. However, the Atlantic Forest is one of the most threatened biomes in the world, being one of the most deforested (Jenkins et al., 2013). Thus, this biome was conferred the title of hotspots due to it being a threatened area, yet rich in biodiversity (Laurance, 2009). Originally the forest area covered approximately 1,315,460 km², and currently there are only 12.5% of this original area, when the fragments above 3 hectares were recorded (SOS Mata Atlântica, 2015). In addition, it is highly fragmented, with 83% of the fragments smaller than 50 ha (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009), being the conservation of the remaining remnants primordial.

Thus, it is necessary to carry out studies related to the spatial characterization of forest fragments in order to establish conservation strategies (Pirovani et al., 2014). In this context, the ecology of the landscape is inserted, since the search for ecological knowledge about the forest fragments of a given area allows applying a correct environmental management as to these forests management (Calegari, Martins, Gleriani, Silva, & Busato, 2010; Negrini et al., 2014). In landscape ecology, the main object to be measured is the landscape structure, which provides characteristics of the constituent elements of the landscape, being commonly expressed through landscape metrics (Skokanová & Eremiášová, 2013). The landscape metrics contribute to the maintenance of biodiversity, since the analysis of these contributes to the determination of management techniques with the purpose of conserving and recovering the remaining forest fragments (Juvanhol et al., 2011). Thus, to evaluate

the landscape becomes important to verify the current problems, to estimate the future ones and to point out the necessary measures to maintain the balance of the ecosystem (Calegari et al., 2010).

Thus, analyzing forest fragmentation is important due to its impacts caused to the environment. According to Matos et al. (2017), the fragmentation process causes changes in forest structure and biodiversity. The main consequences of habitat loss, species isolation, edge effects, invasion of exotic species, decrease of biodiversity, decrease of pollination and consequently disappearance of species (Silva, Metzger, Simões, & Simonetti, 2007; Lindenmayer et al., 2008; Calegari et al., 2010). Thus, in general, the fragmentation process changes the dynamics of populations and communities, ecosystem processes and trophic interactions (Laurance & Vasconcelos, 2009).

Mariota (2015) report that a challenge of the present day is to reliably and economically monitor landscape dynamics in order to implement effective conservation strategies. In this context, several metrics have been used to describe spatial patterns through the use of remote sensing and geoprocessing tools (Jung, 2016), since they provide detection of remnants that present potential for conservation in a fast and accurate way (Silva et al., 2015). These tools are the Geographic Information Systems (GIS).

At present, there are several GIS for manipulation of data from remote sensors, some of them used for analysis of fragmentation, in which they perform calculations of landscape ecology metrics. Recently, researchers have been using the R language for spatial data analysis. The R has several advantages that makes it a promising tool in the area of remote sensing and geoprocessing, since it is free, flexible in the type of data that can be analyzed, it allows changes in available functions and is compatible with all platforms (Muenchen, 2011). Due to these characteristics, R is a complete and extremely powerful programming language (Casajus, 2013).

The study was directed to the hydrographic sub-basin of Arroio Jaquirana, Rio Grande do Sul, due to it is located in areas of the Atlantic Forest biome, characterized by intense agricultural activity with high rates of deforestation and, consequently, presenting itself in an advanced process of fragmentation. Therefore, it was considered important to analyze the landscape structure mentioned in order to understand its behavior before the use of landscape metrics and with that serve as a basis for planning the region in order to recover or preserve the remaining forest remnants. In this context, the present study aimed to calculate landscape ecology metrics using the R language, allowing the analysis of forest fragments under the domain of the Atlantic Forest biome located in the sub-basin of Arroio Jaquirana, Rio Grande do Sul, Brazil.

2. Method

2.1 Location and Characterization of the Study Area

The study area consists on the sub-basin of Arroio Jaquirana, which covers the municipalities of Arroio do Tigre, Lagoão, Segredo, Sobradinho and Passa Sete, located in the State of Rio Grande do Sul, Brazil (Figure 1). The total area of the sub-basin is approximately 41,460 ha.

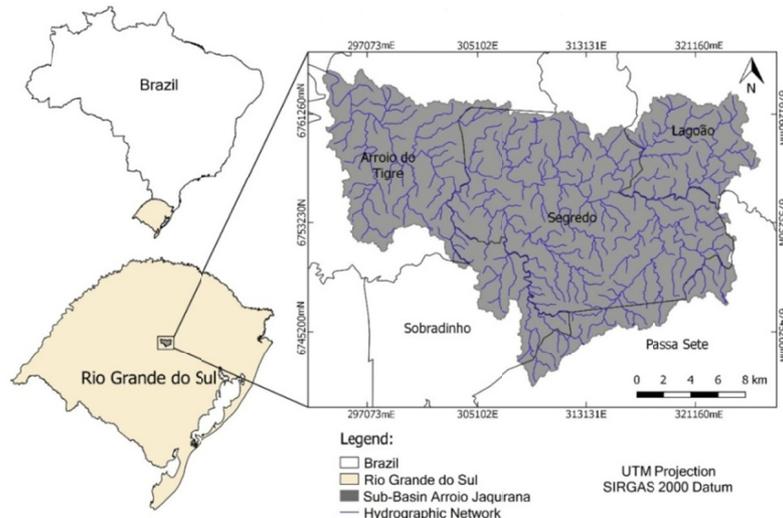


Figure 1. Location of the hydrographic sub-basin of Arroio Jaquirana, Rio Grande do Sul, Brazil

The sub-basin of Arroio Jaquirana is an affluent of the Jacuizinho River, which, in turn, flows into the Jacuí River, thus, is inserted in the catchment area of Alto Jacuí. The main phytogeographic type is the Deciduous Seasonal Forest, belonging to the Atlantic Forest biome, limiting the pastures of the southern campaign and the northern plateau (Rambo, 1956). According to the classification of Köppen the climate is a Humid Subtropical (Cfa), with average temperatures that vary between 16 °C and 20 °C. The precipitations are well distributed throughout the year, varying between 1,600 and 1,900 mm (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2014).

2.2 Mapping of Forest Fragments

Two SRTM (Shuttle Radar Topography Mission) scenes, captured by the Space Shuttle Endeavor, with a 30 m spatial resolution, were available for free from the USGS (United States Geological Survey). The area was automatically delimited using the GRASS modules version 7.0.4, coupled with the QGIS software - Quantum GIS Geographic Information System (QGIS Development Team, 2016), version 2.14.7.

In the SPRING-Georeferenced Information Processing System, version 5.2.7 (Câmara, Souza, Freitas, Garrido, & Mitsuo, 1996), a spatial database with UTM (Universal Transverse Mercator) and Datum SIRGAS 2000 cartography was created. For the mapping of the fragments of native forest four scenes REIS (RapidEye Earth Imaging System) sensors were needed, RapidEye satellite, with a resolution of 5 meters, composed of 5 multispectral bands, dated February 29, 2016. They were obtained by means of a project between the Federal University of Santa Maria and the Interstate Union of the Tobacco Industry (SINDITABACO), which aims to monitor forest cover in areas of Deciduous Seasonal Forest in the Central Sierra region of Rio Grande do Sul state.

Among the techniques of segmentation, this process precedes the classification, it was chosen the region's growth method, which consists of aggregating neighboring pixels to a given region that presents similar characteristics, thus occurring the increase of these regions (Happ, Feitosa, Bentes, & Farias, 2013). For this, it was necessary to define the parameters of similarity and area, being used the values of 10 and 100, since they were better suited to the study area. The classification was performed in a supervised manner using the Bhattacharya algorithm with a 99% acceptance threshold. With this algorithm the Bhattacharya distance measure is used to calculate the statistical separability between pairs of spectral classes, thus measuring the average distance between the probability distributions of the classes (Brites, Bias, & Rosa, 2012).

The efficiency of the mapping was verified using the Kappa index proposed by Congalton and Green (1999), according to Equation 1, and the quality of the generated data was evaluated according to the limits proposed by Landis and Koch (1977), according to Table 1.

$$K = \frac{N \cdot \sum_{i=1}^r X_{ij} - \sum_{i=1}^r X_{i+} \cdot X_{+i}}{N^2 - \sum_{i=1}^r X_{i+} \cdot X_{+i}} \quad (1)$$

Where, r = number of classes; X_{ij} = number of elements sorted correctly; X_{i+} = total of elements classified for a category i ; X_{+i} = total of reference elements sampled for a category i ; N = total number of samples.

Table 1. Quality of the classification according to Kappa coefficient intervals

Kappa value	Quality of classification
< 0.00	Very bad
0.0-0.20	Bad
0.20-0.40	Acceptable
0.40-0.60	Good
0.60-0.80	Very good
0.80-1.00	Excellent

Source: Landis and Koch (1977).

In order to carry out the calculations, 200 points were distributed over the forest theme class, in a stratified random manner, according to Congalton's (1991) methodology, which suggested a minimum size of 50 samples for each category in areas that have a territorial coverage of up to approximately 4,050 Km². To verify the veracity of the classification we used high spatial resolution images of Google Earth Pro (Moreira, Barros, & Rudorff, 2008).

2.3 Analysis of Forest Fragmentation

The raster file containing the forest fragments was imported into the development environment integrated with the R version 3.3.0 (R Development Core Team, 2016), for splitting the fragments into size classes, in which a sequence of commands in R language was employed. The fragments were grouped in adapted classes of Ribeiro et al. (2009), in order to compare the different sizes in the study area (Table 2).

Table 2. Size classes of forest fragments adopted for analysis of landscape ecology metrics

Size class	Size of the fragments (ha)
1	< 5
2	5 — 50
3	50 — 100
4	100 — 250
5	250 — 500
6	500 — 1,000
7	≥ 1,000
8	0 to ≥ 1,000

In order to avoid the use of redundant metrics, they encompassed different groups: area and density, edge, shape, central area and proximity. As shown in Table 3.

Table 3. Landscape ecology metrics used in the study

Group	Initials	Landscape Metrics	Unity
<i>Area and density</i>	CA	Class Area	ha
	NP	Number of Patches	-
	MPS	Mean Patch Size	ha
	MedPS	Median Patch Size	ha
	PSSD	Patch Size Standard Deviation	ha
	PSCov	Patch Size Coefficient of Variation	%
<i>Shape</i>	LSI	Landscape Shape Index	-
	MSI	Mean Shape Index	-
	AWMSI	Area-Weighted Mean Shape Index	-
	MPAR	Mean Perimeter-Area Ratio	m ha ⁻¹
<i>Edge</i>	TE	Total Edge	m
	ED	Edge Density	m ha ⁻¹
<i>Proximity</i>	MNN	Mean Nearest-Neighbor Distance	m
<i>Core area</i>	TCA	Total Core Area	ha
	NCA	Number of Core Areas	-
	MCA	Mean Core Area	ha
	TCAI	Total Core Area Index	%

Functions in R language were developed for the calculation of the metrics based on the equations described by McGarigal and Marks (1995), using as input parameter the raster file containing the forest fragments. In order to perform the calculations, it was needed the *igraph* package (Csardi & Nepusz, 2006) version 1.0.1, *raster* (Hijmans et al., 2016) version 2.5-8, *rgdal* (Bivand, Keitt, & Rowlingson, 2016) version 1.2-4 and *rgeos* (Bivand & Rundel, 2016) version 0.3-2.1 compatible with R version 3.3.0.

The metric calculations were performed for each size class of the fragments as well as for the fragments as a whole, without stratification, in order to obtain general results of the study area and thus enable the comparison among those. The central area metrics were calculated using different edge distances, being 20, 60, 100 and 140 meters based on the method of Juvanhol et al. (2011), and Pirovani et al. (2014), in order to analyze the different results obtained.

3. Results and Discussion

The thematic mapping accuracy of the forest fragments in the sub-basin Arroio Jaquirana for the year 2016 was measured using the Kappa index, in which the value of 0.85 was obtained. In this way, the classification was categorized as "excellent" according to the scale proposed by Landis and Koch (1997). The forest fragments were divided into size classes as shown in Figure 2.

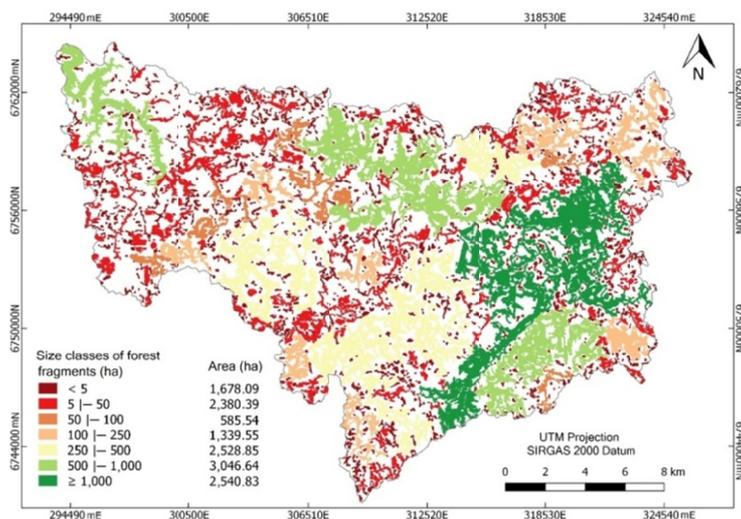


Figure 2. Espacialization of forest fragments in size classes in the sub-basin of Arroio Jaquirana, Rio Grande do Sul, Brazil

The results obtained for the calculated landscape metrics for the native forest fragments are set out in Table 4. Calculations were performed separately for the seven size classes and also for the fragments as a whole.

The number of native forest fragments in the study area, in 2016, totaled 1,995, which covered 14,099.9 ha, equivalent to 34.01% of the total area of study. Most of the fragments belonged to the smaller size class, being well distributed in the study area. It was observed that with the increase of the fragments area decreased their number of occurrence, reaching 2 fragments in the class of larger size ($\geq 1,000$ ha).

Table 4. Values of landscape ecology metrics for the forest fragments of the Arroio Jaquirana sub-basin, Rio Grande do Sul, Brazil

Landscape Metrics	Size of the fragments (ha)							
	1 (< 5)	2 (5 — 50)	3 (50 — 100)	4 (100 — 250)	5 (250 — 500)	6 (500 — 1000)	7 (≥ 1000)	8 (0 to ≥ 1000)
CA (ha)	1,678.1	2,380.4	585.5	1,339.5	2,528.8	3,046.6	2,540.8	14,099.9
NP	1,804	160	9	9	7	4	2	1,995
MPS (ha)	0.9	14.9	65.1	148.8	361.3	761.7	1,270.4	7.1
MedPS (ha)	0.5	9.8	61.5	130.8	329.0	777.9	1,270.4	0.6
PSSD (ha)	0.9	11.5	12.1	42.8	80.1	94.9	38.9	58.2
PSCov (%)	102.82	77.40	18.68	28.76	22.18	12.46	3.06	823.71
LSI	73.5	48.2	20.3	28.1	37.0	33.3	32.1	102.8
MSI	1.8	3.7	6.7	9.4	14.0	16.6	22.7	2.1
AWMSI	2.1	4.4	6.9	9.5	14.1	16.7	22.7	12.4
MPAR (m ha ⁻¹)	976.7	420.4	334.0	317.3	299.5	241.0	254.9	921.6
TE (m)	1,204,409.0	941,411.6	196,648.5	412,050.7	744,639.9	734,893.3	648,102.8	4,882,155.8
ED (m ha ⁻¹)	29.0	22.7	4.7	9.9	17.9	17.7	15.6	117.7
MNN (m)	103.6	244.3	2,568.3	2,696.4	566.9	3,022.7	13.4	43.1

The size class 1, composed of fragments smaller than 5 ha, covered the largest number of fragments in the study area, a total of 1,804, representing 93.43% of the total area. However, the area covered by the fragments belonging to classes 3 and 4 was smaller when compared to the others (Figure 3).

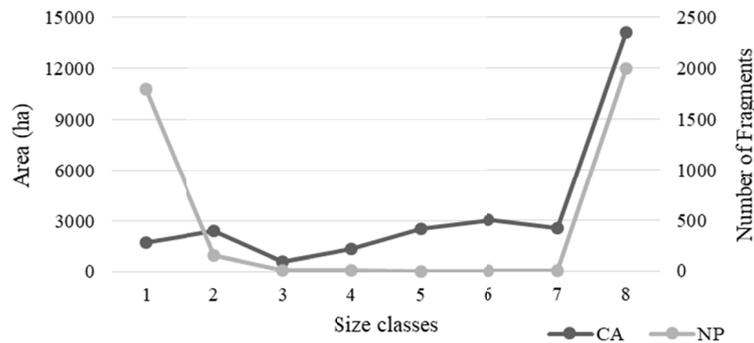


Figure 3. Relationship between the area (CA) and the number of forest fragments (NP) corresponding to each size class in the sub-basin of Arroio Jaquirana, Rio Grande do Sul, Brazil

The size class 2, on the other hand, comprised 160 fragments, being the second class with the largest number of fragments, however, this value is much lower than the one found in the first class, representing only 8.02% of the total fragments. The other size classes totalled 31 fragments, that is, 1.55% of the fragments belonged to classes 3 to 7. Works performed by several authors corroborate with these found in this study. Juvanhol et al. (2011) evaluating areas of the Atlantic Forest biome, in the state of Espírito Santo, also found that most of the fragments belong to the smaller size class (less than 5 ha), covering 83% of the existing fragments. Hentz et al. (2015) also found a larger number of fragments with small areas, analyzing forest remnants of the Atlantic Forest in the Iguaçú river basin in Paraná.

Among the factors that directly influenced the formation of the large number of small fragments (less than 5 ha) in the study area, the Arroio Jaquirana sub-basin is agriculture and cattle raising, since the native forest region has been under high pressure caused by these land uses, causing vegetation suppression (Dessbesell, Pereira, Farias, Vogt, & Welter, 2015). The largest fragments were found in sloping areas, which make agricultural implementation difficult, while in flat areas, which are favorable to agricultural plantations, are the remnants of forest with a higher degree of fragmentation, with a predominance of fragments occupying small areas.

The current situation of fragmentation in the study area, with a high number of fragments with up to 5 ha, becomes a worrisome factor. Since small fragments contain less species richness and often less species density, due to their influence on the edge effect (Laurence & Vasconcelos, 2009). However, Forman and Godron (1986) have pointed out that small fragments can function as linking elements between large areas, in addition, they function as shelter for species that require unique environments that occur only in these areas, large fragments in turn are important for maintaining ecological processes and biodiversity.

With the results obtained for the mean patch size (MPS) of the fragments, it is noticed that it grows as the size class increases. Class 1 presented a mean area of 0.9 ha, indicating that a high number of fragments contained in the class presents an area smaller than 1 ha. In addition to this result, the median patch size (MedPS) was calculated, in which the value of 0.5 ha was obtained for the same size class, showing that half of the fragments of this class have an area smaller than 0.5. In the same context, analyzing the fragments as a whole, the MedPS was 0.6 ha showing that half of the fragments (997 fragments) have an area inferior to 0.6 ha, indicating that the area of study is composed mostly by fragments occupying small areas, thus, the remnants have a low conservation index.

These results indicate that most of the fragments are in critical condition, due to the small areas occupied by them, since they tend to have a lower species richness. Thus, it is relevant to evaluate these fragments, in order to find management alternatives to preserve existing species, avoiding that these fragments will further reduce their areas.

By means of the index of form, it is possible to ascertain how vulnerable the fragments are to the influences of the external environment. The smallest size class, class 1, presented the highest shape index of the landscape

(LSI = 73.5), followed by the second class, with a value corresponding to 48.2, the lowest value found in class 3 (LSI = 20, 3). The LSI measures the perimeter-area ratio for the landscape as a whole, as a function of a standard shape being equal to one when the landscape contains only a regularly shaped fragment (in the case of a raster the standard shape is a square). This, increases according to the greater disaggregation of the class indicating greater heterogeneity of the landscape (McGarigal & Marks, 1995). Thus, it was noticed that class 1 obtained the highest value, due to the high number of fragments indicating a high degree of disaggregation.

The mean shape index indicates the degree of irregularity of the fragments. The lowest value was found in class 1 (MSI = 1.8), indicating that the fragments with up to 5 ha have a more regular shape when compared to the other size classes, being the last class with the highest value, equivalent to 22.7. Pirovani et al. (2014), analyzed areas of Atlantic Forest, obtained values close to the one found in this study, with MSI equal to 1.85 for fragments smaller than 5 ha, presenting a more regular format of the other size classes adopted by the authors.

The area-weighted mean shape index (AWMSI) were higher than those observed for the MSI, however, the values did not show any significant differences, since the AWMSI calculated the shape index and weighted it in relation to the area of the fragments. Thus, larger values indicate that fragments of larger area present more irregular forms than the average fragments.

For the mean perimeter-area ratio (MPAR), the value of 976.7 m ha^{-1} was obtained in the lowest class of fragments. The results obtained for this metric were directly proportional to the perimeter of the fragments; thus, indicate that high perimeter values lead to high MPAR values. The higher the perimeter, the greater the area exposed to the effects of the anthropic actions and the environmental conditions of the environment (Martins, Soares, Silva, & Brites, 2002), leading to a greater edge effect and consequently an intensification of deleterious actions on the remaining ones (Oliveira & Mattos, 2014). Thus, Colli et al. (2003) pointed out that the reduction of edge effects can be achieved by reducing the perimeter/area ratio of the fragments.

By means of the total edge (TE) and edge density (ED) metrics, it is possible to infer about the border effect in which the fragments are subject and the irregularity of them. Of the total border, 1,204,409.0 m represented class 1, this value equivalent to border density of 29.0 m/ha. This class encompasses the smaller fragments, thus covering most of the fragments present in the study area, which resulted in a higher edge value, when compared to the other classes. Juvanhol et al. (2011) emphasize that in small fragments the transition between the matrix and the forest is quite abrupt, thus, an edge is developed exposing the forest to the effects of the external matrix, thus, causes microclimatic changes, which in turn will change the structure of vegetation and the composition of species.

Among the metrics that determine the isolation of fragments is that of the nearest neighbor, which is considered important, since it indicates the need for implementation or existence of connection elements (Vidolin, Biondi, & Wandembruck, 2011). According to Table 4, the average distance of the mean nearest neighbor (MNN), obtained for each size class, presented the lowest value among the fragments of the largest size class (Class 7) totaling 13.4 m. These fragments are located in sloping areas of the sub-basin, resulting in regions that are not suitable for agricultural cultivation. In this way, larger fragments located near each other were found, when compared to the other fragments of the study area.

Analyzing the fragments as a whole (Class 8), without stratifying by size classes, an average distance of 43.1 m was obtained, considered low compared to most size classes. This is due to the small fragments that soften the distance between the larger fragments, since they have high density and are well distributed in the study area. In this context, these fragments have an important ecological function, since they reduce the isolation of the larger fragments. Cemin, Perico, and Rampel (2009), when analyzing the distance of the nearest neighbor in deciduous forest areas in the Taquari Valley, Rio Grande do Sul, found a mean distance of 59.62 m, close to that obtained in the present study, which totaled 43.1 m. Pirovani et al. (2014) also found the shortest distance when analyzed the fragments as a whole. Thus, the authors emphasize the importance of considering smaller fragments as ecological trampolines, in addition reducing the distance between fragments of larger size. Silva and Souza (2014) point out that isolation reduces biological diversity as well as immigration rates. In this context, it is possible to perceive the importance that the smaller fragments present for the biodiversity maintenance, being able to be used as ecological corridors.

The central area is a better indication of the quality of forest fragments (McGarigal & Marks, 1995). The results for the central area metrics are shown in Table 5.

Table 5. Values of the central area metrics for the forest fragments of the sub-basin Arroio Jaquirana, Rio Grande do Sul, Brazil

Distance of Edge (m)	Size Class 1 (< 5 ha)				Size Class 2 (5 — 50 ha)			
	TCA	NCA	MCA	TCAI	TCA	NCA	MCA	TCAI
20	264.8	1,382	0.2	15.8	988.0	919	1.1	41.5
60	0.7	14	0.1	0.5	123.8	133	0.9	5.2
100	0.0	0	0.0	0.0	17.7	28	0.6	0.7
140	0.0	0	0.0	0.0	1.8	3	0.6	0.1
	Size Class 3 (50 — 100 ha)				Size Class 4 (100 — 250 ha)			
	TCA	NCA	MCA	TCAI	TCA	NCA	MCA	TCAI
20	288.4	154	1.9	49.2	705.3	334	2.1	52.6
60	49.7	38	1.3	8.5	181.0	97	1.9	13.5
100	8.8	6	1.5	1.5	70.5	25	2.8	5.3
140	0.5	2	0.0	0.0	32.3	4	8.1	2.4
	Size Class 5 (250 — 500 ha)				Size Class 6 (500 — 1000 ha)			
	TCA	NCA	MCA	TCAI	TCA	NCA	MCA	TCAI
20	1,372.4	493	2.8	54.3	1,897.6	443	4.3	62.3
60	296.3	199	1.5	11.7	616.9	179	3.4	20.2
100	63.3	54	1.2	2.5	210.7	62	3.4	6.9
140	11.9	12	1.0	0.5	57.5	30	1.9	1.9
	Size Class 7 (≥ 1000 ha)							
	TCA	NCA	MCA	TCAI	TCA	NCA	MCA	TCAI
20	1,897.6	443	4.3	62.3				
60	616.9	179	3.4	20.2				
100	210.7	62	3.4	6.9				
140	57.5	30	1.9	1.9				

Analyzing the results it was possible to notice that for the 20 m border size class 1 presented a total of 1,382 fragments, which covered a total core area (TCA) of 264.8 ha, corresponding to 15.8% (total core area index-TCAI). In other words, this percentage of the total amount of fragments of this class is under the border effect in 20 meters. The second class with the highest number of fragments was 2, which covered a total of 919 fragments, corresponding to an area of 988.0 ha, equivalent to a central area index of 41.5%.

With the increase of edge distance, the number of fragments and the area occupied by them decreased in all study size classes. The total core area (TCA) presented higher values at the edge of 20 m, in this distance of edge, the larger size classes obtained larger central areas (Figure 4).

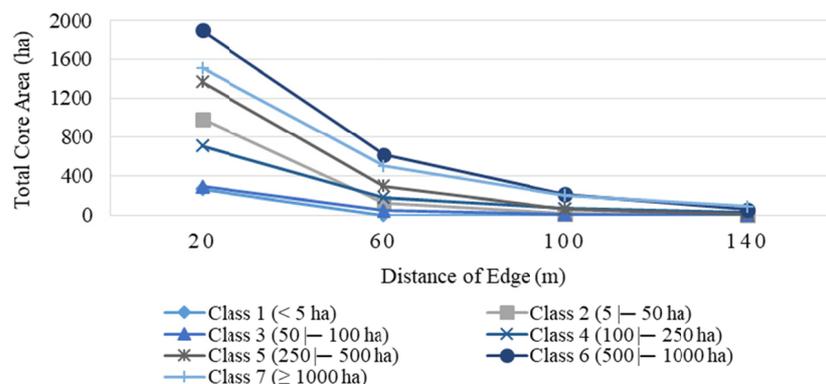


Figure 4. Behavior of the total core area (TCA) with increasing edge distance for the size classes of the forest fragments of the sub-basin Arroio Jaquirana, Rio Grande do Sul, Brazil

In size class 1, few fragments present a central area when the 60 m edge was removed, while fragments with 100 and 140 m edge distances were not found, with total domination by edge effect. Thus, this result indicates that these fragments, which have an area smaller than 5 ha, are more susceptible to external effects. The same was

obtained by Silva et al. (2015), in which the authors found null fragments, for those that presented areas lower than 5 ha, at border distances bigger than 80 m.

Périco and Cemin (2006), when characterizing landscapes under the Atlantic Forest domain, observed that, over the years, there was decreasing in the central area of forest fragments, indicating an increasing in fragmentation. Ribeiro et al. (2009) when analyzing the Atlantic Forest as a whole observed that almost half of this one is under effect of edge inferior to 100 m.

With this, it was observed, in the study area, that native forest fragments presented small central area when evaluating high edge distances. This factor leads to several negative consequences for the native species which inhabit these environments, since there are species intolerant to the effects caused by the edge, among them, the climatic changes and the occupation by exotic species.

In all size classes, with the exception of class 1 (< 5 ha), the number of fragments found for certain edge distances was higher than the number of fragments without edge removal. The highest values were verified in the distance of 20 m, occurring decrease in the others. The same pattern was found by Pirovani et al. (2014), the author points out that this fact is due to the irregular shape of the fragments, which entails in several central areas. Thus, by analyzing the fragments in the study area it is possible to infer that these are composed of several elongated arranged forest areas, occupying small areas, which function as ecological corridors, between the larger areas.

In general, with the results obtained in this study it was verified that the areas of Atlantic Forest are highly fragmented with predominance of small fragments in which their central areas are exposed to the effects of the external matrix. Thus, with the analysis performed it is possible to verify the current situation of the native forest, serving as the basis for the proper management of the area.

4. Conclusion

The R program proved to be a promising and efficient tool for the manipulation of spatial data, which allowed performing the spatial analysis of forest fragments. By means of the ecology of the landscape, it can be concluded that most of the forest fragments in the sub-basin Arroio Jaquirana, under the domain of the Atlantic Forest biome, were small indicating the high degree of fragmentation of the local forest.

Thus, it is very important to establish measures to minimize edge effects and/or increase the connectivity between the fragments through ecological corridors using the smaller fragments, since they are well distributed in the study area and in large amount. It is also necessary to develop public policies and research to manage the region in order to preserve the remaining forest fragments, since the Atlantic Forest is quite devastated.

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