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The context of the size and distance of Atlantic Forest fragments in a small city in Southern Brazil

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ABSTRACT. The Atlantic Forest is highly anthropized, this reduce the areas of native vegetation and impacts the biodiversity of the biome. The objective of this study is to analyze forest remnants with native vegetation characteristics using a free GIS. This analysis takes place using landscape metrics and was based on the supervised vectorization of land use in the municipality of California, PR. The area of the vectored polygons was obtained and a classified, and then the calculation was made with the nearest neighbor index, mean distance observed, Patton diversity index and the perimeter/area ratio of forest fragments. The results show that most of the fragments have an area smaller than 1 ha, the fragments with more significant area (<50 ha) represent more than 16% of the native vegetation area. The small fragments are important to maintain the connectivity, since the withdrawal of these increases the mean distance observed and nearest neighbor index. Most of the fragments are elongated and amorphous in accordance with the perimeter/area ratio and the Patton diversity index respectively, this may demonstrate the fragments may be subject to edge effects. Even with these characteristics, these fragments may be part of what is planned in public policy for preservation in the Atlantic Forest in the state of Paraná. Therefore, even small fragments with little core area are important for maintaining biodiversity, especially in a highly anthropogenic landscape.

Keywords: Small fragments; Biodiversity; California; Semideciduous Seasonal Forest.

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Introduction

The change of land used for human exploitation implies the reduction of natural areas, making these areas restricted to small stretches of land (Tomadon, Dettke, Caxambu, Ferreira, & Couto, 2019; Ferreira, Bragion, Ferreira, Benedito, & Couto, 2019). This process characterizes forest fragmentation and it is known that there is a need to understand the process to acquire knowledge of the interactions with neighboring patches and the matrix (Fahrig, 2003; Metzger, 2001, 2003; Tabarelli, Aguiar, Ribeiro, Metzger, & Peres, 2010). The impact can be unpredictable and occur in several ways, considering that currently global situation shows that most forest fragments are less than 10 ha in size, half of which are at 500 m from the edge of forests (Haddad et al., 2015).

Two Brazilian biomes are widely affected by this problem, the Brazilian Savanna (i. e. Cerrado) and the Atlantic Forest and they are classified as a biodiversity hotspot, since they have a high degree of endemism and are widely anthropized. This means that any fragment, even if very small and isolated, may be the only one suitable for certain species (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000; Campanili & Schaffer, 2010).

The Atlantic Forest (the focus of this research) is distributed along the East coast of Brazil and was once one of the largest tropical forests in the America. It occupied about 150 million hectares under extremely heterogeneous environmental conditions, but only 22% of the original forest remains, where 83.4% of the remaining fragments are smaller than 50 ha (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009). Therefore, small fragments are important because they reduce the isolation between the fragments, acting as stepping stones, which are small areas of habitat dispersed across the matrix that can facilitate the flows between the remnants of some species (Ribeiro et al., 2009; Ferreira et al., 2018; Tomadon et al., 2019).

The size and distance of a forest fragment is an important aspect that must be taken into consideration to approach the aim to analyze the quality of a given landscape. It is directly involved with the carrying capacity of an environment in harboring greater richness and functional diversity of species, thus controlling the population density of fauna and flora through extinction rates (Metzger et al., 2009; Munguía-Rosas & Montiel, 2014; Gross, 2017). The largest fragments, which are those that can sustain the highest biodiversity, are increasingly scarce, most of the remaining's are the smaller fragments with a limited number of habitats (Ribeiro et al., 2009). Another important aspect is the connectivity between the fragments that compose the landscape, which can be inferred by the distance between the forest fragments. Connectivity is responsible for directly influencing the dynamics of the species in fragmented environments, being able to alter and interrupt the gene flow and variability of the species in the long term (Calegari, Martins, Gleriani, Silva, & Busato, 2010; Boscolo & Metzger, 2011). The reduction of the isolation between the larger fragments by the presence of smaller fragments (serving as steppingstones) was also demonstrated by Uezu, Beyer, and Metzger (2008), and Tomadon et al. (2019).

These fragile environments are compromised because Brazil's current conservation policies are weakened (Alves et al., 2019). To change this situation, it is necessary to take actions that value science according to the agricultural practices present in the country (Magnusson et al., 2018). Thus, it is still possible to reverse Paraná's alarming situation, which is among the states that deforest the most, with a loss of 2,049 hectares between 2017 and 2018 (SOS Mata Atlântica, 2019).

The conservation can be assisted by the maintenance of the small fragments, because they are important for the preservation of environments where only these remain. For the Paraná's landscape, the preservation of these fragments can be part of plans for future recovery processes (Haddad et al., 2015; Volenec & Dobson, 2019). In a local level, the small fragments are important due to the functions performed, such as a resting place, nesting and protection of the species present within the ecosystem (Haddad et al., 2015; Proesmans et al., 2019).

The present study aims to investigate the context of the size and distance of Atlantic Forest fragments in a city (California – Paraná State) in Southern Brazil and the relevance of small forest fragments for connectivity of forest remnants, for this were analyzed the shape of these fragments and how they can be part of what is planned in the actions of public policies of preservation.

Material and methods

The city of California has an area of 142,094 km^2 with a density of 60.05 pop. km^{-2} (Instituto Paranaense de Desenvolvimento Econômico e Social [IPARDES], 2019) (Figure 1) and is in a climatic unit of transition between tropical and subtropical climate, with annual average rainfall of 1,700 mm. The predominant climate is humid temperate, with temperate summer, average temperatures in the coldest month below 18°C and average temperatures in the hottest month not exceeding 22°C (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). The forest cover of the region is presented with Phyto physiognomy of the Atlantic Forest, the Semideciduous Seasonal Forest (Instituto de Terras, Cartografia e Geociências do Paraná [ITCG], 2009).

California's land use was obtained from the supervised vectorization, using the QGis 2.14 (2015), from a set of images provided by the Bing search platform (2012) achieved through the SAS. Planet (2015) with a resolution of 0.27 m pixel^{-1} (z = 20).

It was used QGis 2.14 to do the operations of polygons representing the vegetation patches in different situations. In order to analyze the variations of the Observed Mean Distance (OMD) and Nearest Neighborhood Index (NNI) when the minimum area of the fragments is altered, the first thing to be done was to determine the values with all the polygons, after this, calculations were made with the removal of polygons that represent forest fragments with an area of less than 1 ha. After assuming a minimum area value of 1 ha, this process was repeated with other values as minimums (5, 10, 20, 30 and 50 ha).

The area (A) and perimeter (P) of the polygons of the forest fragments were used to obtain the perimeter ratio per area and the Patton diversity index (DI) (Patton, 1975) (Equation 1).

$$DI = \frac{P}{2 * \sqrt{A * \pi}}$$

The information on the Strategic Areas for the conservation of biodiversity in Paraná (Paraná, 2009; Instituto Ambiental do Paraná [IAP], 2014) and the data present in the Rural Environmental Registry

Systems (Sistema de Cadastro Ambiental Rural [SICAR]) in Brasil (2019) were used to analyze how the actions originated in public policies can influence the fragments present in the territory of California.

The city of California has 1,470 forest fragments, occupying an area of 2,495.15 ha that represents 17.6% of the total city area. The main land uses are perennial crops (36.4%) and pastures (26.9%), that occupies more than 60% of the territory (Figure 1).

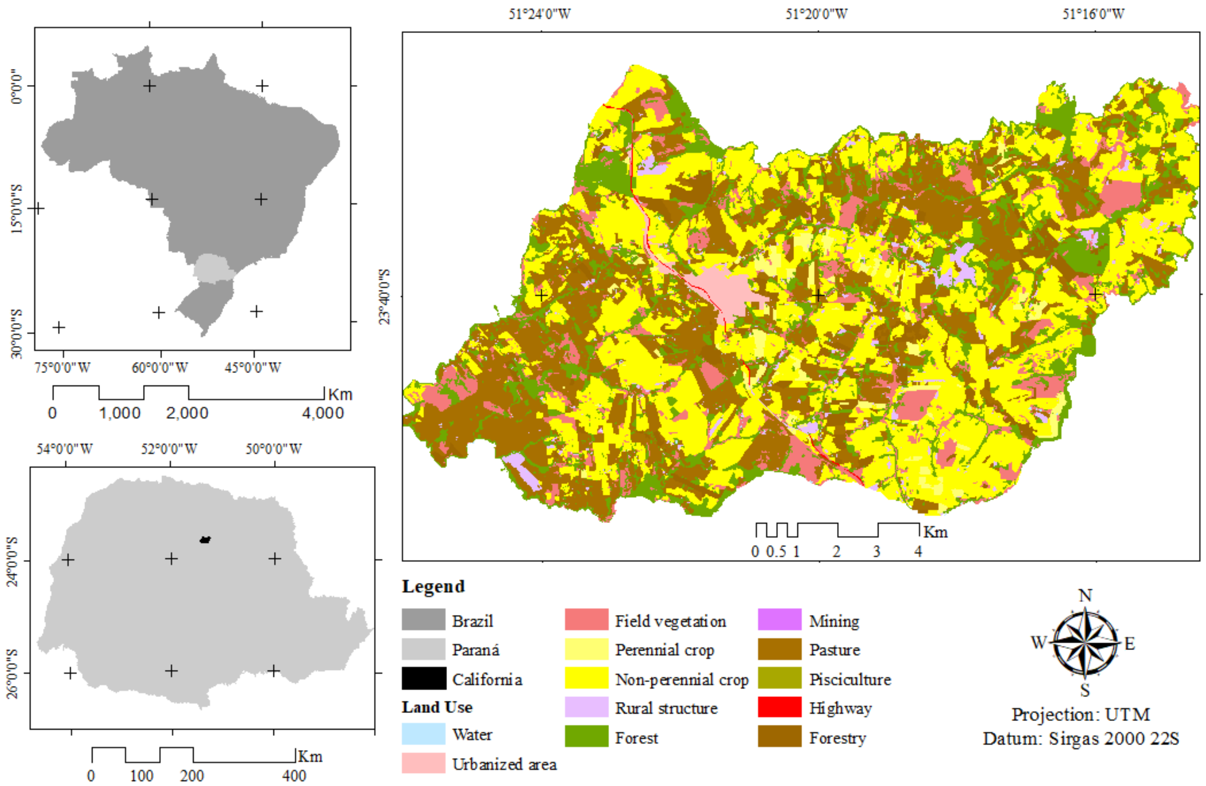

Figure 1. Location and land use of the municipality of California, Paraná, Brazil.

Results

Of these fragments, the majority have an area of less than 1 ha (81.1%) and represents 56.3% of the total area occupied by forests. Only 0.27% of the total number of fragments have an area greater than 100 ha and correspond to 16.7% of the forest area (Figure 2).

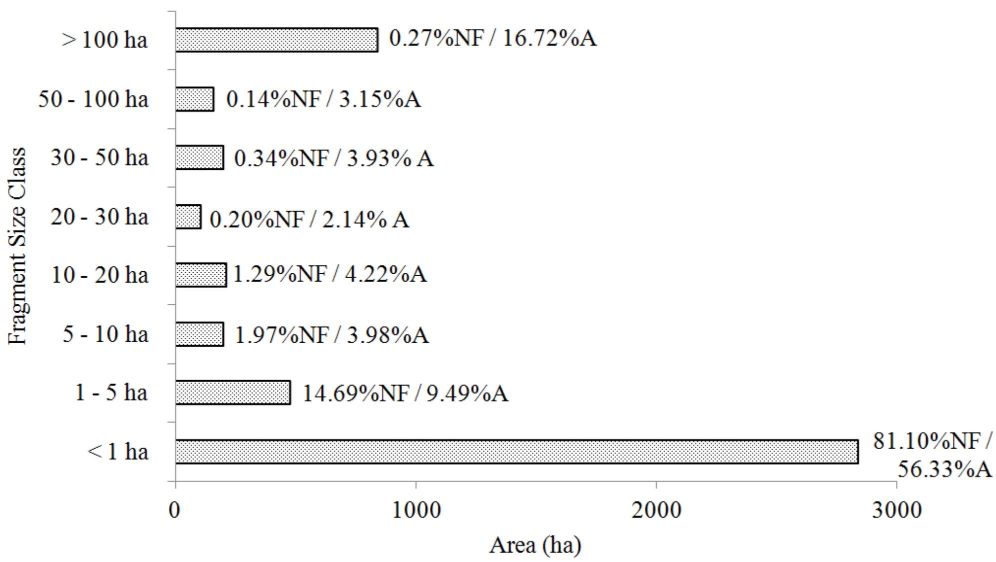

Figure 2. Distribution of area values of California forest fragments - Pr.% NF: Total percentage of fragments number. % A: Percentage of total area.

Only 18.9% of the fragments have an area greater than or equal to 1 ha and 0.41% of these are larger than 50 ha. The mean area of the fragments is 1.71±12.92 ha (n = 1,470), the largest fragment is 389.64 ha and the lowest is 0.0008 ha.

It was observed that the small fragments are responsible for the connection between the large fragments, because this landscape has no ecological corridors. It was detected that the MOD between all the fragments is 0.14 km and with NNI of 0.74. When the small fragments are removed, there is an increase in the MOD between the remaining points, which makes the MOD between the fragments with an area of more than 50 ha greater than 6 km and the NNI of 2.5 km (Figure 3).

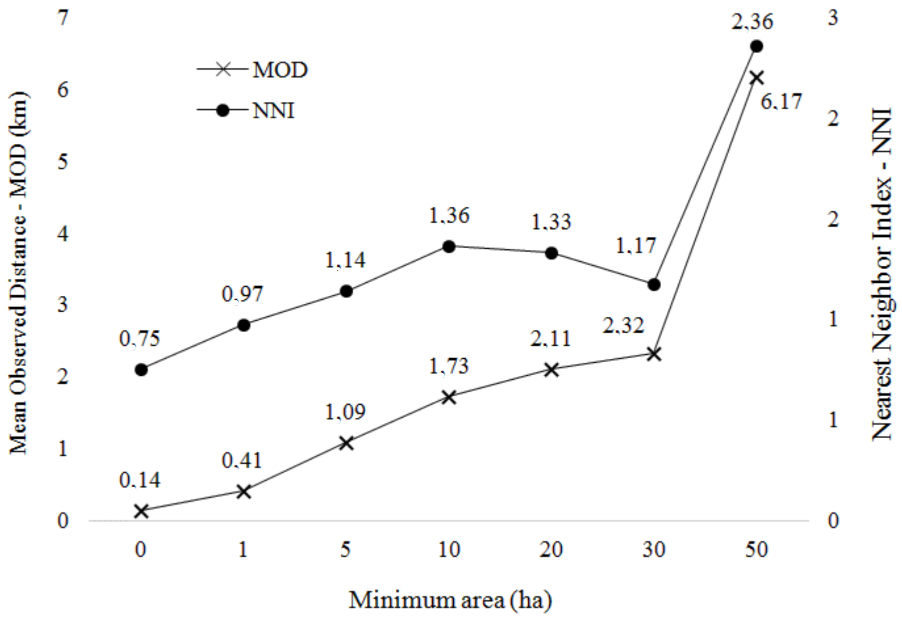

Figure 3. Mean Observed Distance (MOD) and Nearest Neighbor Index (NNI) for different values of minimum area of California / PR forest fragments.

In addition to the characteristics of the location of the fragments within the landscape, two landscape metrics (Perimeter per area ratio and the Patton diversity Index) were applied to analyze the shape of the patches.

The perimeter per area ratio has a mean and median of 0.12 and 0.10, respectively. The minimum value is 0.016 and the maximum is 3.109. From the values of this ratio, 0.2% have a perimeter per area ratio greater than 0.8, 0.136% have a value between 0.6 and 0.8, and 99.659% have values lower than 0.6. From the fragments analyzed, 99.38% have a perimeter per area ratio of less than 0.6 and an area of less than 100 ha.

The mean value of the Patton diversity index is 1.614, and the median is 1.381. The maximum value is 19.154 and the minimum is 1.023.

Discussion

From the mapping of California land used, it was found that most of the forest fragments are small, with an average area of 1.71 ha, and fragments with an area greater than 50 ha represent only 0.41% of the total number. The MOD between these fragments is 0.14 km and with NNI of 0.74, the removal of the small fragments increases the MOD and NNI values. According to the perimeter per area ratio and the Patton diversity index, the fragments are elongated and amorphous, respectively.

The pattern of having more small fragments is repeated in the study presented by Andrade, Silva, Ribeiro, Paro, and Paula (2012) which evaluated the state of forest fragmentation in the *Quadrilátero Ferrífero* – Minas Gerais/Brazil and found out that 50% of the fragments identified had less than 2 ha.

In a study in the Mourão River basin (Paraná) was obtained the same trend, where the small fragments are the most representative in quantity and area occupied. In the period from 1991 to 2016 it was observed the increase of the average area and the reduction of the fragment's quantity of this basin (Ferreira et al., 2019).

In the Alonzo river basin, also in Paraná, were classified 888 forest fragments, with area ranging from 0.15 ha to 2,509.82 ha, occupying 12.5% of the basin's territory (283,390 ha). It was observed that most of the fragments have an area of less than 50 ha (85.3%), therefore the smallest fragments represent the highest percentage of natural forest vegetation, as well as in the present study (Ferreira et al., 2018).

It is not known all the effects of forest fragmentation and how species react to it. The California situation may not be ideal for some bat species, which require larger and more structured fragments (Reis, Barbieri, Lima, & Peracchi, 2003). For bees, it may be important for the maintenance and conservation of these pollinators, since the small fragments are able to support some populations (Sofia & Suzuki, 2004; Proesmans et al., 2019). For birds, it can serve as a nesting site or as a connector during other periods of the year (Barbosa, Knogge, Develey, Jenkins, & Uezu, 2017). The richness of some species of insects, such as the leafhopper species in small fragments may be dependent on the connectivity with large fragments of the area (Rösch, Tscharntke, Scherber, & Batáry, 2013). The diversity of beetle fauna is directly related to the size of the fragments, so a larger number of small fragments can cause a smaller abundance and diversity of these insects (Salomão, Brito, Ianuzzi, Lira, & Albuquerque, 2019). Small forest fragments also serve to stock carbon, and for this reason, they help to protect the global climate (Dulamsuren, Klinge, Bat-Enerel, Ariunbaatar, & Tuya, 2019).

Due to the distribution of the fragments in the landscape, the smaller fragments located in the central area of the territory serve to connect the large fragments. Then, the removal of the small fragments explains the growth of the MOD (Figure 3). This situation results in a landscape with fragments more disperse, altering the grouping pattern, a fact also evidenced by the increase in NNI.

It was observed that the mean distance between the fragments is 0.14 km, a value lower than obtained by Ferreira et al. (2018). In Alonzo River basin, the average distance between the fragments is 0.344 km and this inferiority may be due to the difference in scale between the studies, which may result in a larger number of small fragments in the present. In the same study, the authors calculated the average distance considering only the fragments with an area greater than 50 ha, obtaining a value of 0.793 km, while the present study observes the value of 6.17 km. This high value may be because they are only seven fragments with an area greater than 50 ha and these are located, in the majority, in the bordering areas of the municipality (Figure 4).

Therefore, the importance of the small fragments to maintain the connectivity between the most representative fragments with areas is observed, since these can act as stepping stones, where the individuals that are able to pass through the inhospitable matrix can use these fragments to forage (Ricklefs, 2011).

California's current landscape matrix is composed primarily of agriculture and grazing, which makes it more complex to pass. Thus, to reduce this complexity, a change in land use can be made to other types of practices (agroforestry and subsistence agriculture). As a complement to state-led governance, voluntary sustainability initiatives seek to codify the practice of sustainable agriculture in standards, defining criteria which producers must meet to be certified as environmentally and socially responsible (Milder et al., 2014). Certifications under these standards has expanded rapidly in recent years and its coverage highlighted as a key indicator of progress toward Aichi Target 7 (Tittensor et al., 2014). The creation of ecological corridors and improvements in border habitat, can represent an increase in the permeability of the matrix and, over a long period of time, these fragments can increase in area, becoming able to support more species, reduce the isolation of the patches and the risk of extinction of local populations (Ricketts, 2001; Calegari et al., 2010; Goulart, Takahashi, Rodrigues, Machado, & Soares-Filho, 2015; Barbosa et al., 2017).

Besides that, small fragments can favorize the occurrence of metapopulations, because the individuals will move between the fragments regardless of size, so the matrix must be more permeable. Anjos (1998) studied five fragments of different sizes in the northern state of Paraná and the study shows that lower levels of isolation support the occurrence of species, bringing more importance to this factor than the area of the fragment. In the author's study, a smaller fragment (7 ha) connected to another with 656 ha presented the occurrence of the species as a fragment of 60 ha that was isolated. Then, the small fragments serve to connect grids fragments and are influenced by them, like an ecological corridor.

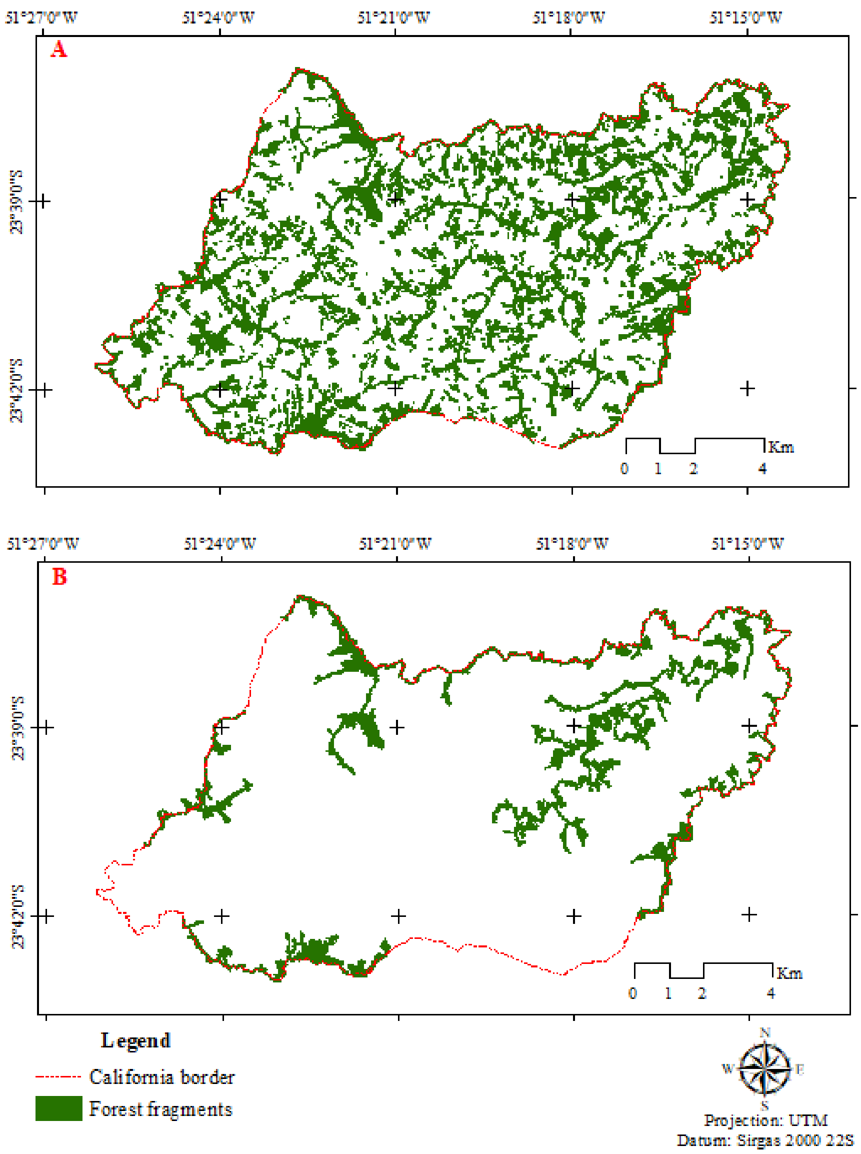

Figure 4. Distribution of California forest fragments (A) and location of fragments with an area greater than 50 ha (B).

Therefore, most of the fragments are small and elongated and those with a larger area tend to be amorphous. In another study carried out in the Atlantic Forest (Eunápolis, Bahia - Brazil) in the margins of the rivers has obtained a result with the same trend, a great number of elongated fragments. (Oliveira, Silva, Brites, & Souza, 1997).

Viana and Pinheiro (1998) adopted values of perimeter per area ratio, less than 0.6 are considered very elongated, from 0.6 to 0.8 are elongated and greater than 0.8 are circular. Following this classification, 99.8% of the fragments are elongated or very elongated.

The results of the Patton diversity index can be divided into classes, according to Sarmiento (2003), so that the shape of the fragment can be considered as round to values lower than 1.25, oval rounded to values between 1.25 and 1.5, elongated oval for values between 1.5 and 1.7, rectangular oblong for values between 1.7 and 2 and amorphous for values greater than 2. Table 1 shows the percentage of fragments belonging to each class and the mean area of fragments. From the mean area of the classes presented in Table 1 it was observed that the small fragments are circular, while the fragments with more significant areas are amorphous (Figure 4B).

The fragments with the highest Patton values are those that are most subject to the edge effect (Ferreira et al., 2018), which may cause lower growth rates at the edges of the fragment, due to the occurrence of lianas that shadow this area and cause the delay of growth release events (Godoy-Veiga et al., 2018).

To mitigate the effects of the edges, it is possible to make changes in the matrix, such as barriers formed by eucalyptus lines around the fragment, associated with the management of lianas, which may favor the reestablishment of native species at the edges of these (Nascimento, Poggiani, Durigan, Iemma, & Silva Filho, 2010; Godoy-Veiga et al., 2018).

Table 1. Results obtained in the calculation of perimeter per area, classified according to the classes presented by Sarmiento (2003).

Class	Percentage (%)	Averagearea (ha)
Round (> 1.2)	32.38	0.19
Rounded oval (1.2-1.5)	27.48	0.39
Elongate oval (1.5-1.75)	16.39	0.59
Rectangularoblong (1.75-2)	9.39	0.79
Amorphous (< 2)	14.35	1.38

Changing patterns of distribution and shape of forest fragments, connecting the small fragments to the larger and older ones, can help maintain local biodiversity and expand the services it provides (Tabarelli et al., 2010). This process is important to maintain economic activities, but this is not done by Brazilian corporations that use natural resources, so this could be based on requirements present in public policies (Reale, Magro, & Ribas, 2019).

A first analyzed action is determined in the Joint Resolution SEMA[1] / IAP[2] N°. 05, of September 29, 2009 (Paraná, 2009), which establishes areas for restoration in the state of Paraná, for this reason, the maintenance and conservation of fragments of California can be part of the proposed restoration process due to the proximity to the areas (Figure 5).

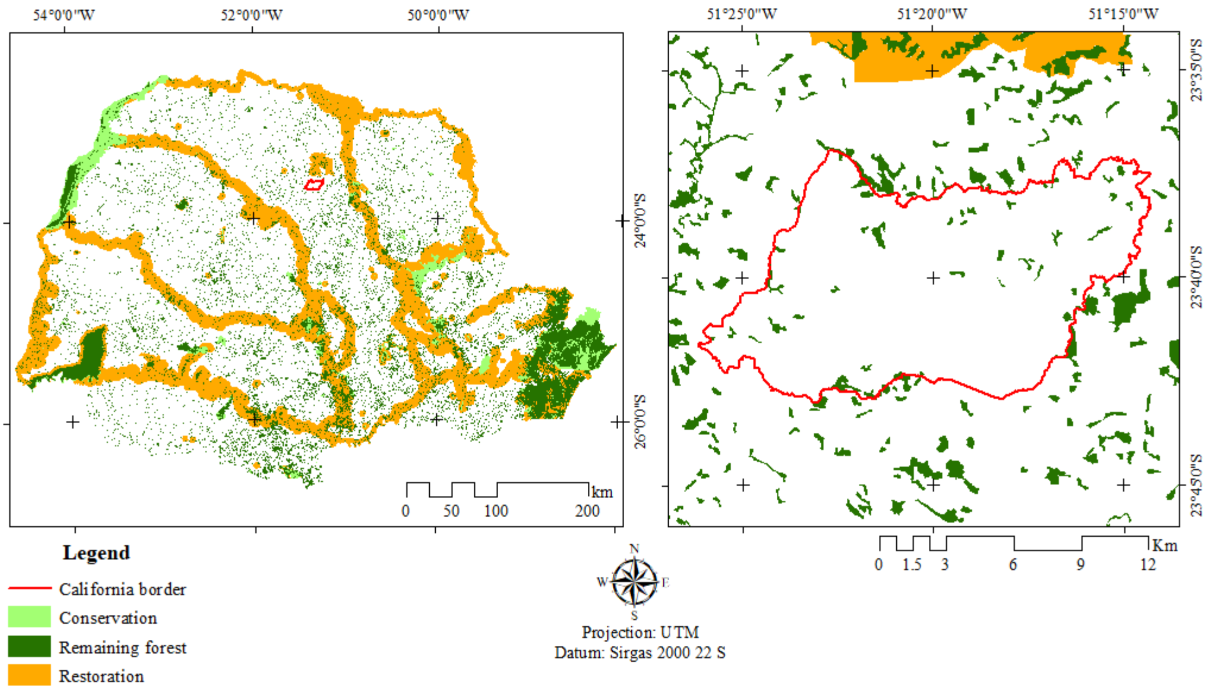

Figure 5. Mapping of strategic areas for the conservation and restoration of biodiversity in the state of Paraná, (IAP, 2014), and the focus in the municipality of California.

Even with the territory of the city not included in the restoration areas proposed by the resolution (Figure 5), forest remnants of this city can make up the network of interconnected fragments within a system of protected areas that could reach the areas of interest. This would increase the area and the connectivity of these fragments, extrapolating administrative limits and considering the natural conditions of the north of Paraná landscape (Tabarelli, Pinto, Silva, Hirota, & Bêde, 2005).

The increase of these remnants and the creation of preservation areas make possible the collection of financial resources through the ecological ICMS[3] for Biodiversity, which the city did not participated in 2018 and previous years (Instituto Ambiental do Paraná [IAP], 2018).

[1] SEMA – Secretaria do Meio Ambiente e Recursos Hídricos, (*Secretariat for the Environment and Water Resources*);
[2] IAP – Instituto Ambiental do Paraná, (*Environmental Institute of Paraná*);
[3] ICMS - Imposto sobre Circulação de Mercadorias e Serviços, (*Brazilian state excise tax).*

Therefore, the fragments, even if small and with little core area, are important for maintaining biodiversity. In a highly anthropized landscape like this, to mitigate the impact caused by the observation of anthropic pressure and for the development of the city, changes should be sought in the matrix, in order to reduce the impact caused by exploratory land use on forest remnants and to define management actions for landscape diversification, so that there are fragments of different sizes and capable of supporting specialist or generalist species, aiming at ensuring the success of biodiversity conservation (Rösch, Tscharntke, Scherber, & Batáry, 2015).

The Rural Environmental Registry (*Cadastro Ambiental Rural*) is another important policy of Brazil. It was created in the most recent Brazilian Forest Code (Law nº 12,651/2012) with the aim of obtaining environmental information on rural properties and possessions related to preservation areas and forest remnants in order to compose a database for monitoring, planning and combating deforestation (Brasil, 2012). This register is part of the Environmental Regularization Program, which objective is regularizing the environmental situation in accordance to the forest code (Brasil, 2012).

The information available in SICAR shows that the preservation areas present in city of California are the permanent preservation areas and the legal reserves (Figure 6). The main function of permanent preservation areas is to protect water bodies and legal reserves to ensure the sustainability of rural properties. In the Atlantic Forest these areas should occupy 20% of the property (Brasil, 2012).

The process of delimitation of permanent protection areas is based on a buffer applied to the lines of water resources based on values present in the legislation, the results obtained in the vectorization of the cadaster show that these areas occupy 1,647.2 ha of the city, while the legal reserves occupy 1,631.3 ha.

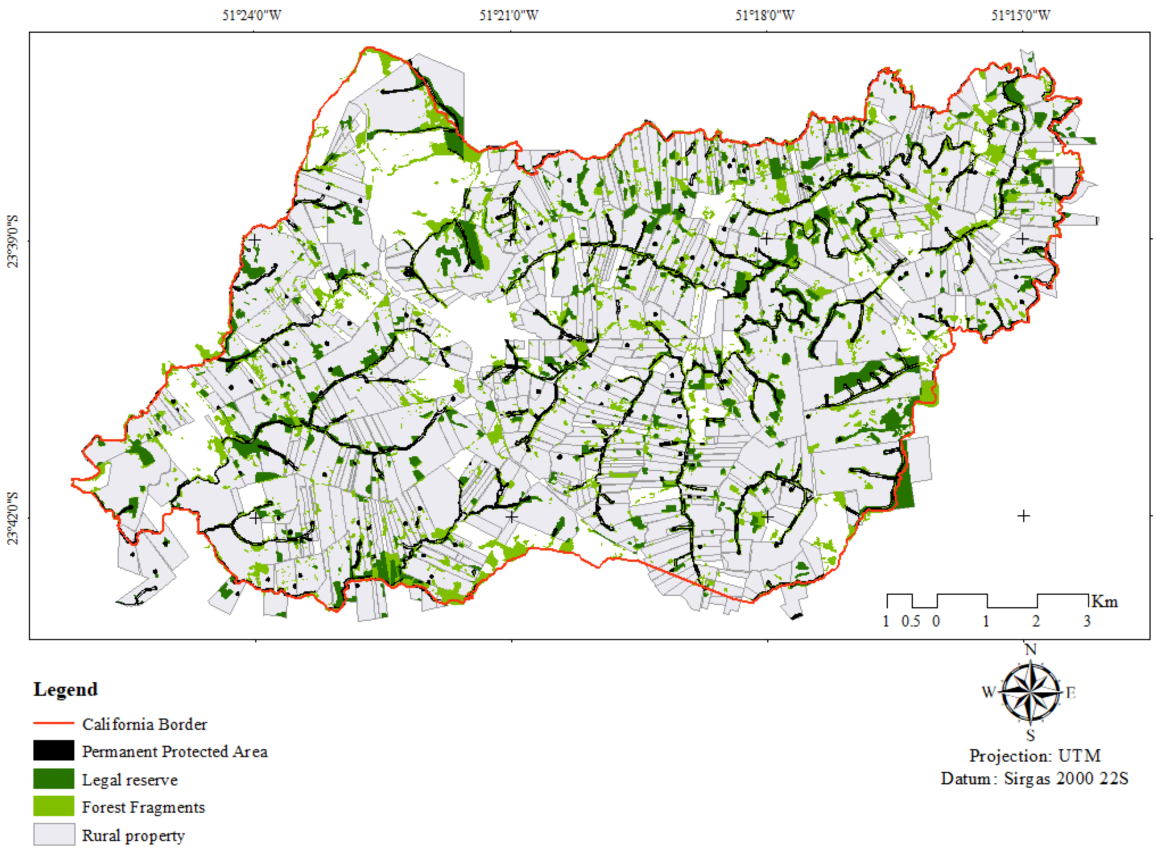

Figure 6. Borders of rural properties, permanent preservation area and legal reserve, obtained in SICAR, delimited in the city of California - PR.

It is observed that the sum of the areas destined for protection (3,278.5 ha) results in a value higher than that occupied by the forest fragments (2,495.15 ha). The large fragments (Figure 4B) make up part or all the Legal Reserve of rural properties and serve as a permanent preservation area because they are located on the margins of the rivers (Figure 7). Some areas were classified with both types of protection, which can occur as long as it is an area that has been conserved or is in the process of being recovered, if it does not involve land use change and it has been reported in the CAR (Brasil, 2012).

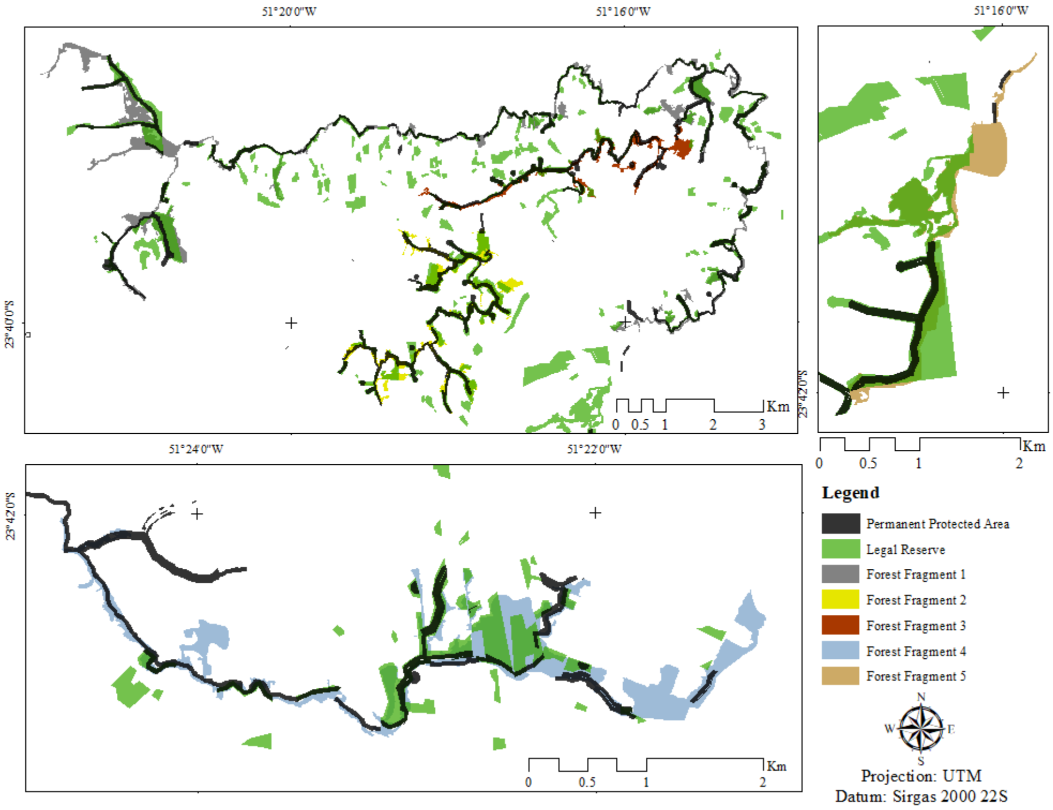

Figure 7. Permanent preservation area and Legal Reserve, obtained in SICAR, which have some relation with the forest fragments with an area superior to 50 ha in the municipality of California - PR.

Some conflicts can be noted between the data obtained in the vectorization of this work and those available in the SICAR database of California. These can be explained by differences in the year of the images used in the vectorization (2008 and 2012), the resolution of the images (30 m and 0.27 m), the method of vectorization or by different interpretations of the images. Conflicts between use within the data provided to SICAR have already been detected in another study, conducted in Anápolis (Goiás - Brazil), where some areas of permanent preservation had anthropic use, violating the legislation because these areas were unduly occupied (Santos, 2018).

With this comparison of results can be expected the need for adjustments to the data provided to SICAR and changes in land cover to meet the requirements of the Environmental Regularization Program, based on plans for recovery of degraded areas.

Conclusion

The results of this study showed that there is a pattern repeated in other parts of the Atlantic Forest due to the advanced state of impact of human activity on the biome, where most fragments occupy a very small area with an elongated shape.

These fragments exert an important function in the context in which they are present, they are connectors and maintainers of biodiversity. California's forest fragments can make up state-level recovery policy. They are not fully protected, so this protection should be requested and, if necessary, recovery should be carried out accordingly.

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