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GEOGRAPHY

Spatial dimension landscape metrics of Atlantic Forest remnants in Paraná State, Brazil

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ABSTRACT. Forest fragmentation may negatively impact fauna and flora. An important tool for the development and implementation of research on these effects is the use of a geographic information system (GIS). This paper aims to perform an integrated analysis of the landscape fragments that compose the Alonzo River watershed, Paraná State, by using remote sensing tools and landscape ecology metrics. The analyzed landscape metrics were Patton's index, total area of the patches, edge length, edge density, forest fragment density, and the core area of the patches. The results showed 888 forest patches with area values ranging from 0.15 ha to 2509.82 ha, and it represents 12.5% of the total forest land cover of the studied basin; this means that 85.3% of the forest patches are less than 50 ha and that 75% of those fragments have a Patton's index value of less than 3.9. The fragments that compose the studied area may be subject to edge effects and biodiversity loss as long as they present reduced areas and small core areas. Thus, the use of GIS and landscape ecology metrics is a quick and efficient way to evaluate the effect of fragmentation over large areas.

Keywords: conservation; connectivity; GIS.

Dimensões espaciais de métricas da paisagem de remanescentes da Mata Atlântica no Estado do Paraná, Brasil

RESUMO. A fragmentação florestal pode exercer influências negativas sobre a fauna e da flora. Uma importante ferramenta para o desenvolvimento e aplicação de trabalhos sobre efeito da fragmentação florestal é o uso de Sistema de Informação Geográfica (SIG). Esta pesquisa objetivou analisar fragmentos que compõem a bacia hidrográfica do rio Alonzo no Estado do Paraná, usando ferramentas de geoprocessamento e métricas em ecologia de paisagem. As métricas analisadas foram o índice de Patton, área total dos fragmentos, comprimentos de borda, densidade de borda, densidade dos fragmentos florestais e área de núcleo dos fragmentos. Os resultados mostraram 888 fragmentos florestais com valores de área variando de 0,15 ha até 2.509,82 ha, o que representa 12,5% da cobertura vegetal total da bacia estudada, da qual 85,3% dos fragmentos possuem área inferior a 50 ha, e 75% com o índice de Patton inferior a 3,9. Os fragmentos que compõem a área de estudo estão sujeitos à influência do efeito de borda e perda de biodiversidade, pois apresentam reduzidas áreas e, consequentemente, menor área de núcleo. Dessa forma, o uso de SIG e métricas de ecologia de paisagem é uma forma rápida e eficiente de avaliação do efeito da fragmentação em grandes áreas.

Palavras-chave: conservação; conectividade; SIG.

Introduction

The effect of land use for agropastoral activities, development, and the expansion of urban areas, the habitats that compose the biomes of Brazil have undergone severe fragmentation processes throughout history. The fragmentation caused by human activities is one of the major causes of the loss of diversity, both physical and biological, which leads to changes in the structure and dynamics of animal and plant communities (Laurance; Vasconcelos, & Lovejoy, 2000; Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009).

The main effect of landscape fragmentation is the reduction of habitats into smaller environments, leading to the loss of ecological function. As the size of a forest patch is reduced, there is an increase in the amount of transition environments between the central part of a fragment and its surrounding matrix, which directly influences local diversity interactions (Fahrig, 2003; Metzger et al., 2009).

The spatial gap between fragments and their size may have a negative impact on the local flora and fauna species, such as the barriers to movement among fragments experienced by some potentially colonizing species, thus restricting genetic variability. This phenomenon may result in the local or total extinction of a species, especially if it is an endemic species (Triantis & Bhagwat, 2014).

The use of geographic information systems (GISs) has become an important tool in the development and implementation of projects related to the effects of fragmented landscapes and the preservation and conservation of biodiversity, which contribute to the mitigation of the environmental impacts caused by humans (Gurevitch, Scheiner, & Fox., 2006; Couto, Souza Filho, & Hayakawa., 2011).

The study sought to analyze the landscape fragments that compose the Alonzo River subwatershed in Paraná. Thus, the spatial dimensions of fragment size, distance and shape will be evaluated using remote-sensing tools and landscape ecology metrics.

Material and methods

The Alonzo River watershed is approximately 283.390 ha in size and is responsible for an average input flow to the Ivai river of 51 $m^3 s^{-1}$ (Leli, Stevaux & Nobrega, 2010). The Alonzo River watershed drainage network (Figure 1), which is located between the North and Campos Gerais regions of Paraná State that include the municipalities of Faxinal, Rosário do Ivaí, Grandes Rios, Ortigueira, Cruzmaltina, Rio Branco and Reserva, is incorporated into the subbasin mosaic of the Ivai river. The Alonzo River watershed is between the transition areas of the Second and Third Paraná Plateau geomorphological units (Couto, Fortes, & Ferreira, 2014), and it is comprised of a very heterogeneous landscape consisting of escarpment ridges, hills, ridge-aligned diabase dikes and large areas of pediments. Its geological composition aggregates geological formations from different ages with rocks ranging from the Devonian to the Cretaceous, which have generated a very diverse landscape composed of several forest sub-typologies (Couto, Manieri, Manosso, & Fortes 2011; Couto, Fortes, Sordi, Marques, & Camolezi, 2012; Couto et al., 2014).

According to the Köppen-Geiger classification, the predominant climate in the Alonzo River basin is Cfb, but Cfa and Cfa/Cwa climates also occur. The Cfb climate is characteristic of temperate regions with an average temperature below 18°C in the coldest month and an average temperature not exceeding 22°C in the hottest month. The Cfa and Cfa/Cwa climates have tropical characteristics with occasional frosts in the wintertime and rains that are well distributed in the summer months; the average temperatures range from below 18°C in the coldest month to above 22°C in the hottest month.

The Alonzo River basin extends over two of the main phytogeographic units of Paraná State: the mixed ombrophilous Forest, or forest with Araucaria species, and the semidecidual seasonal forest (Instituto Brasileiro de Geografia e Estatística [IBGE], 1992). The first type includes the basin portion located in the Second Paraná Plateau, and one of its major features is the occurrence of *Araucaria angustifolia* (Bertol.) Kuntze (Araucariaceae). In contrast, the semidecidual seasonal forest is predominantly in the Third Paraná Plateau portion of the basin and is characterized by the double climatic seasonality of the forest canopy; it is more destitute in terms of floristic diversity than ombrophilous forests (IBGE, 1992; Roderjan, Galvão, Kuniyoshi, & Hatschbach, 2002).

To perform this study, the Paraná State forest fragments database of the S.O.S. Mata Atlântica Foundation was used. Based on the available of forest fragment data, a geographic database in digital format, which was georeferenced to the SIRGAS 2000/UTM zone 22 datum for the southern hemisphere and contained information in vector and raster format, was elaborated using the free GIS QGIS® 2.14.2 software. Additionally, it was possible to calculate some of the landscape metrics that are the subject of this research, such as forest patch density, edge density and the total core area, using a free and open-source plugin for QGIS called LecoS® (Landscape Ecology Statistics).

The nearest-neighbor distance was computed in ArcView GIS® 3.3 software using the vector layer from the forest fragments. To demonstrate the mitigating effect that small fragments may have on isolation processes, the distances between the patches that were calculated using a vector layer containing the real information from the S.O.S. Mata Atlântica database and those calculated from a vector layer containing only fragments greater than 50 ha were compared.

Furthermore, the fragments were classified in classes according to size as suggested by Ribeiro et al. (2009), by which small fragments of the Atlantic Forest are those with an area less than 50 ha. The area and the Patton's Index were individually calculated for all patches using the attribute calculator and the vector data from the attribute table.

The forest patch density is given by the number of patches in the landscape relative to the total landscape area, and it can be used as an index to express the degree of landscape fragmentation if only the number of forest patches is considered and not their areas or spatial distribution (McGarigal, Cushman, & Ene; 2012). For instance, in landscapes with the same area but different numbers of patches, the more fragmented landscape will be the one with the highest number of patches. Similarly, edge density is the sum of all forest edges per unit area and is expressed in meters per hectare (McGarigal, & Marks, 1994).

The total core area is given by the sum of the core areas of each patch in the landscape and taking a specified buffer value into account. Landscapes with a high core area value are related to the presence of large fragments with low shape irregularity and thus lower edge effects. A large core area may be indicative of good patch quality and low disturbance because it preserves the original biotic and abiotic conditions of a patch prior to fragmentation (McGarigal et al., 1994; Rutledge, 2003).

Regarding Patton's diversity index (Patton, 1975), it takes the area and perimeter of forest patches as parameters and evaluates the complexity of the shape of a patch relative to a circle (the geometric form with the lowest area to perimeter ratio) to quantify the edge effect. The larger the index value, the more complex the shape of the fragment, which results in a higher likelihood of multiple micro-habitats and greater edge effects. The index can be calculated using equation 1.

$$DI = \frac{P}{2\sqrt{\pi.AREA}} \quad (1)$$

Where "DI" is the Patton diversity index; "P" is the total perimeter of a forest fragment; and "AREA" is the area of a forest fragment.

Results

The Alonzo River basin consisted of 888 forest fragments with area values ranging from 0.15 ha to 2,509.82 ha (Figure 1). The fragments accounted for 12.5% of the total area, which means that for an original total area of 283,390 ha, only 35,560.4 ha would be represented by the forest remnants.

Figure 2 shows the distribution of the patches in hectares for the Alonzo River basin. It can be observed that the studied area mostly (85.3%) presents fragments smaller than 50 ha.

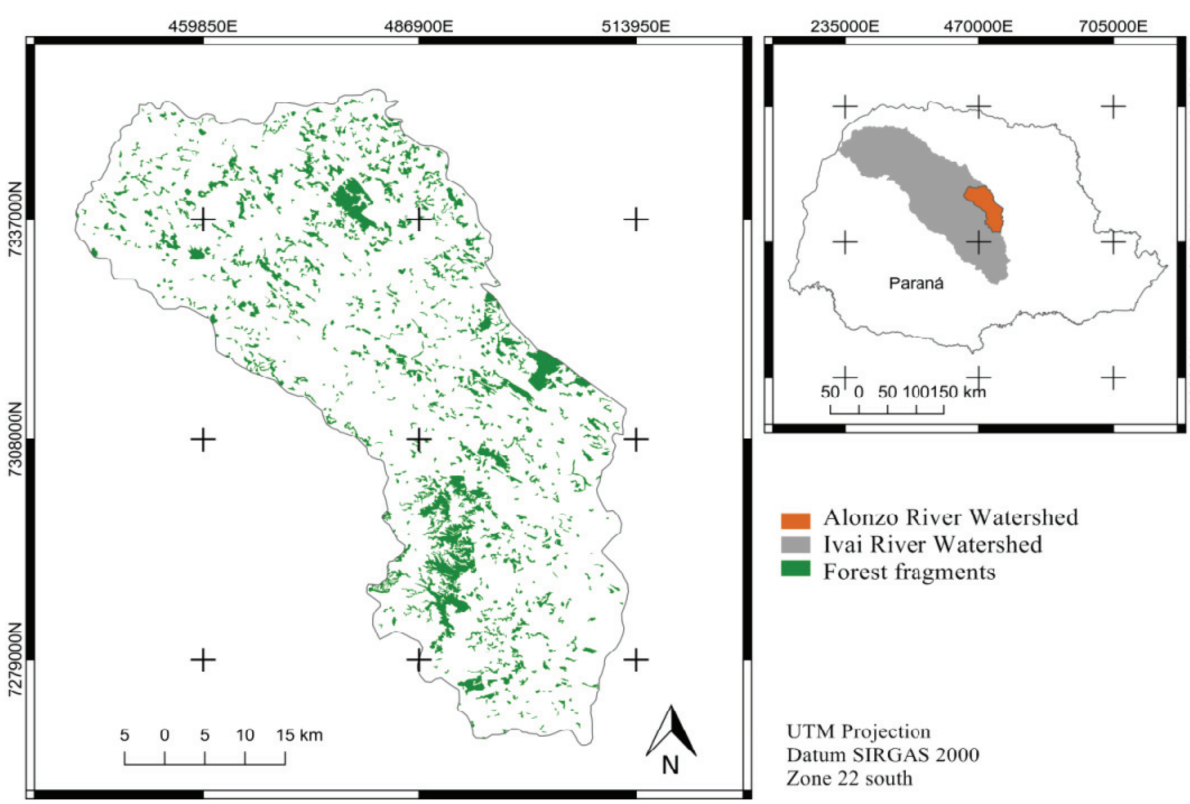

Figure 1. Forest fragments of the Alonzo river watershed, Paraná State.

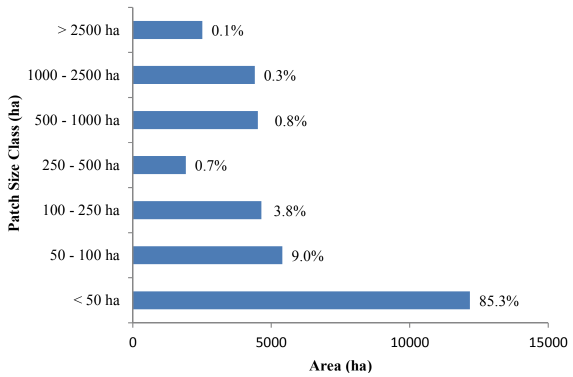

Figure 2. Distribution of the forest fragment areas in the Alonzo river watershed.

In general, the watershed showed a patch density of 3.36×10^{-7} patches per hectare and a total core area of 3,420 ha, which is very small if compared to the sum of all patches. Additionally, the Alonzo River watershed was found to have an edge length of 3070.4 km and an edge density of 0.0012 m ha^{-1}.

The nearest-neighbor distance calculation (Figure 3A) found that the average distance between fragments decreased from 793 meters to 344 meters when fragments smaller than 50 ha were considered.

Concerning the shape complexity of the watershed forest fragments (Figure 3), 50% of the Patton's diversity index values were below 1.59, and 75% were below 1.97 with 1.04 as the minimum value. The maximum value was 9.58, which corresponded to the fragment with the most complex shape in the studied watershed that was also the largest patch (Figure 4A).

The four largest patches in the studied watershed had areas of 2,509.8 ha, 1,784.2 ha, 1,335.5 ha and 1,281.2 ha (Figure 4), and the Patton's diversity index values were ranked from 9.57 for the largest fragment to 3.46, 6.08, and 2.08 for the others in order of decreasing area.

Discussion

The remaining forests in the Alonzo River watershed are composed of many patches with small areas. The total number of patches smaller than 250 ha accounts for 98.1% of the patches in the watershed and 62.5% of the total forest land cover. The area of a patch is closely linked to its ability to accommodate greater species diversity, since larger areas can offer better conditions for species-habitat interactions, consequently promoting the establishment of viable populations of local species (Metzger et al., 2009). The fragmentation process in this area may be related to the intense land occupation and deforestation in Parana State since 1930 (Instituto Nacional de Pesquisas Espaciais [INPE], 2013).

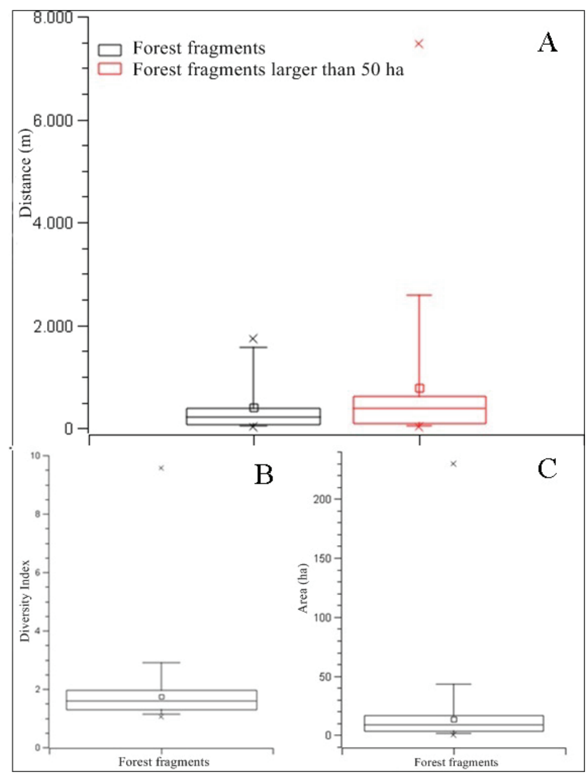

Figure 3. A: Distance to the nearest forest patch. B: Patton's diversity index values of the forest fragments of the Alonzo River watershed. C: Areas of forest fragments with Patton's diversity index values less than 1.97.

The smaller Alonzo River watershed patches, which are isolated from the remaining ones, can be negatively influenced by species-habitat interactions, resulting in local biodiversity loss. This decrease in biological diversity may be linked to ecological changes such as the imbalance of the higher rate of species extinction and the lower immigration rate of species from the neighboring fragments (Laurance & Vasconcelos, 2009). For example, Kageyama, Gandara and Souza (1998) reported a decline in the genetic variability of *Cedrela fissilis* Vell. (Meliaceae) individuals and an increased risk of inbreeding, which caused mal-adaptation and reproductive failure in the population.

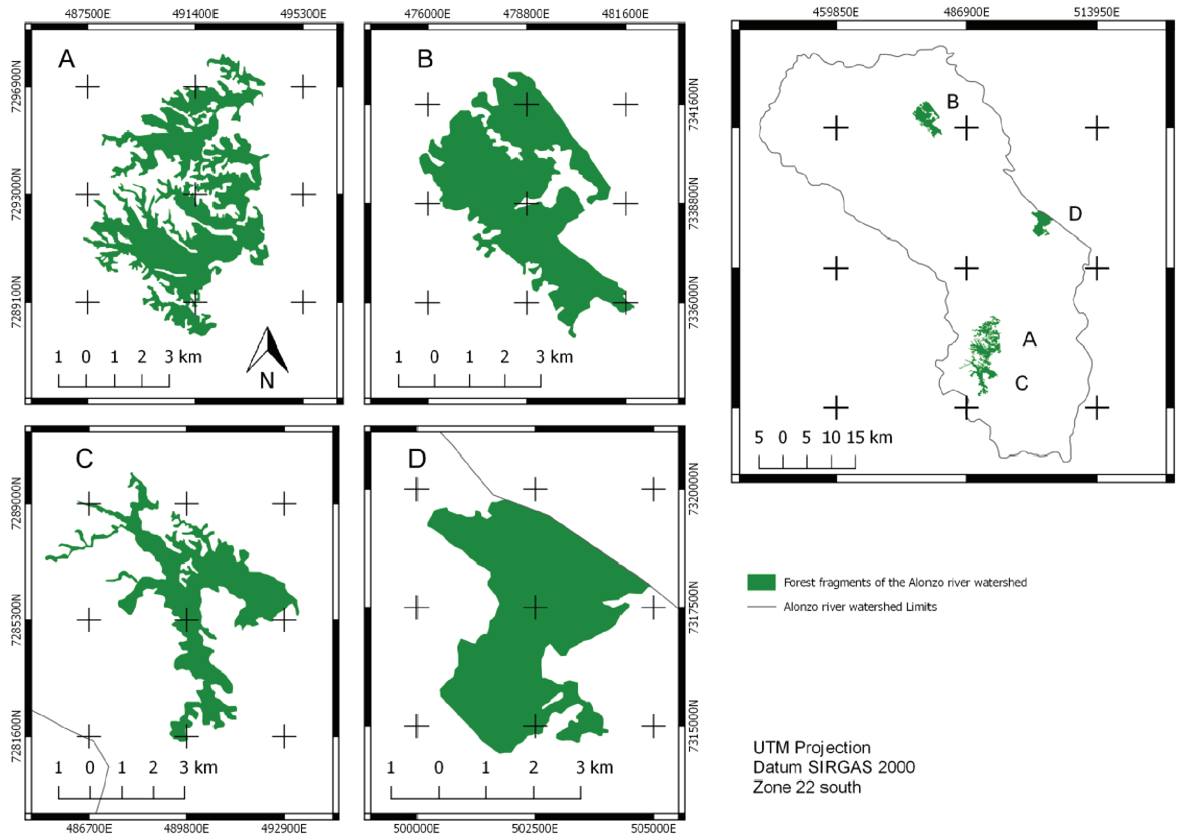

Figure 4. Location of the four largest forest patches in the Alonzo River watershed. A: Largest patch in the Alonzo River watershed (Area = 1784.2 ha; DI = 9.57). B: Second largest patch in the Alonzo river watershed (Area = 1784.2 ha; DI = 3.45). C: Third largest patch in the Alonzo River watershed (Area = 1335.5 ha; DI = 6.08). Fourth largest patch in the Alonzo River watershed (Area = 1281.2 ha; DI = 2.08).

However, the presence of small fragments becomes an important starting point for reducing the spatial isolation of the existing large fragments, as suggested by Ribeiro et al. (2009), who compared the isolation indices of fragments larger or smaller than 50 ha in all the Atlantic Forest remnants. Similar to the findings of these authors, the Alonzo River basin fragments smaller than 50 ha reduced the average distance between patches in this study. In fact, if the patches smaller than 50 ha were not considered in the distance calculation, the average distance between the nearest neighboring fragments would have been 793 meters, but the distance was 344 meters when the small fragments were considered (Figure 5).

Small fragments bring greater ecological benefits to the landscape because they can be used as stepping stones for species movements, increasing the connectivity between fragments. Although small fragments increase the genetic flow through the surrounding matrix and promote the patch colonization process, the efficiency of these small fragments as stepping stone is related to the permeability of the matrix (Baum, Haynes, Dillemuth, & Cronin, 2004). The more suitable the matrix, the more support it offers to species that move among the patches (Gascon et al., 1999; Murphy & Lovett-Doust, 2004).

Patton's diversity index has great relevance to landscape ecology since it can be associated with edge effects and the dimensions of the preserved core area (Calegari, Martins, Gleriani, Silva, & Busato, 2010); greater ecological functionality is expected in fragments that present lower index values. Nevertheless, as also observed by these same authors, the index value for the total core area in this study was not be related to the edge index but to the size of the fragments since most patches that have low diversity index values (75% of the values were below 1.97) also have small areas (75% of those had areas less than 20 ha), which negatively influences the dynamics of animal and plant species and exacerbates the edge effects, as suggested by Borges et al. (2004). Thus, the higher degree of ecological efficiency of a forest fragment, as indicated by Patton's diversity index, may be linked to relatively large patch area values.

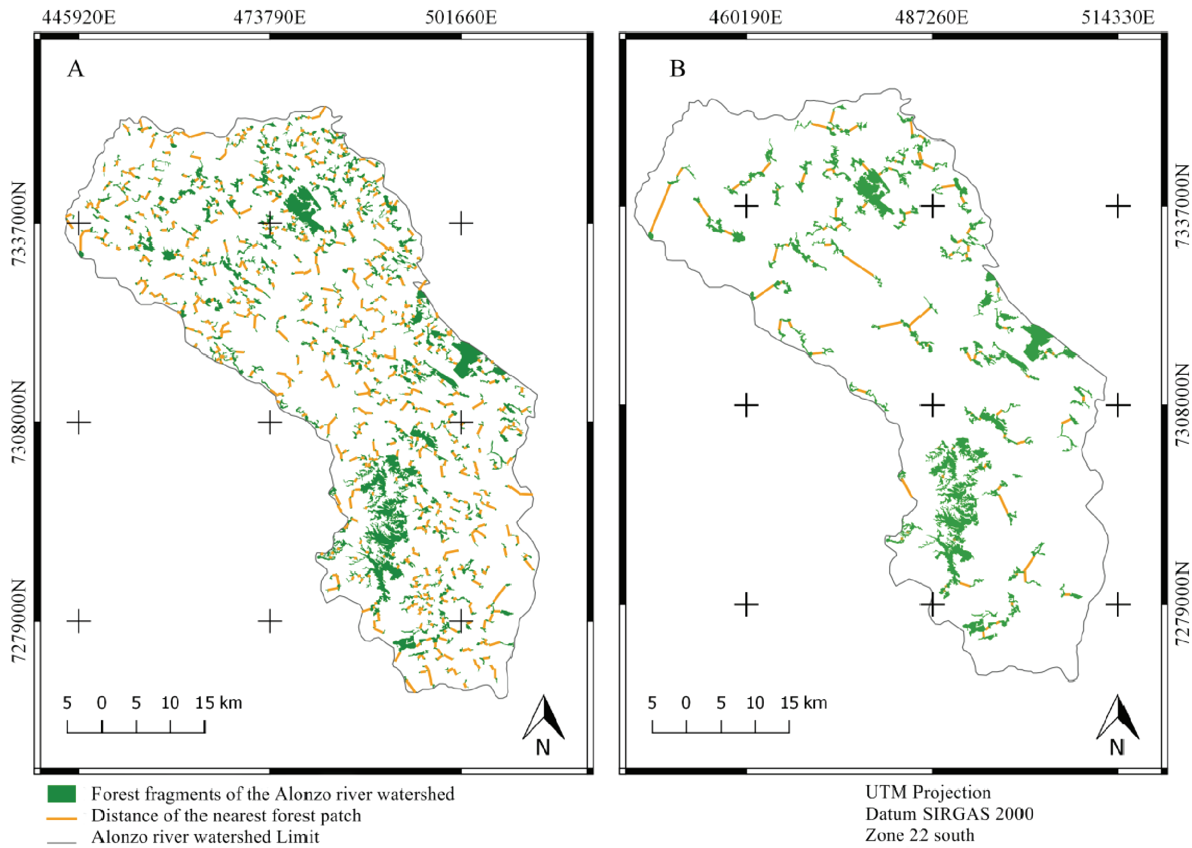

Figure 5. Distance to the nearest forest patch. A: Alonzo River watershed including patches of all sizes. B: Alonzo River watershed including only patches larger than 50 ha.

The edge effect is directly related to higher Patton's index values, but it also corresponds to patch size and the core patch area. Small patches have small core areas, which makes them less ecologically effective and more vulnerable to invasion or dominance by edge specialists, such as heliophytic species (Laurance et al., 2002; Laurance et al., 2007). For example, Silveira Neto, Monteiro, Zucchi, and Moraes (1995) observed a 35.1% reduction in edaphic fauna in forest fragments over 25 years, and Brown and Hutching (1997) observed a decrease in butterfly populations. Furthermore, Gomes et al. (2006) observed a decrease in populations of the arthropod order Collembola in forest fragments. In addition to the reduction in population richness, factors such as the loss of genetic variability could also be considered aggravating in terms of the ecological functionality of a fragment.

The core area is related to the portion of a forest with a lower level of environmental perturbation generated by human action, which preserves the original conditions of the local biome and enables sensitive species to be more resistant to environmental changes and predation by edge-specialist species (Fisher & Lindenmayer, 2007). Overall, the total core area of the Alonzo River watershed was 3,420 ha, which is a relatively low value that can be explained by the large numbers of fragments less than 20 ha in area and with Patton's diversity index values lower than 3.9 (Figure 3C).

Another factor that influences the size of the core area and indicates the level of watershed fragmentation is the relationship between patch density and edge density. For the studied area, edge density was significantly greater than patch density, which combined with the shape complexity index and patch area values, makes it possible to infer that the fragments are subjected to a large edge effect. According to Pereira, Batista, Thalês, Roberts, and Venturieri (2001), this effect may be related to an increase in the number of patches in the original landscape as a result of environmental degradation, which reduces the core vegetation cover of a fragment as well as increases its exposure to physical factors such as solar incidence and low humidity as well as edge-specialist species and the influence of the matrix.

In this area, the relationship between the variation in shape complexity, Patton's diversity index, patch area and the expected environmental functionality of the patch is apparent. By comparing the four largest forest fragments, it can be seen that those patches with the highest Patton's diversity index values (see Figure 4A and C) are responsible for the fragment shapes with the highest complexity. Accordingly, these fragments may contain a greater number of habitats but lower species richness, while the others may become less complex as indicted by the decrease in their respective indices. Therefore, although the fragment represented in Figure 4A possesses the largest area, the fragment in Figure 4D could have the lowest edge effect and be more suitable for the conservation of biodiversity and the richness of the local biome.

Conclusion

The Alonzo River basin is highly fragmented with varying Patton's diversity index and area values. Most of the fragments are small, which may reflect in loss of local biodiversity. Although the shape complexity indices are relatively small, the total forest area and the size of the core area may influence the edge effects, which in turn may increase the vulnerability of the fragments and limit local biodiversity.

Further investigation of the ecological effects on local fauna and flora, with a focus on the importance of ecological balance, may contribute to a better understanding of fragmentation processes. The use of GIS and landscape ecology metrics enables the effects of landscape fragmentation to be evaluated quickly and efficiently over large areas.

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