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LANDSCAPE GEOTECHNOLOGIES AND METRICS IN A PROTECTED AREA

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ABSTRACT

The analysis of the alteration of the spatial relationships between the different elements present in the landscape that influence the distribution of matter, energy and species over time is one of the fundamental characteristics of landscape ecology, called landscape dynamics. The study of landscape dynamics allows the analysis of the behavior and variation (flow) of matter, energy and species. The objective of the present work was to evaluate the dynamics of the landscape of a formal conservation unit, the Parque Estadual das Nascentes do Rio Taquari, through the analysis of the fragmentation of vegetation over time, using geotechnologies. With the multitemporal analysis of different spatial elements such as the area occupied by the remnants of tree vegetation, indicating the loss/gain of habitat, the degree of fragmentation, the size and shape of the fragments (through landscape metrics), that is, the parameters that determine the existing ecological processes and their importance in biological conservation, it was possible to evaluate the effectiveness of the protection of this conservation unit. And it also made it possible to relate simple parameters such as the quantity, size, and perimeter of the fragments with the amount of matter, energy, and species. Comparing the values of these parameters over time indicates

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the behavior and variation of matter, energy, and species (flow) in each fragment and in the landscape as a whole.

Keywords: Landscape ecology; Satellite imagery; Multitemporal analysis; Landscape dynamics.

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INTRODUCTION

In Mato Grosso do Sul, whose area is approximately 358,000 km2, the Cerrado occupies 65.5% of the total area of the state (IBGE, 2025). In 1985, 41.6% of the Cerrado in Mato Grosso do Sul was occupied by areas intended for agricultural activities, and the occupation of these areas intensified in the 1990s. Currently, the area is much smaller and in many properties there is not even 20% of native vegetation required by law (Pott and Pott, 2003; Pagotto *et al.,* 2006; Gamarra et al, 2021).

Habitat fragmentation and the conversion of land cover for agricultural purposes are constant threats to biodiversity conservation in the Cerrado Biome. These landscapes dominated by agricultural activities have become dynamic mosaics, which are formed by different land uses (Carvalho et al., 2009). Machado et al. (2004) estimate that the Cerrado biome is expected to be totally destroyed by the year 2030 if current rates of habitat loss are maintained.

In view of the drastic fragmentation of Cerrado areas, it is essential to carry out research, especially in places that have significant fragments and that are protected under some form of conservation unit. Thus, one of the obstacles to the conservation of the biological diversity of the Cerrado is the insufficiency of studies aimed at solving environmental problems (Klink and Machado, 2005). Knowing the environmental variability and dynamics of forest fragmentation provides data for correct management and conservation.

Among the most important consequences of the forest fragmentation process are the decrease in biological diversity, the extinction of species, the modification of pollination, seed dispersal by animals, herbivory, herbivore predation and other disturbances in the hydrological regime of the watersheds, climate change, degradation of natural resources and the deterioration of the quality of life of traditional populations (Scariot *et al.,* 2005). In addition, fragmentation results in remnants of native vegetation that are close to agricultural areas and other forms of use, significantly altering soil water and nutrients (Saunders *et al.,* 1991; Coutinho, 2016). It reduces and isolates the areas conducive to the survival of native populations, causing changes in the landscape as a whole (Metzger, 1999; Moreira, 2012).

In this context, the concepts of Landscape Ecology combined with Geotechnology tools (Remote Sensing and GIS – Geographic Information System) provide an important subsidy for the understanding and planning to solve environmental problems.

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Landscape ecology focuses on the horizontal relationships between different landscape units and considers the development and dynamics of spatial heterogeneity, the interaction and exchange across the landscape, the influence of heterogeneity on biotic and abiotic processes and their management (Turner, 1987; Metzger, 2001; Cain et al., 2017).

Geographic Information Systems and Remote Sensing are considered "the most important holistic tools for landscape analysis, planning, and management" (Lang and Blaschke, 2009).

In view of the above, this study seeks to evaluate the dynamics of the landscape of the Nascentes do Rio Taquari State Park through the multitemporal analysis of vegetation fragmentation over time, using geotechnologies.

METHODOLOGY

FIELD OF STUDY

The Taquari River Springs State Park (PENRT), in addition to its importance for the Cerrado biome, is home to springs of this important river for the Pantanal. It is located in the Midwest region of Brazil, in the State of Mato Grosso de Sul, between coordinates 17º59' to 18º15' S and 53º10' to 53º26' W. The PENRT was created through State Decree No. 9,622 of October 9, 1999 (Mato Grosso do Sul, 1999), with an area of 30,618.96 hectares. covering 26,849.62 hectares in the Municipality of Alcinópolis-MS and 3,769.34 hectares in Costa Rica-MS (Figure 1). It is one of the core areas of the Emas-Taquari Biodiversity Corridor (brCarbon, 2025), that is, one of the most environmentally important remnants in the Cerrado.

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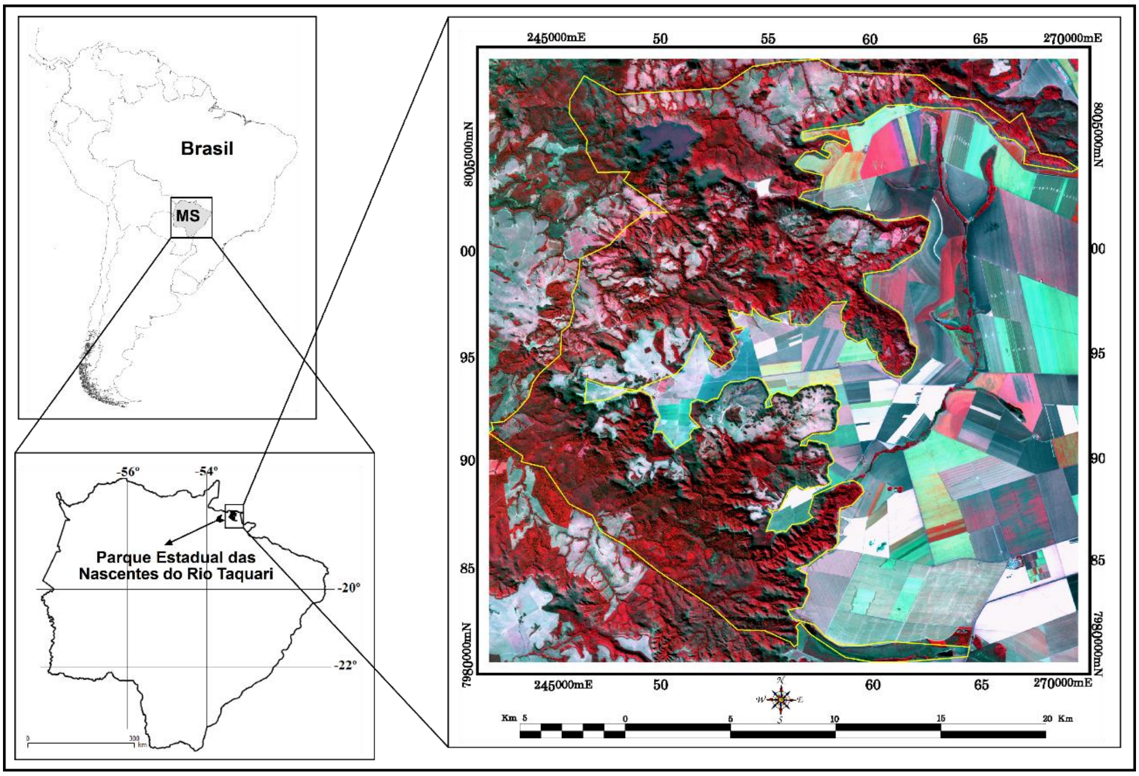
Figure 1. Location of the Taquari River Springs State Park (PENRT), a remnant of the Cerrado Biome and an important fragment of the Emas-Taquari Biodiversity Corridor, it houses the springs of an important river for the Pantanal.



Source: Image from the ALOS satellite AVNIR-2 sensor with a spatial resolution of 10 m from July 4, 2010. False color RGB 432 composition. PENRT boundary in yellow. On the left side of the image, the areas in deep red signify dense vegetation. The geometric pattern on the right side of the image shows agricultural areas, which surround the PENRT (Gamarra et al., 2016).

MATERIALS USED

In the realization of the work, six scenes from the LANDSAT 5 (*Land Remote Sensing Satellite*) satellite, TM (*Thematic Mapper*) sensor, orbit/point 224/073, with 30 m of spatial resolution, of July 18, 1984 (INPE, 1984), July 16, 1989 (INPE, 1989), July 30, 1994 (INPE, 1994), July 28, 1999 (INPE, 1999), July 25, 2004 (INPE, 2004) and July 26, 2010 (INPE, 2010). As support material, two orthorectified scenes from the ALOS (*Advanced Land Observing Satellite*) satellite were also used, one from the AVNIR-2 (*Advanced Visible and Near Infrared Radiometer type 2*) sensor with 10 m of spatial resolution of July 4, 2010 (GlobalGeo, 2010a) and another from the PRISM (*Panchromatic Remote-sensing Instrument for Stereo Mapping*) sensor with 2.5 m of spatial resolution of August 19, 2010 (GlobalGeo, 2010b).

All six scenes of the LANDSAT 5 satellite were georeferenced with an error of less than 1 pixel, using the scenes of the ALOS satellite (UTM, spindle 22, WGS84) as a

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reference base. These scenes were cut using the vector of the official limit of PENRT (in *shapefile format*) obtained from the Interactive System of Support for Environmental Licensing (SISLA) of the Institute of Environment of Mato Grosso do Sul (IMASUL) (SISLA, 2025).

In the multitemporal analysis, only LANDSAT 5 images were used, all from the dry season, to ensure greater distinction between the phytophysiognomies and less interference of seasonality (phenology). In addition to maintaining the characteristics of the image (spatial, spectral and radiometric resolution).

The programs used were Geomatica 2018 (PCI, 2018) for the georeferencing and cropping of satellite images and integration of all data in a Geographic Information System (GIS) environment and Ecognition 2.0 (Definiens, 2002) for object-oriented classification.

DATA COLLECTION IN THE FIELD

Three stages of fieldwork were carried out in order to identify the types of soil cover (including the phytophysiognomies described by Ribeiro and Walter, 1998) and to recognize the vegetation fragments in order to relate them to the satellite images of the study area, using a digital camera, spherical densiometer and GPS receiver (*Global Positioning System*) navigation. During the survey of the history of the area, the residents and the park manager were interviewed about the changes that occurred in the land cover of the study area. Bibliographic surveys also helped in this activity.

LAND COVER: CLASSIFICATION OF IMAGES

After the fieldwork, to generate the land cover maps of the different years, the object-oriented classification was carried out in the six clippings of the LANDSAT 5 satellite images, using the Ecognition 2.0 program (Definiens, 2002), according to the method used in Gamarra (2013). Four classes of land cover were used, including the phytophysiognomies described in the key of Ribeiro and Walter (1998) and grouping different spectral classes of land cover described in Paranhos Filho et al. (2021), which makes the relationship between Cerrado phytophysiognomies and Landsat satellite images for the Cerrado:

a) Forest Formation: It encompasses the phytophysiognomies Cerradão, Dry Forest, Riparian Forest and Gallery Forest;
b) Savanna Formation: Corresponds to the Cerrado Restricted Sense

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phytophysiognomy;

c) Grassland Formation: It encompasses the phytophysiognomies Campo Limpo, Campo Sujo and Campo Rupestre. It is worth mentioning that the field formation class includes both native fields and pastures and other exotic/cultivated field formations;

d) Water/ Wetland: Corresponds to aqueous bodies such as rivers and lakes and wetlands such as swamps, paths and wetlands.

It is important to highlight that the Cambaúva or cambauvais fields were included in the spectral class of Grassland Formation Grassland, which are fields where a native species of bamboo (*Apoclada arenicola*), known as Cambaúva, which are found predominantly in the slope areas of the PENRT, were included in the spectral class of soil cover Grassland.

ANALYSIS OF LANDSCAPE FRAGMENTATION

The degree of fragmentation of the vegetation cover (evaluated through the number of fragments existing in the PENRT in each year analyzed) and the Circularity Index (CI) were calculated from the fragments of tree vegetation, i.e., only the spectral classes of land cover Forest Formation and Savannah Formation (phytophysiognomies of riparian forest, Dry forest, Cerradão and Cerrado in the strict sense), because this index is generally used in forest fragments, but since the Cerrado is a biome with predominantly tree-shrub vegetation, fragments of phytophysiognomies that have trees were included.

From the vectors generated in the object-oriented classification of the cutouts of the images of the different years analyzed (with attributes of area and perimeter of the polygons) a GIS database was created.

The first step was to dissolve the adjacent polygons of the Forest Formation and Savannah Formation classes, so that the polygons came to represent the vegetation fragments.

It is worth mentioning that the fragments with an area of less than 1 ha were discarded because they are subject to area and perimeter distortion at the time of vector generation from LANDSAT 5 satellite images (30 x 30m pixel).

Landscape Metric: Circularity Index (CI)

The Circularity Index (CI) of each fragment was obtained through the equation:

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$CI = 2.\sqrt{\pi}. S/P$ (1)

where:

CI = circularity index;
S = fragment area (in square meters);
P = perimeter of the fragment (in meters).

The classification of the fragments according to shape was carried out based on the CI values, which allow the identification of whether the fragments have elongated or circular tendencies. CI values equal to 1 indicate fragments with a circular tendency and, as this value becomes smaller, the fragment presents a more elongated tendency (Nascimento *et al.,* 2006; Hentz et al., 2015).

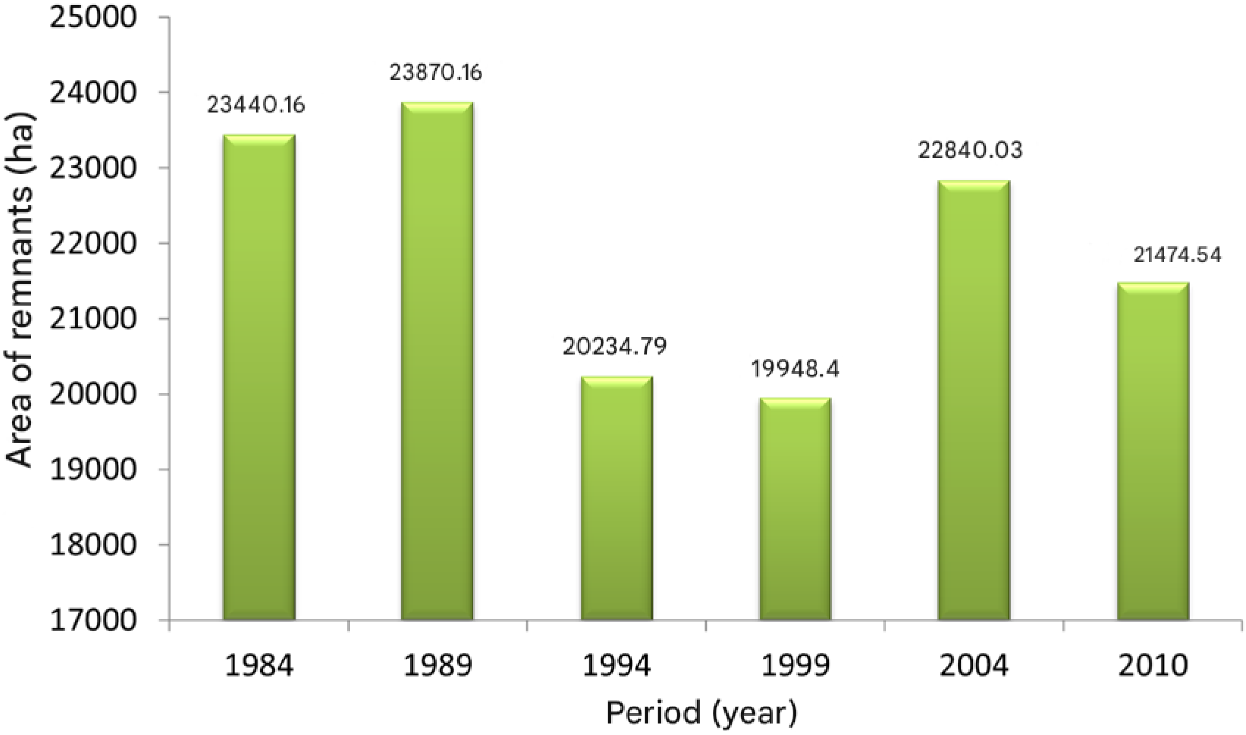
Thus, in the present study, fragments that presented CI values < 0.4 were classified as very irregular, with CI between 0.4 and 0.65 as irregular and with CI > 0.65 as regular.

RESULTS AND DISCUSSION

AREA OCCUPIED BY THE REMNANTS

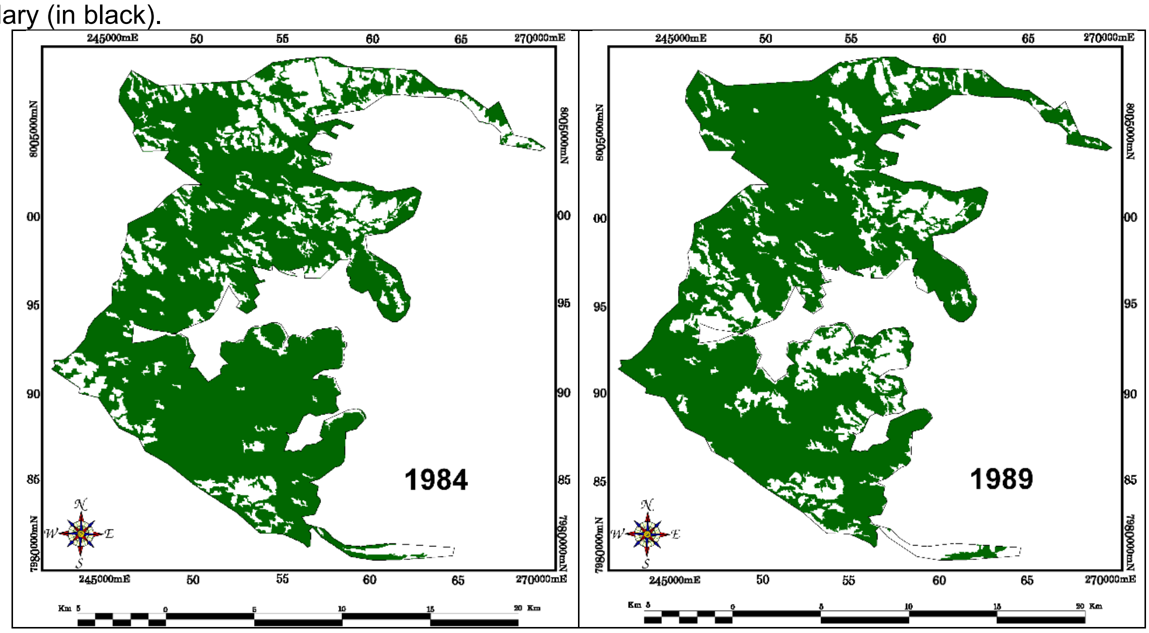
Here habitat loss was first analyzed (Figure 2) and landscape fragmentation will be addressed later (Figure 11). A key issue for conservation is the relative importance of habitat loss versus habitat fragmentation (Fahrig, 2003; Laranjeira, 2012). That is, what is the relative importance of how much habitat remains in the landscape versus how fragmented it is? Some studies suggest that both habitat loss and habitat fragmentation are significant influences, although habitat loss is generally a stronger influence for a higher proportion of species (Bennett and Saunders, 2010).

Figure 2. Area (ha) occupied by the remnants of tree vegetation of the PENRT in the period analyzed.



The area occupied by the remaining tree vegetation of the PENRT (sum of the areas of fragments larger than 1 ha) increased by 1.47% in the period from 1984 to 1989 (Figure 3).

Figure 3. Area occupied by the remnants of the PENRT in the period from 1984 to 1989 (in green) and its boundary (in black).



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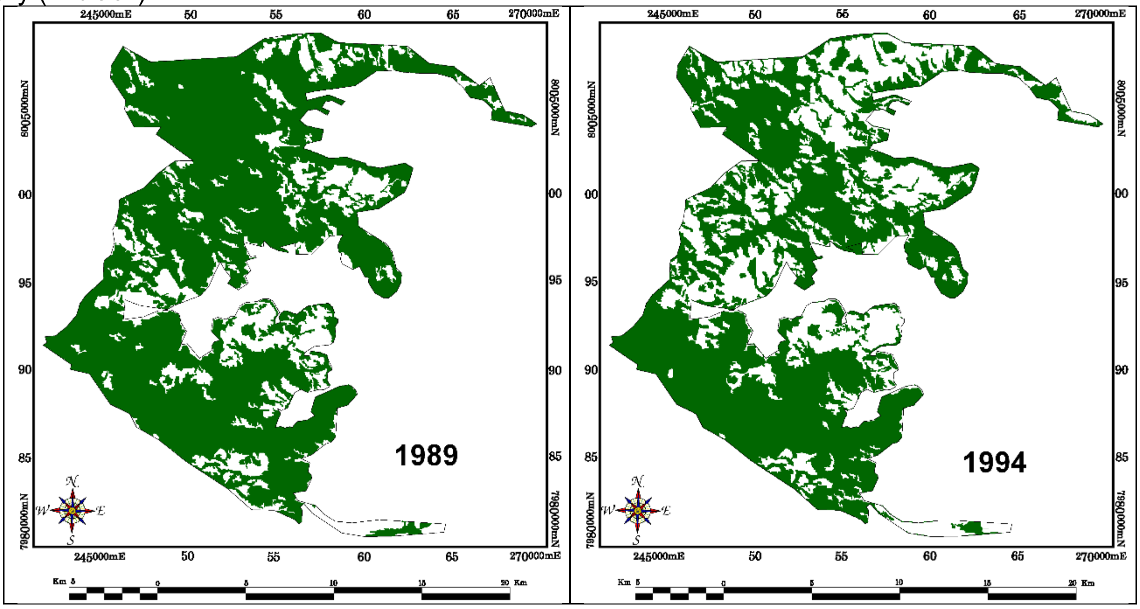
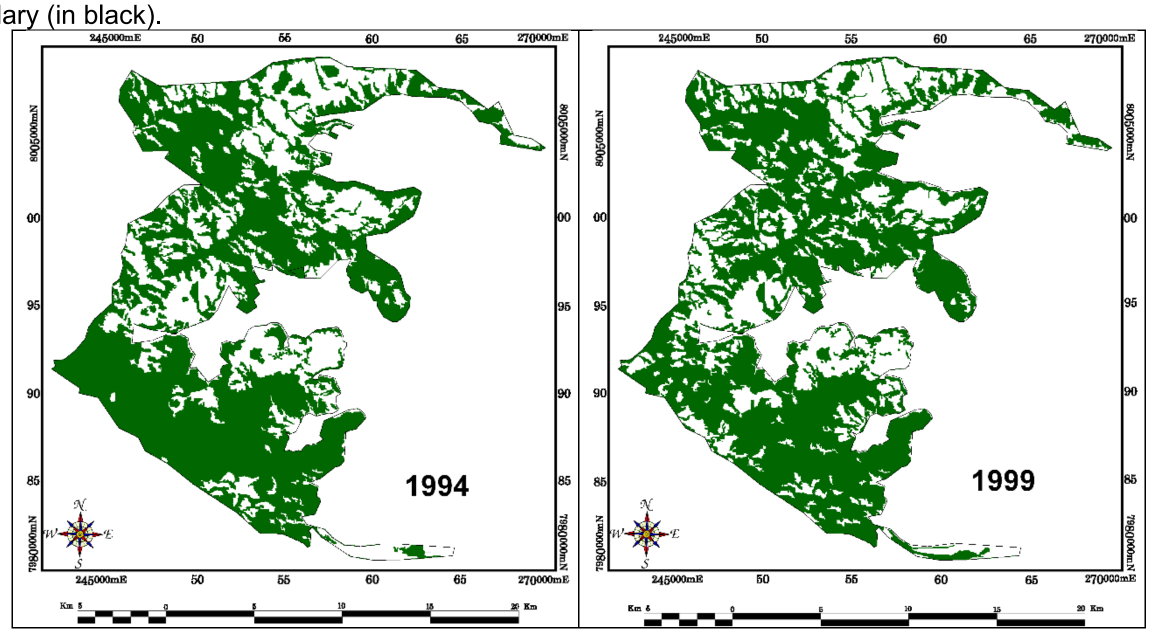
From 1989 to 1994, there was a reduction of 14.93% in the area of the remnants (Figure 4).

Figure 4. Area occupied by the remnants of the PENRT in the period from 1989 to 1994 (in green) and its boundary (in black).



In the period from 1994 to 1999, there was a reduction of 1.42% in the area of the remnants (Figure 5).

Figure 5. Area occupied by the remnants of the PENRT in the period from 1994 to 1999 (in green) and its boundary (in black).



From 1999 to 2004, there was an increase of 14.5% in this area (Figure 6).

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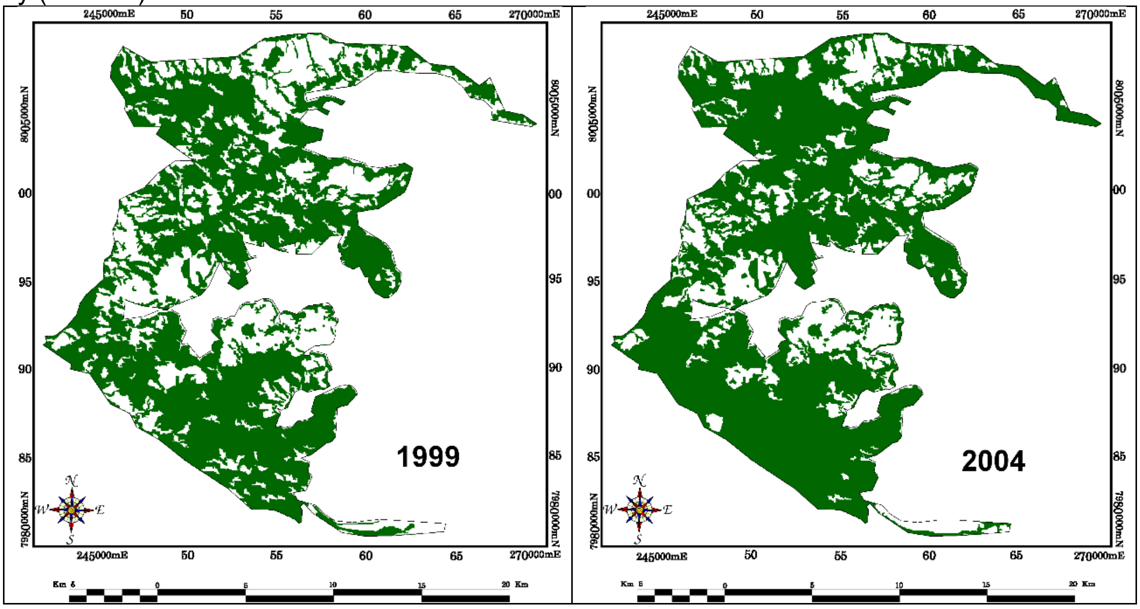
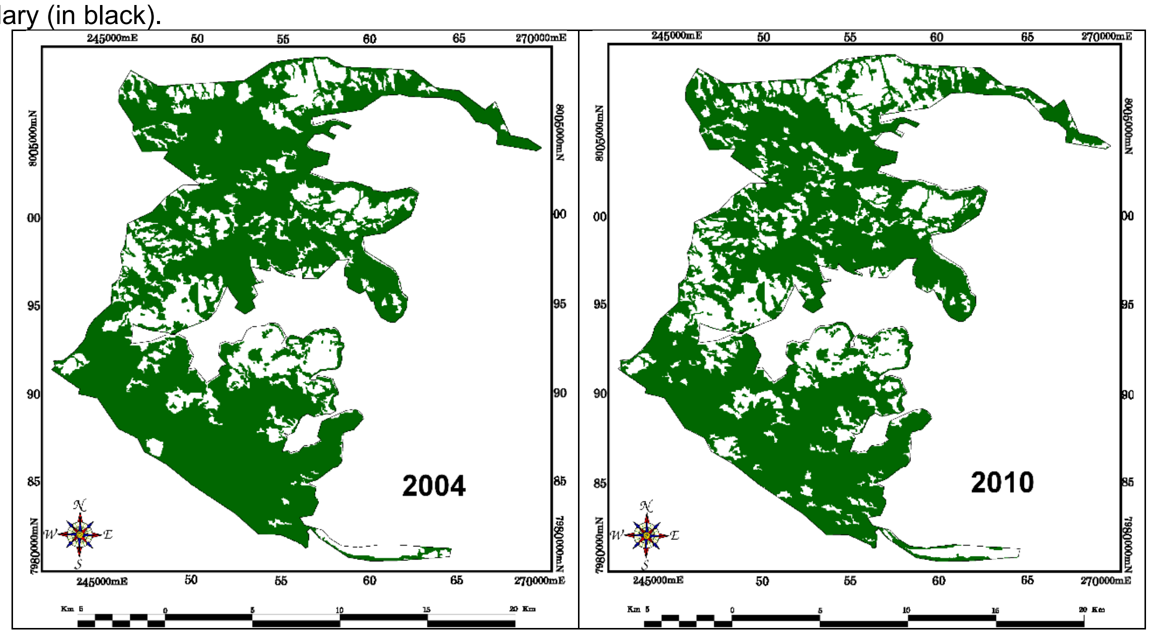
Figure 6. Area occupied by the remnants of the PENRT in the period from 1999 to 2004 (in green) and its boundary (in black).



In the period from 2004 to 2010, there was a reduction of 5.98% in the area of the remaining tree vegetation of the PENRT (Figure 7).

Figure 7. Area occupied by the remnants of the PENRT in the period from 2004 to 2010 (in green) and its boundary (in black).



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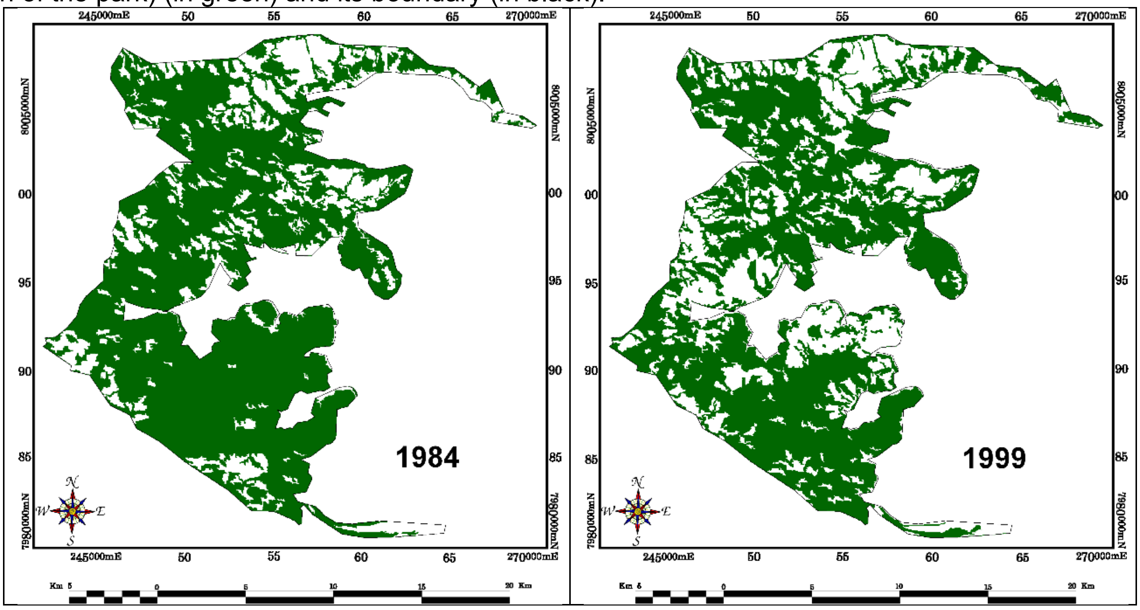
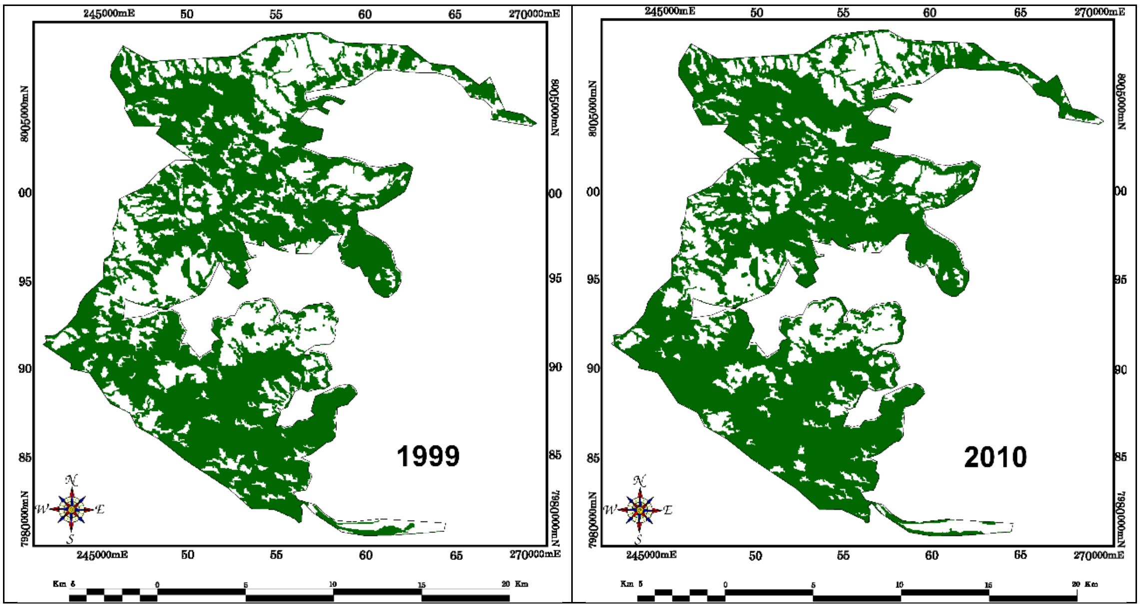
It is worth mentioning that the PENRT was created in 1999, so from 1984 to 1999 (the period before the creation of the conservation unit) there was a reduction of 14.9% in the area of remaining tree vegetation (Figure 8).

Figure 8. Area occupied by the remnants of the PENRT in the period from 1984 to 1999 (period before the creation of the park) (in green) and its boundary (in black).



In the period from 1999 to 2010 (after the creation of the conservation unit) there was an increase of 7.65% in the area of the remnants (Figure 9). These results demonstrate that the creation of the park helped in the regeneration of the arboreal vegetation of the region.

Figure 9. Area occupied by the remnants of the PENRT in the period from 1999 to 2010 (after the creation of the park) (in green) and its boundary (in black).



Even after the creation of the PENRT, in the period from 2004 to 2010 there was a small reduction in the area of the remnants. One of the factors that may have contributed to this is fire. The PENRT region frequently suffers from fires, characteristic of the Cerrado biome. And as the PENRT has rugged relief and is often difficult to access, large areas of the park are consumed by fire.

When analyzing the entire period studied, from 1984 to 2010, it can be seen that there was a reduction of 9.15% in the area of remaining tree vegetation. This is mainly a reflection of the period prior to the creation of the PENRT (Figure 10).

Figure 10. Area occupied by the remnants of the PENRT in the period from 1984 to 2010 (all period studied) (in green) and its boundary (in black).

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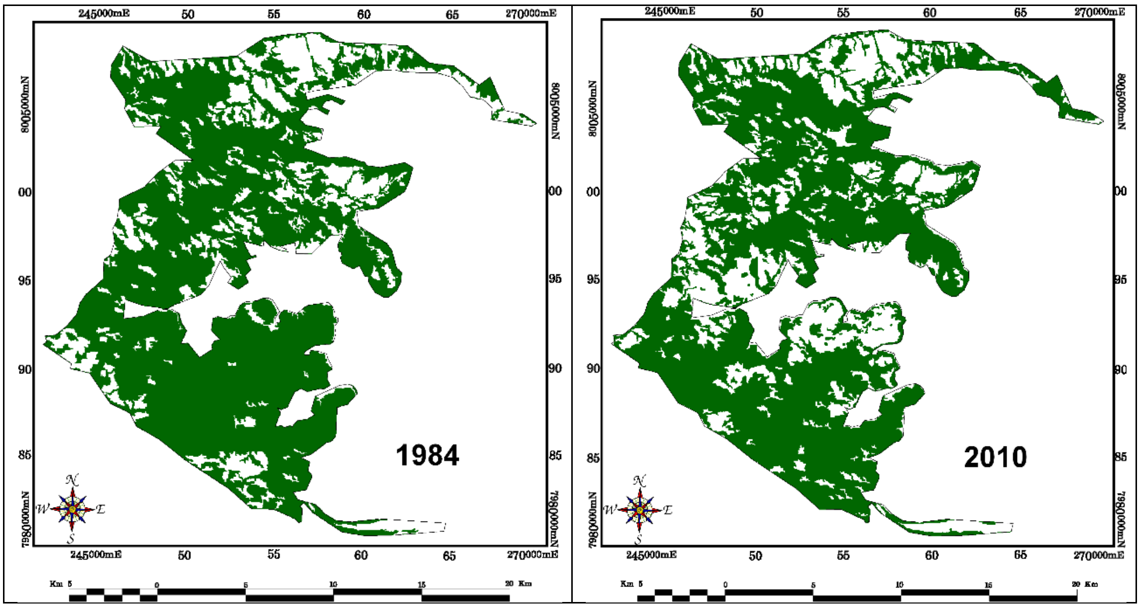

DEGREE OF FRAGMENTATION

Regarding the degree of fragmentation of the tree vegetation (number of fragments) of the PENRT, a response similar to the variation in the area occupied by the remnants in each year is observed (Figure 11). In the periods when the area of the remnants increased, there was a reduction in the number of fragments. In the periods in which there was a reduction in the area of the remnants, there was an increase in the number of fragments.

Figure 11. Degree of fragmentation (number of fragments) in each year analyzed.

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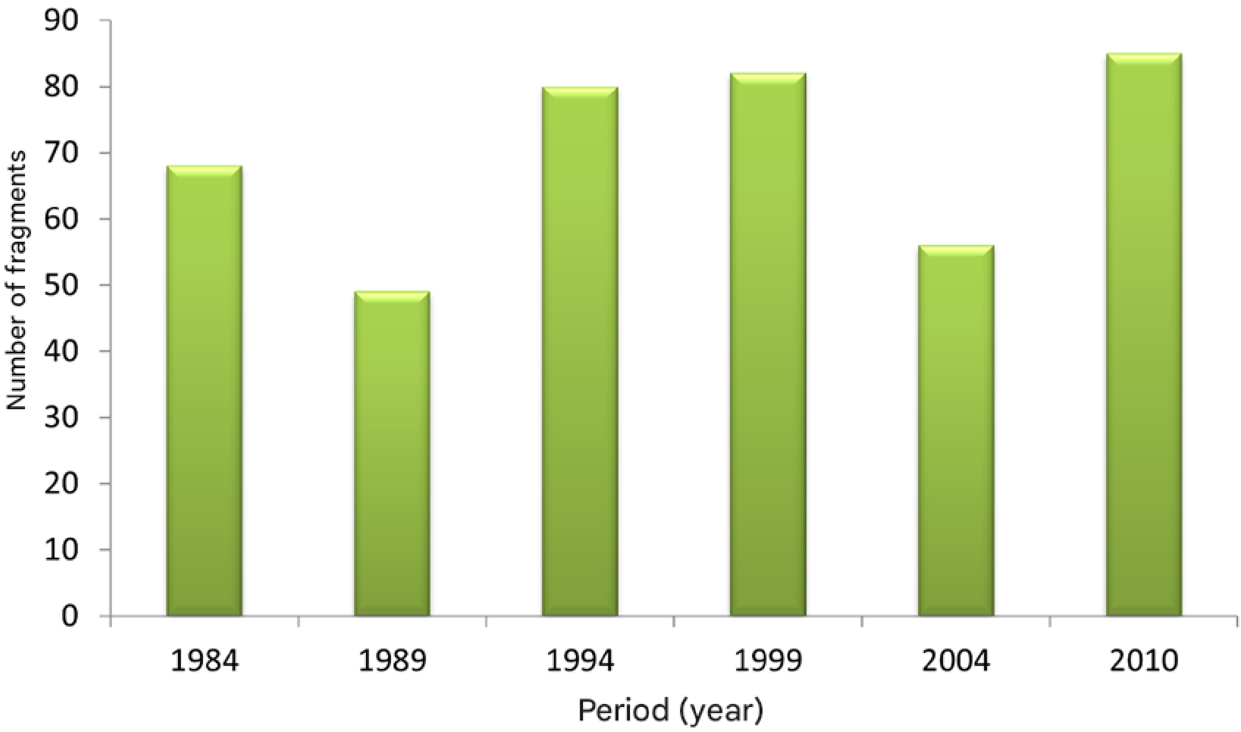

According to Bennett and Saunders (2010) landscape alteration is a dynamic process, a series of land cover maps at intervals over time is an important method, as it illustrates the pattern of change of the original vegetation, as presented in the present work. Characteristic changes along this time trajectory include a decrease in the total area of the fragments, a decrease in the size of many fragments (large patches become scarce and small fragments predominate), an increase in the isolation of fragments from similar habitats, and the shapes of the fragments dominated by straight edges when compared to the curvilinear boundaries of natural features, like rivers.

SIZE OF THE FRAGMENTS

The variation in the size of the fragments over the years was analyzed (Figure 12) and it was possible to relate the size of the fragments with the distribution of matter, energy and species (species-area relationship).

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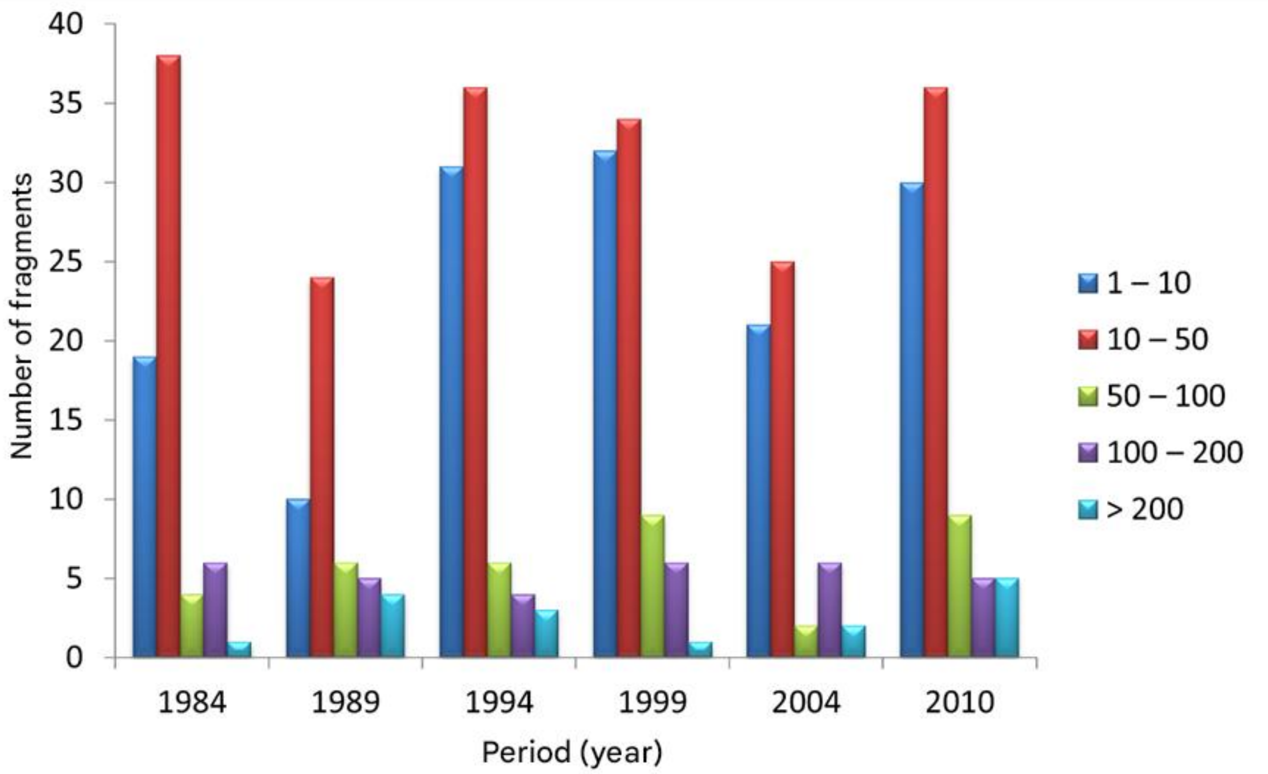
Figure 12. Number of fragments in each size class (ha) in the different years analyzed.



The species-area relationship shows that with the increase in habitat size, there is an increase in species richness (Arrhenius, 1921; Preston, 1962a; Preston, 1962b). Small areas have less habitat diversity, support smaller populations, therefore, fewer species can maintain viable populations, and represent a small sample of the original habitat, and may have fewer species than a larger sample, i.e., when habitats are fragmented into smaller parts, species are lost (Connor and McCoy, 1979; Miranda et al., 2019).

Later, the species-area relationship was used as a central element in the creation of the Theory of Island Biogeography by MacArthur & Wilson (1963). In this theory, an insular equilibrium model was described that determines that the number of species present on an island is the result of dynamic equilibrium between the rate of immigration of new species to the island and the extinction rate of the species present on the island. Thus, a comparison of this model of islands with the fragments of vegetation was made. In addition to the greater heterogeneity of habitats, large areas can harbor more species because they are greater targets for colonization and also because they have more resources and sustain larger populations, reducing the risk of local extinctions.

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In all the years analyzed, the presence of one or two fragments representing approximately 90% of the remaining tree vegetation of the PERNT was verified. They are large fragments that are extremely "cut out", but totally connected in their parts. In 1984 this large fragment had more than 21,000 ha. In 1989 its size practically remained the same. In 1994 the fragment decreased to approximately 17,000 ha. In 1999 it increased to approximately 17,500 ha. In 2004 this large fragment split into two parts, one with almost 12,000 ha and the other with approximately 9,000 ha. In 2010 these two parts decreased a little and were left with approximately 9,500 and 8,400 ha, however, the number of fragments larger than 200 ha increased.

These fragments practically connect all the other smaller fragments that exist in the PENRT, allowing the entire conservation unit to function as a single large fragment, as the smaller fragments are located in its surroundings. The large number of watercourses within the PENRT can also promote the connectivity of these fragments, functioning as biodiversity corridors.

A set of small isolated but close fragments can effectively provide access routes, functioning as ecological stepping stones. While the large fragments are important for the maintenance of biodiversity and large-scale ecological processes, the small remnants fulfill extremely relevant functions throughout the landscape, functioning as connecting elements between large areas, promoting an increase in the level of heterogeneity of the matrix and acting as a refuge for species that require particular environments that only occur in these areas (Forman and Godron, 1986).

SHAPE OF THE FRAGMENTS

As landscape ecology deals with the relationship between spatial patterns and ecological processes, it becomes necessary to accurately quantify spatial patterns. One of the forms of quantification is the use of the so-called "landscape metrics". There are more than a hundred metrics, but many of them measure the same thing differently. Calculating metrics is simple and often automatic (when using a program). It is much more difficult to interpret and analyze the results in relation to the biological/ecological data collected, that is, more important than the value of the metrics is the interpretation of their biological meaning. The calculation of metrics can be automatic, but the proper use cannot (Metzger, 2006; Silva et al., 2019).

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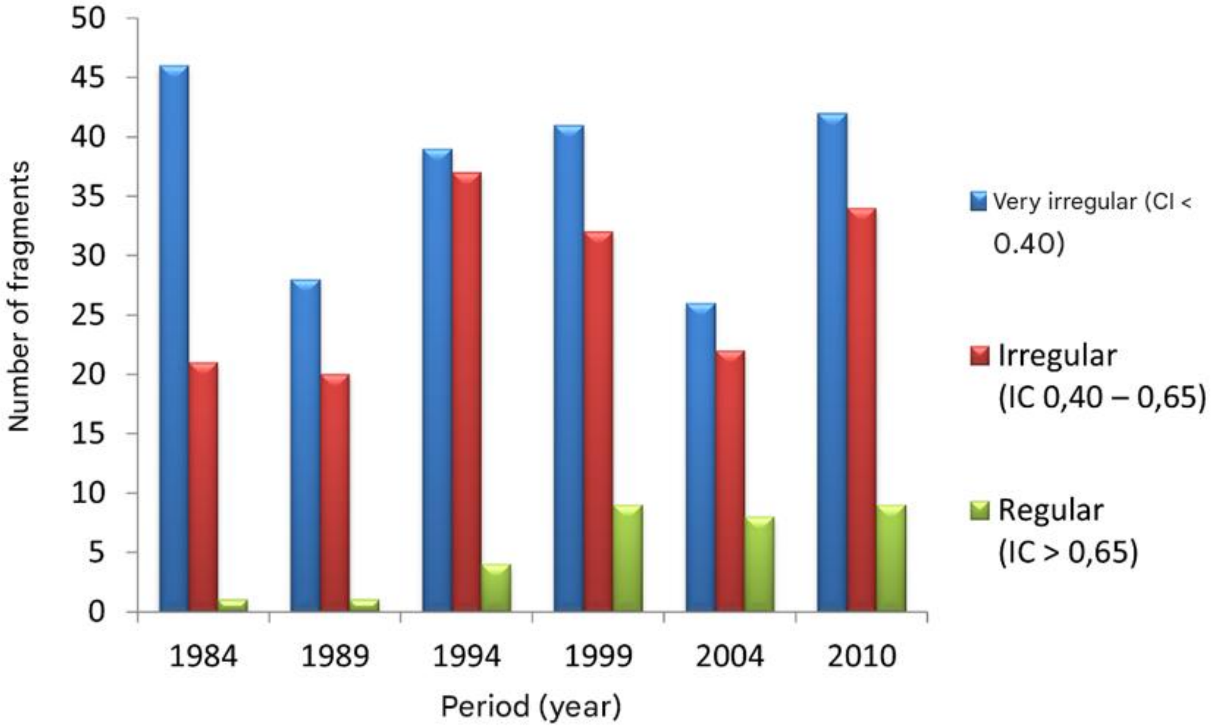
Here we use the circularity index (CI) to evaluate the shape of the fragments. We found that the vast majority of the fragments have an irregular and very irregular shape, that is, they have low circularity index (CI) values in all the years analyzed (Figure 13).

Figure 13. Number of fragments in each shape class (CI: Circularity Index).



Habitat fragments closer to the circular shape have the edge-to-area ratio minimized and, therefore, the center of the area is farther from the edges and consequently more protected from external factors.

All edge-related effects are particularly intense in small fragments, but the shape of the fragments, and especially those that are very narrow and elongated or very irregularly shaped, with many invaginations, may allow the changes to penetrate a large part of the area or even the entire area of the fragment. This causes species sensitive to these changes to be excluded from the entire area of the fragment (Kapos, 1989; Laurance *et al*., 1998; Cerqueira *et al*., 2021).

The predominance of irregular shapes of the fragments can be explained by several factors, one of them is the relief of the PENRT, which is quite rugged, thus forming fragments of a very irregular shape.

Another factor that must be considered is the land tenure situation of the PENRT, which is made up of many farms that have not yet been expropriated, in these farms the main activity is cattle raising, in this way part of the vegetation was suppressed for pasture formation.

Thus, these remnants of tree vegetation end up being "cut" in different ways, causing fragments of different shapes to exist and often these shapes have a very large perimeter in relation to their area.

FINAL CONSIDERATIONS

With the multitemporal analysis of different spatial elements such as the area occupied by the remnants of tree vegetation, indicating the loss/gain of habitat, the degree of fragmentation, the size and shape of the fragments, that is, the parameters that determine the existing ecological processes and their importance in biological conservation, it was possible to evaluate the effectiveness of the protection of this conservation unit. And it also made it possible to relate simple parameters such as the quantity, size, and perimeter of the fragments with the amount of matter, energy, and species. Comparing the values of these parameters over time indicates the behavior and variation of matter, energy, and species (flow) in each fragment and in the landscape as a whole.

The technique and tools used proved to be efficient, minimizing costs and time to obtain this information.

We found that from 1999 to 2010 (the period after the creation of the PENRT) there was an increase in the area of tree vegetation remnants and in the number of large fragments, i.e., the park's vegetation has been recovering over the analyzed period.

It is worth mentioning that a large part of the PENRT area has not yet been expropriated, so agricultural activities still occur within the park. Another concern is its buffer zone, its eastern limit is completely taken over by extensive soybean and cotton plantations. Some springs (Ribeirão do Engano) are close to the park, in its surroundings, but outside the protection area, surrounded by plantations. It would be of great importance that the region surrounding the park also receive greater attention, so that as the expropriations are carried out, the vegetation of the park and its surroundings can regenerate.

Thus, the present work aims to contribute to the better management of this conservation unit, helping it in its sustainability and in the maintenance of local biodiversity.

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