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Artigos

Criteria for the implementation of ecological corridors in fragmented areas in southern Brazil

Proposta de implantação de corredores ecológicos para áreas fragmentadas de ecossistemas tropicais no Brasil

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ABSTRACT

The present study aims to analyze the potential of areas for the implementation of ecological corridors. The study area represents a transition between the Atlantic Forest and Cerrado domains and is extensively fragmented. Geographic Information System was used to determine suitable areas for the implementation of ecological corridors based on their ecological and structural potential, while multi-criteria classification was used to generate a final ecological map of the area. Weights and notes were assigned to vegetation class, river width, elevation and declivity in their respective maps, which were overlaid using ArcGis 10.3 software. Structural analysis of the area used the landscape metrics *mean area*, *mean shape* and *total edge* of fragments and *mean connectivity* among fragments in Fragstats software. The results indicated an ecologically and structurally suitable area for the implementation of ecological corridors in the study area.

Keywords: Cerrado; Mata Atlântica; Ecological corridors; Espinhaço Mountain Range; Landscape ecology

RESUMO

O presente estudo tem como propósito analisar áreas potenciais para a implantação de Corredores Ecológicos. Atualmente a área encontra-se fragmentada e está sob os domínios de Cerrado e Mata Atlântica. Baseado no Sistema de Informações Geográficas, foram determinadas possíveis áreas, do ponto de vista ecológico e estrutural, para a implantação dos Corredores Ecológicos. Para a geração do mapa final de potencial ecológico da área, utilizou-se a metodologia de classificação por múltiplos critérios. Foram atribuídos pesos e notas às classes de vegetação, largura dos rios, altitude e declividade em seus respectivos mapas. Após a determinação dos pesos e notas, realizou-se a sobreposição dos mapas no software ArcGis 10.3. Para analise estrutural da área utilizou-se às métricas de paisagem *área média*, *formato médio* e *borda total* dos fragmentos e *conectividade média* entre os fragmentos no software Fragstats. Os resultados apontaram para uma área ecologicamente e estruturalmente viável para a implantação dos Corredores Ecológicos na área de estudo.

Palavras-chave: Cerrado; Mata Atlântica; Corredores ecológicos; Cordilheira do Espinhaço; Ecologia de paisagem

1 INTRODUCTION

Preserved natural areas have decreased in number and become restricted in tropical regions of Brazil due to human activities (LAURENCE *et al.,* 2014). Expanding agriculture and pasture are among the causes responsible for the reduction of natural areas in the Cerrado and Atlantic Forest biomes in Sourtheast Brazil (SILVA *et al.,* 2016).

The Cerrado (Brazilian savanna) originally occupied approximately 23% of the territory of Brazil (DANTAS *et al*., 2018), comprising forest, savannic and grassland vegetations (RIBEIRO; WALTER, 1998). The biome is considered the second largest in Latin America, encompassing more than 200 million hectares, and due to its favorable topography hosts the most of agricultural activities for grain and beef production in the world (SANO *et al.,* 2019). Furthermore, due to high levels of endemic and threatened biodiversity, the Cerrado is considered a global hotspot for biodiversity conservation (DANTAS *et al.,* 2018).

The Cerrado has experienced an extended reduction in its original vegetation cover in the Southeast Region of Brazil due to the expansion of land use for pasture and agriculture (SILVA *et al.,* 2016). Replacing native areas of the Cerrado with exotic pastures can influence vegetation structure (MACEDO *et al.,* 2020) and approximately half of the original coverage of the biome has been converted into planted pastures, annual crops and other land use types (BACARJI *et al.,* 2020).

The Atlantic Forest is one of the most threatened biomes in Brazil, and with a small proportion of its original area remaining its natural landscape is highly fragmented (COSTA *et al.,* 2019). Currently, the biome occupies approximately 1,300.00 km^2, which extends over 17 Brazilian states and originally occupied 15% of the national territory (LIPORACCI *et al.,* 2017). Exploitation of the Atlantic Forest began late in the 14th century with the removal of trees and by the 19th century it was partially suppressed by the development of agriculture (LIPORACCI *et al.,* 2017). Because of the high level of exploitation of natural resources, the Atlantic Forest has undergone alterations in land use, resulting in the fragmentation of its original structure.

Landscape Ecology is the science that studies the processes of fragmentation, isolation and connectivity in landscapes with the aim of determining the influence that spatial patterns have on ecological processes (SALOMÃO *et al.,* 2018). Also, landscape research serves as a tool for making sustainable and integrated decisions, and provides a perspective for obtaining information relevant to territorial planning at various scales (PREMKE *et al.,* 2016).

Landscape analyses should never disregard any spatial characteristics because their interpretation is precisely what is useful in proposals aimed at restoring the connectivity and ecological integrity of areas of interest for the maintenance of ecological functions that provide ecosystem services (NORIEGA *et al.,* 2017). Such interpretation is based on quantitative data and facilitates a better understanding of patterns and process for the analysis and prediction of future scenarios and the mitigation of existing problems (PREMKE *et al.,* 2016).

There is, however, a lack of quantitative methods capable of assessing ecological connectivity and fragmentation on a regional scale (MINASIEWICZ *et al.,* 2018). In this context, spatial assessment based on geographic information system (GIS) and multicriteria analysis (FERRETI; POMARICO, 2013) are needed to make this process effective. The development of systematic studies of landscape fragmentation based on GIS and multicriteria data analysis will allow the identification of areas with ecological and structural potential and allow delimiting them as priority areas for preservation. Such studies will also contribute to landscape monitoring and strategic planning (SILVA *et al*., 2017).

One way to maintain dispersal and migration of organisms has been the creation of ecological corridors as part of strategic planning (FERNANDES; FERNANDES*,* 2017). In the context of spatial pattern connectivity, ecological corridors can guarantee functionality with respect to mobility since they provide links of connectivity within a heterogeneous territory (PEREIRA *et al.,* 2007).

The marked increase in socio-economic activity in the Cerrado and Atlantic Forest has favored large-scale landscape changes to these biomes, resulting in many highly fragmented areas in Southeast Brazil. In the region of Conceição do Mato Dentro, in the state of Minas Gerais, Southeast, Brazil, the area of transition between the Cerrado and Atlantic Forest domains has been largely deforested for pasture, resulting in a highly fragmented landscape.

Motivation for the development of the present study came from concerns about the loss of biological diversity in this region. Thus, the aim was to promote reintegration of the local ecosystem by evaluating the ecological and structural potential of areas of Atlantic Forest and Cerrado in the region, through the use of GIS, for the implementation of ecological corridors, and contribute to the development of guidelines for planning actions and interventions in that fragmented areas.

2 MATERIAL AND METHODS

2.1 Delimitation of the study area

The study area is located in the municipality of Conceição do Mato Dentro in the state of Minas Gerais, Southeast, Brazil. According to the Koppen – Geiger climatic classification, the climate of the region is tropical of altitude, which is represented by elevations above 500 m, mild temperatures between 18ºC and 26ºC, and an annual thermal amplitude of between 7ºC and 9ºC. The elevation of the area varies from 679 to 1472 m and the landscape comprises an area of transition between two Brazilian domains — the Cerrado and the Atlantic Forest.

The Cerrado domain is represented by a high-altitude rupestrian environment with rocky outcrops (campos rupestres). Ribeiro and Walter (1998) proposed classifying rupestrian phytophysiognomies as campo rupestre and cerrado rupestre. These two phytophysiognomies are generally located on rocky outcrops at high altitudes, but differ in that campo rupestre has only 5% tree cover, while the rupestrian cerrado belongs to savanna formations, whose tree cover ranges from 5% to 70% (PINTO *et al.,* 2009). Thus, several studies in the Cerrado biome have generalized the vegetation located in rupestrian environments, considering them such only because they are located on rocky outcrops and at high altitudes (RIBEIRO; WALTER, 1998).

2.2 Identification of areas with ecological potential for the implementation of ecological corridors

This step consists of identifying areas of ecological potential and defining factors for choosing them. Firstly, a map of ecological potential was generated for the study area using the multi-criteria classification methodology called Weighted Linear Combination (WLC) (DONHA *et al.,* 2006). This method consists of multiplying each factor by its weight, and then summing the results; this calculation is done pixel by pixel, thus generating a very detailed final map (DONHA *et al.,* 2006).

The model chosen for combining maps was the overlap model using index or weighted average when the maps are analyzed together by means of a combination of importance weights for factors and notes for the classes, according to the judgment of their influence on the phenomena being modeled (MEDEIROS; CESTARO, 2020). Factors were chosen according to literature review. The higher the weight of a factor and note of a class the greater the degree of importance of the factor and the class for implementing ecological corridors. Weights from 0 to 100% were assigned to factors, while notes of 0 to 3 were assigned to classes. Notes below 2 represented areas with low and medium ecological potential, while scores above 2 represented areas with high and very high ecological potential (Table 1).

Table 1 – Quantification of ecological potential for the chosen factor

Factor	Class	Weight (%)	Note	Potential
Vegetation	Arboreal	40	3	Very high
	Shrub		3	Very high
	Herbaceous		1	Medium
	Exposed soil		0	Low
River width	0 to 92.40 m	40	3	Very high
	92.40 to 238.31 m		2	High
	238.31 to 515.53 m		1	Medium
	515.53 to 1240.29 m		0	Low
Altitude	679.14 to 834.46 m	10	3	Low
	834.46 to 1011.50 m		2	Low
	1011.50 to 1210.28 m		1	Medium
	1210.28 to 1471.19 m		1	High
Declivity	0 to 25º	10	1	Low
	25º to 45º		2	Medium
	45º to 59º		3	Very high
	59º to 125º		3	Very high

Source: Authors (2016)

Weights were attributed to each factor through related bibliographic analysis studies obtained according to Andrade *et al.* (2017). According to this author, vegetation and hydrography are the most important factors for determining suitable areas for the implementation of corridors since the conservation of both minimizes the effects of erosion and silting in watercourses and helps to control the water regime of rivers.

The factor 'vegetation' was classified using a vegetation map of the study area that indicates arboreal (Atlantic Forest), herbaceous and shrub (Cerrado) vegetation, with arboreal and shrub areas having the greatest ecological potential (Table 1) (FERRAZ *et al.,* 2020). The interval values used for classifying the factors 'river width', 'altitude' and 'declivity' were analyzed using histograms for maps of hydrography, altitude and declivity, respectively, of the region, and are shown in Table 1.

For the factor 'river width', areas with narrower river widths were considered to have greater ecological potential because they have lower environmental risks and can facilitate the implementation of ecological corridors (FERRAZ *et al.,* 2020). Thus, very high and high ecological potential were attributed to areas with river widths of less than 238.31 meters, and medium and low ecological potential for areas with river widths of more than 238.31 meters (Table 1).

Classification of the factors 'altitude' and 'declivity' was done according to Lei do Código Florestal (Forest Code Law 12.651/2012) on the delimitation of Áreas de Preservação Permanente (APP; permanent preservation areas). According to Guidotti *et al.* (2020), APPs are areas of ecological potential because they promote habitats for fauna, protect water bodies from sedimentation and contamination from pollutants from economic activities, and serve as ecological corridors interconnecting large forests.

According to the forest code, areas above 1800 meters and hillsides with declivities greater than 45º are delimited as APPs. This delimitation indicated that altitude classes below 1011.50 meters were areas of low ecological potential and areas above 1011.50 meters were areas of medium and high ecological potential (Table 1). For declivity, areas with declivities of up to 45º were of low and medium ecological potential, while areas with declivities greater than 45º were of very high ecological potential (Table 1).

After determining the factors with their respective weights, and notes for each class, the maps were overlapped using ArcGis 10.3 software, and a final map of the ecological potential of the study area was generated.

2.3 Identification of landscape structure for the implementation of ecological corridors

To determine structurally favorable areas for the implementation of ecological corridors, the study area was divided into 13 sub-areas (quadrants) of approximately 702.28 ha each. The structure of the landscape was determined by analysis of the spatial configuration of each quadrant from the calculation of landscape metrics in Fragstats 4.2 software.

The landscape metrics *mean fragment area* (area_mn), *total border* (TE), *mean connectivity* (connect_mn) and *mean shape* (shape_mn) were calculated with Fragstats 4.2 software to analyze the structural potential of each sub-area. A distance of 100 meters was used for calculating edge and connectivity. Considering that areas with fragments that are larger and have less total border (CABACINHA *et al.,* 2010), more connectivity and shapes varying between 1 and 2 are ideal for conservation and the implementation of ecological corridors (STEWART, 2019), they were assigned classification interval values for the landscape metrics identified in Table 2. Since there was little variation among the intervals of the calculated means, the values were quantified as of high and low structural potential (Table 2).

Table 2 - Quantification of structural potential for the landscape metrics

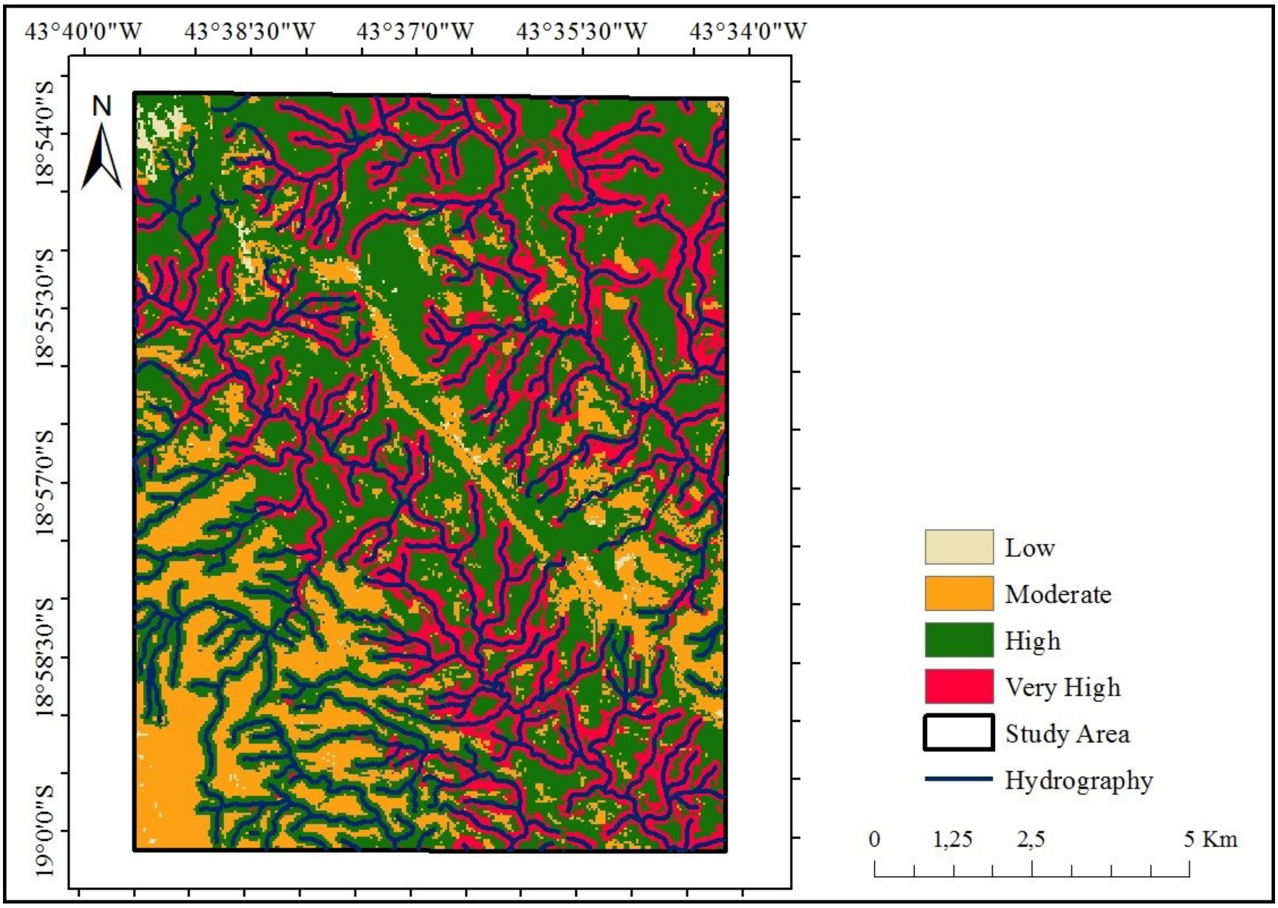
Metric	Value	Structural potential
Area_mn	<0	Low
	>0<1	High
Total border (TE)	>405750.0	Low
	<405750.0	High
Connect_mn	<0.7831	Low
	>0.7831	High
Shape_mn	<1	High
	1	Low

Source: Authors (2016)

3 RESULTS

The figure 1 shows the final map of ecological potential for the implementation of ecological corridors. Note that these are areas of native tree and/or shrub vegetation associated with watercourses with hydrographic proximities of between 92.40 m and 238.31 m, declivities of between 45° and 125° and altitudes above 1210.28 m (Fig. 1).

Figure 1 – Ecological potential map for implementation of ecological corridors in the municipality of Conceição do Mato Dentro, state of Minas Gerais, Brazil



Source: Authors (2016)

The table 3 shows the sub-areas with high structural potential for the implementation of ecological corridors. It can be seen that all quadrants had a mean area between 0 and 1 and a mean shape equal to 1. Thus, considering only total border below 405750.0 and mean connectivity among fragments above 0.7831, areas with structural potential can be seen to be located in quadrants 1,3,4,5,6,10 and 13 (Table 3).

Table 3 – Landscape metrics in the sub-areas studied

	Metrics			
Sub-areas	**Area_mn(ha)**	**shape**	**te**	**Connect**
1	0.1101	1.0000	376260.0	0.9169
2	0.1017	1.0000	460710.0	0.7627
3	0.1038	1.0000	431280.0	0.9219
4	0.1256	1.0000	381630.0	0.8634
5	0.1073	1.0000	405750.0	0.7919
6	0.1030	1.0000	403020.0	0.7915
7	0.1062	1.0000	446100.0	0.6768
8	0.1124	1.0000	415890.0	0.7514
9	0.1241	1.0000	410970.0	0.7831
10	0.1037	1.0000	404870.0	0.7959
11	0.1139	1.0000	385290.0	0.6895
12	0.1052	1.0000	397350.0	0.6616
13	0.1175	1.0000	367950.0	0.9762

Source: Authors (2016)

4 DISCUSSION

The map of areas of ecological potential within the study area reveals that all vegetation classes are associated with the presence of water bodies. This finding makes the area important for conservation since, from an ecological point of view, riparian vegetation contributes to the equilibrium of the environment and the resilience of the hydrographic basin (LAPOLA; FOWLER, 2008).

In its entirety, the riparian ecosystem includes the dynamics of the riparian zone, its vegetation and its interactions, and facilitates direct runoff in micro-basins, increased storage capacity, maintenance of water quality (buffer effect), stability of river banks, thermal equilibrium of water and the formation of ecological corridors (ATTANASIO *et al.*, 2012). The implementation of ecological corridors in riparian areas is favored because they, when well conserved, provide connectivity (BRESSIANI; SCHMIDT, 2016), which facilitates gene flow and the displacement of local fauna (FERRAZ; VETTORAZZI, 2003).

With regard to vegetation, ecological corridors are expected to be implemented areas with native tree and shrub vegetation; vegetation classes where ecological potential was considered very high. The high ecological potential of these vegetation classes is due to the greater phytosociological composition and structure of the arboreal-shrub stratum, with regards to the number of species, diversity and cover of vegetation, when compared to the herbaceous stratum (MULLER; WAECHTER, 1991). However, native herbaceous species are essential for the diversity of fragmented forests because they act as a source of propagules in forest regeneration (SILVA *et al.,* 2009).

The medium ecological potential of the herbaceous class for the implementation of ecological corridors is due to the presence of exotic herbaceous species from the use of areas for pasture. Exotic grasses may impair the establishment and development of native species due to competition for nutritional resources of the soil, and thus change plant morphophysiology and the quantity and quality of nutrients absorbed by plants (PIRES *et al.,* 2012). Therefore, it is recommended that ecological corridors be implemented in these areas only if there is intervention to control exotic grasses through recovery projects.

Analysis of the ecological potential for the implementation of corridors in areas with hydrographic proximity revealed that the hydrographic network is well distributed in the study area; however, the implementation of corridors between 0 and 92 meters and 92 to 220 meters is recommended. These values are attributed to the geomorphology of the study area, with most of the native vegetation occurring in areas with steep declivity, and although there has been no flooding in these areas, the risk is high. Geomorphological studies associate the risk of flooding with river width, declivity and sediment load. According to Mello *et al*., 2016, the greater the river width, the greater the sediment load. Therefore, if there is flooding in areas where the rivers are wider, there will be greater loss of vegetation through the processes of erosion and sedimentation.

The map of ecological potential reveals that APP areas are found in areas of higher altitudes and with greater declivities. The implementation of ecological corridors in areas of APPs is, therefore, suggested since, from an ecological point of view, the preservation of APPs is of fundamental importance to the management of watersheds because they are able to control soil erosion and water quality, and thus assure stabilization of the river banks and minimize accumulation of sediment from the highest parts of the terrain (EUGÊNIO *et al.,* 2011). According to Borges *et al.* (2011), interventions in these areas to open new agricultural areas will compromise, in the future, the replacement of water in aquifers, the quality of surface and underground water, and soil retention.

Another important factor for the implementation of corridors in areas of APPs is the wide distribution of the hydrographic network in these areas. The rivers present in higher areas are considered natural reservoirs of the ecosystem because they transfer water to the lower areas (TAMBOSI *et al.,* 2015). In this way, lower areas depend greatly on the quality of the water transferred from higher areas. The forests located in these areas are ecologically important since they are able to influence the quantity, form and quantity of water that will be transported to the rest of the basin (ORTIZ *et al.,* 2018).

The areas that exhibited low ecological potential for the implementation of ecological corridors were considered so mainly because they are areas of exposed soil and further from water bodies. When soil is impacted, depending on the intensity of the removal of vegetation cover, an area may or may not be recovered (RODRIGUES *et al.,* 2006). However, these areas were observed to have very degraded soil due to the impacts of agricultural activity, and thus may have lost their capacity for regeneration (CORRÊA; MELO, 1998).

Relating structural potential to the size and shape of fragments, all areas were noted to possess small irregular fragments. Although small fragments possess smaller populations and are more susceptible to external factors, when they are dispersed in the matrix they can be structurally important for the implementation of ecological corridors since they can facilitate the displacement of animals and contribute to the recolonization of areas in the process of natural regeneration (MUCHAILH, 2010).

With regard to shape, Cabacinha *et al.* (2010) affirmed that values below 1 refer to more circular fragments, which are less elongated and less influenced by the edge effect. Circular areas minimize the area-edge relationship, with the center being further away from the edge when compared to elongated shapes. Thus, the more a fragment is cut, the greater the contact area between the forest and the matrix, and the larger the contact area the greater the edge effect (SANTIAGO *et al.,* 2007). Analysis of shape for determining structural potential of the study area revealed that the whole area possessed elongated (or irregular) fragments, which implies, for this study, that although the area possesses sub-areas with structural potential for the implementation of ecological corridors, all areas are under the border effect.

Areas with greater structural potential for the implementation of ecological corridors were observed to have greater connectivity among fragments and less total border. Regarding connectivity, the higher the mean connectivity among fragments the greater the potential dispersal and colonization, thus assuring greater the gene flow among populations (TAYLOR *et al.,* 1993). Areas with lower structural potential possessed lower connectivity because greater isolation limits the dispersion of species and reduces gene flow, which can result in inbreeding and loss of diversity (GIBBS, 2001). In addition, most of the fragments must be considered small, and populations isolated in very small fragments will have even lower persistence due to reduced population sizes and the effects of stochastic processes (MEDINA; VIEIRA, 2007).

With respect to total border, areas that possess greater mean border are likely to experience greater influence from external factors. They are also likely to possess a shorter distance between the interior (nucleus) and the edge, which means a reduction in the central area that is sufficient to support species (NASCIMENTO; LAURANCE, 2006).

5 CONCLUSIONS

The use of remote sensing together with the application of landscape metrics has effectively supported the proposal to implement ecological corridors. The routes of the corridors permitted the identification of areas with structural and ecological potential. Additionally, the results indicated the extreme necessity of implementing ecological corridors in the study area since even though it has high ecological potential, structurally the area is quite affected by small irregular fragments and edge effects.

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