REVISTA FLORESTA Engenharia Florestal

ISSN 1982-4688
Edição 54
Universidade Federal do Paraná
Setor de Ciências Agrárias

CONNECTIVITY OF THE HABITAT OF TAPIRUS TERRESTRIS (LINNAEUS, 1758) IN THE MATA DOS GODOY STATE PARK AND ITS BUFFER ZONE

Adilson Wandembruck[1], Gisley Paula Vidolin[2], Daniela Biondi[3]

[1]Instituto Água e Terra, Ger. de Fiscalização e Monitoramento, DMT, Curitiba – PR, Brasil – adilsonwandembruck@iat.pr.gov.br
[2]Fundação de Pesquisas Florestais do Paraná, Universidade Federal do Paraná, Curitiba – PR, Brasil – paulavidolin@gmail.com
[3]Universidade Federal do Paraná, Departamento de Ciências Florestais, Curitiba – PR, Brasil – dbiondi@ufpr.br

Received for publication: .13/07/2023 – Accepted for publication: 05/10/2023

Resumo

Conectividade do habitat de Tapirus terrestris (Linnaeus, 1758) no Parque Estadual Mata dos Godoy e em sua Zona de Amortecimento. Este estudo teve como objetivo avaliar a conectividade funcional do Parque Estadual Mata dos Godoy (PEMG) e da sua zona de amortecimento (ZA), com área de 38.950,45 ha que abrange parte dos municípios de Londrina, Arapongas e Apucarana, identificando manchas florestais que possuem maior capacidade conectiva entre si e que são utilizadas por *Tapirus terrestris*. Utilizou-se o *shapefile* do uso e ocupação do solo disponibilizado pelo Instituto Água e Terra (IAT), a partir do qual se procedeu ao recorte espacial do mosaico paisagístico estudado. As análises da estrutura da paisagem foram realizadas mediante o uso do ArcGis 10.3 e as de conectividade funcional mediante o uso do *Conefor Sensinode* 2.6. Este recorte resultou na análise funcional de 266 remanescentes de vegetação nativa com grande amplitude de tamanhos de áreas, e que perfazem 28,75% (11.209,74 ha) do mosaico paisagístico estudado. Destas manchas, 255 (95,86%) foram categorizadas como de baixa conectividade; 10 (3,76%) de média conectividade e apenas uma (0,38%) de alta conectividade. O índice dIIC para a mancha de prioridade alta (=78,50%) indica que, embora as condições da paisagem atual sejam bem diferentes da primitiva, ainda assim é utilizável por *Tapirus terrestris*, e que a mancha de habitat mais importante como conectora funcional da paisagem, considerando a capacidade de dispersão de 2.000 m da espécie é aquela que engloba o PEMG. Como conclusão tem-se que a ZA do PEMG, embora possua matriz predominante antrópica, apresenta índices que demostram que possui um bom grau de conectividade, a qual é mantida basicamente por uma única mancha de habitat, que inclui o PEMG.
Palavras-chave: índices de conectividade, fragmentação florestal, unidade de conservação, Conefor.

Abstract

This study aimed to assess the functional connectivity of Mata dos Godoy State Park (PEMG) and its buffer zone (ZA), covering an area of 38,950.45 hectares, spanning parts of the municipalities of Londrina, Arapongas, and Apucarana. The objective was to identify forest patches with enhanced connective capacity among themselves, which are utilized by *Tapirus terrestris*. The land use and land cover shapefile provided by the Instituto Água e Terra (IAT) was employed for spatial delineation of the studied landscape mosaic. Landscape structure analyses were conducted using ArcGIS 10.3, and functional connectivity assessments were carried out using Conefor Sensinode 2.6. This spatial delineation resulted in the functional analysis of 266 remnants of native vegetation, encompassing a wide range of area sizes, accounting for 28.75% (11,209.74 hectares) of the studied landscape mosaic. Among these patches, 255 (95.86%) were categorized as having low connectivity, 10 (3.76%) as having moderate connectivity, and only one (0.38%) as having high connectivity. The dIIC index for the high-priority patch (=78.50%) indicates that, despite the current landscape conditions differing significantly from the original state, it remains suitable for *Tapirus terrestris*. The most crucial habitat patch for functional landscape connectivity, considering the species' dispersal capacity of 2,000 meters, is the one encompassing PEMG. In conclusion, despite having a predominantly anthropogenic matrix, the buffer zone (ZA) of PEMG exhibits connectivity indices demonstrating a substantial degree of connectivity, primarily maintained by a single habitat patch that includes PEMG.
Keywords: connectivity indices, forest fragmentation, conservation unit, Conefor.

INTRODUÇÃO

Landscape connectivity has a strong influence on the maintenance of free-living animal populations, and the loss of connectivity can compromise the metapopulation scenario, resulting in the genetic isolation of these populations in patches, intensifying the phenomena of genetic drift and inbreeding (FRANKHAM *et al.*, 2008) and, consequently, stochastic extinctions.

Given the importance of such analyses, various software enable studies that depict the degree of landscape connectivity through metrics or connectivity indices. The interpretation of these indices allows us to demonstrate how the landscape is used by species based on their movement characteristics and exploration behaviors within the area, as well as their search for food. This reveals the complexity of relationships that are established, thus confirming the close relationship between movement and the use of habitat patches.

One of the main softwares developed with this focus is the Conefor Sensinode, created by Saura and Torné (2009), who conceived it as a tool for spatial ecology analysis. It is based on graph theory to quantify the importance of habitat patches for landscape connectivity. A graph is a set of nodes or vertices connected to each other by links (connections), and in this concept, this program evaluates the landscape as a set (graph) where its elements, nodes (patches), may or may not be functionally connected (links) based on a pre-established threshold (distance). In this way, Conefor allows for the identification, quantification, and prioritization of habitat patches and connections for the maintenance or improvement of landscape connectivity.

This software has been used in various landscape connectivity studies, such as the one by Santini *et al.* (2016), which found that protected areas in Brazil play a significant role in promoting continental connectivity; the study by Saura *et al.* (2017), which assessed the connectivity of protected areas on a global scale and identified that protected area networks exhibit intermediate levels of connectivity for most terrestrial species, with disparities in connectivity levels for the Atlantic Forest, Cerrado, and Caatinga regions; and also the study by Castro *et al.* (2020), which analyzed the connection between forest fragments in the Xingu Endemism Area in Eastern Amazon.

Another highly interesting study was conducted by Du *et al.* (2023), in which they used the MSPA-MCR metric from Conefor to construct an ecological network in the Yanqing district of Beijing, China, tracking 66 ecological corridors spanning a total length of 1,057.18 km.

Conefor establishes connections between habitat patches based on a pre-established distance threshold, which is well-suited for the use of species-landscape. Species-landscape are considered those that possess a set of complementary ecological characteristics, utilize large ecologically diverse areas, and play significant roles in the structure and function of ecosystems, based on the identification of five criteria: species area requirements, habitat heterogeneity, vulnerability, ecological functionality, and socioeconomic importance (COPPOLILLO *et al.*, 2004). Based on these premises, *Tapirus terrestris* (South American tapir) (Linnaeus, 1758) can be used as a species-landscape since it meets all five established criteria. It is considered an endangered species in the State of Paraná, Brazil, classified as 'in danger' (PARANÁ, 2010). It primarily inhabits forested environments and wetlands, playing fundamental ecological roles such as predation, seed dispersal, and nutrient cycling (GONZÁLEZ *et al.*, 2021; ÁLVIZ *et al.*, 2023). Mosquera-Guerra *et al.* (2023) employed a multispecies approach, including *Tapirus terrestris* as a landscape species for modeling corridors in the Colombian savanna.

The movements of this species between different types of environments can be facilitated or restricted depending on the configuration of the landscape mosaic. In this sense, the interactions between the behavioral processes of the species (movements) and the physical structure of the landscape can be used as indicators of the functionality of these mosaics (VIDOLIN *et al.*, 2013).

Several other studies with similar objectives have used species of the *Tapirus* genus as indicators of landscape functional connectivity. For example, Alonso *et al.* (2017) conducted connectivity analyses of *Tapirus pinchaque* habitats to propose habitat restoration within the Podocarpus-Yacuambi micro-corridor in Ecuador. Carrillo *et al.* (2019) also assessed landscape connectivity for the same species in Mexico. Similarly, Iezzi *et al.* (2022) assessed the contribution of remnants of Atlantic Forest habitat in Argentina for landscape connectivity and habitat availability for five species of mammals sensitive to landscape transformation, including *Tapirus terrestris*. In Brazil, among the studies on *Tapirus terrestris* that provide information about the influences of landscape structure and functionality on habitat use dynamics by the species, are the works of Vidolin *et al.* (2013).

Studies on landscape functional connectivity provide valuable information that can be used for various purposes, ranging from identifying areas to be restored to reestablish the landscape connectivity network, to identifying priority conservation areas for species or necessary existing corridors within landscape mosaics. Also, the establishment of conservation zones or buffer areas around protected areas, taking into consideration these species-landscape relationships, allows for planning the conservation of both remaining patches and restoration in areas where land use has substantially affected functionality due to forest cover loss. This approach represents a cost-effective strategy, guiding necessary actions for conservation unit managers to implement measures to maintain or restore landscape connectivity.

The reestablishment of connectivity becomes even more important in regions where land prices are high and suitable for agriculture, as is the case in the study area. In such regions, available financial resources can be directed towards the protection of patches with the best characteristics of landscape connectivity functionality, thereby creating better conditions for species to utilize the landscape beyond the boundaries established by the conservation unit itself. This model contributes to increasing the gene flow of the species that the conservation unit (UC) aims to protect while also promoting and enhancing the achievement of the objectives that led to the creation of the conservation unit.

Within this context, this study aimed to assess the functional connectivity of the buffer zone of the Mata dos Godoy State Park (PEMG) in Paraná, where the species *Tapirus terrestris* has confirmed occurrences (FLESHER; MEDICI, 2022), identifying priority habitats as well as those with higher connective capacity between habitat patches used by the species. It is worth noting that the Mata dos Godoy State Park (PEMG) is considered one of the last natural reserves of native forest in northern Paraná, and it still houses species of fauna and flora that are threatened with extinction (SILVA *et al.*, 2019). This underscores the importance of conducting studies that can support conservation efforts in this legally protected area.

MATERIAL AND METHODS

Study Area

This study was conducted in the landscape mosaic formed by the Mata dos Godoy State Park (PEMG) and its buffer zone (ZA), covering an area of 38,950.45 hectares. Within this total, 680.11 hectares comprise the PEMG itself. This landscape mosaic (Figure 1), located in the phytogeographical region of the Seasonal Semideciduous Forest, is situated in northern Paraná, with a centroid area at geographic coordinates 23°28'39.809" South latitude and 51°16'08.095" West longitude, spanning parts of the municipalities of Londrina, Arapongas, and Apucarana.

The area is highly fragmented, characterized by anthropogenic matrix, and predominantly composed of agricultural lands with annual crops (especially grains like soybean, corn, and wheat on a larger scale), livestock farming, forestry, and built-up areas. Forest cover is significantly reduced, with only a few remnants of the original native vegetation remaining, often in altered conditions and varying in size. In addition to the low forest cover, there is a general absence of riparian buffer zones along watercourses in many properties in the region. The areas in better conservation and connectivity condition mainly include the PEMG itself and some contiguous forested areas located primarily on the eastern boundaries of the Conservation Unit.

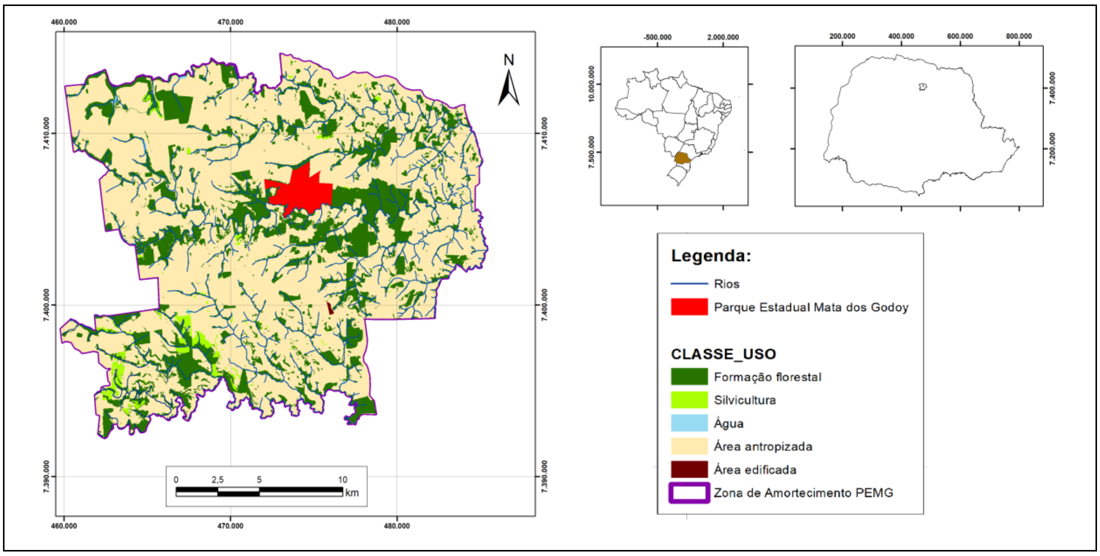

Figure 1. Location of the study area and its corresponding landscape mosaic.
Figura 1. Localização da área de estudo e respectivo mosaico paisagístico.

Methodological Procedures

Database - Land Cover and Land Use Mapping

All metrics or functional connectivity indices were calculated using maps of native vegetation obtained from the Instituto Água e Terra – IAT, which maintains a database of environmental data available for the State (IAT, 2022).

Therefore, the selected database for the study was the mapping of native forest vegetation in Paraná, prepared by the Geographic Intelligence and Information Unit of this Institute, which was completed in May 2021 and made available in 2022 in shapefile format for public consultation (IAT/ NGI, 2022). This mapping for the year 2021 updated the data on native vegetation for the state of Paraná, which dated back to 2019, using Sentinel 2020/2021 and Planet 2021 images.

Using the ArcGIS 10.3 software, the shapefile was spatially clipped to define the landscape mosaic considered as the study area. The mosaic's configuration was achieved by overlaying the vector of buffer zone boundaries on the mapping of native forest vegetation (IAT/ NGI, 2022), resulting in a vector layer representing the intersection between the two. This clipped area covers 38,950.45 hectares, containing 266 native vegetation fragments, which constitute 26.69% (10,395.85 hectares) of the studied landscape mosaic.

Landscape Analyses - Structure and Functional Connectivity

For the analysis of landscape structure, several area-based indices were obtained using ArcGIS 10.3. These indices are commonly used to quantify landscape composition and enable inferences about the dynamics of animal populations, as the size of an area conditions species distribution and affects resource availability. The indices used were: (i) CA (área of class) - the area of all patches of the same class in hectares; (ii) PLAND (percentage of landscape) - the percentage of the landscape occupied by patches of the same class; (iii) NP - the number of patches of the same class in the landscape. These metrics were exclusively calculated for the Native Forest Formation class, as this class represents the most suitable habitat for the species in question (tapir).

Functional connectivity analyses were conducted using the Conefor Sensinode 2.6 program. For this purpose, the studied landscape mosaic was represented as a graph, where all habitat patches scattered across this landscape were depicted as nodes. These nodes contain various attributes of these patches that influence the sizes of species populations that rely on these areas for survival, such as size and environmental quality. The values of these attributes are used in formulas to calculate landscape connectivity metrics

Meanwhile, the connections between each node represent the possibilities for individuals of the target species to move between two habitat patches. These possibilities can be determined by various factors, including the distance between these patches, the type of matrix existing between the patches, and the dispersal capacity of the species under consideration.

To generate the input files containing node information and connection distances from the forest remnants map, an ArcGIS extension developed specifically for this purpose, Conefor_inputs_10, was used. Two input files in txt format (node file and connection file) and a shapefile were then generated for insertion and processing with the Conefor program.

Two types of connection models were calculated: binary and probabilistic. Binary indices represent the possibility of species movement between two fragments, providing information about connectivity structure. The data resulting from the Conefor analysis in this case are either yes or no and 1 or 0. Meanwhile, probabilistic indices indicate the likely connectivity between two fragments based on landscape structure and a species' ability to move through the matrix, providing information about functional connectivity (PASCUAL-HORTAL; SAURA, 2006; SAURA; PASCUAL-HORTAL, 2007; SAURA; RUBIO, 2010).

From the data processing (input files constituted by the map of forest remnants) by Conefor the map was generated with the values of importance incorporated from the patches for landscape connectivity. The indices calculated based on the literature (PASCUAL-HORTAL; SAURA, 2006; SAURA; PASCUAL-HORTAL, 2007; SAURA; RUBIO, 2010; SAURA; TORNÉ, 2012) were: (i) Number of links or connections (NL), where a higher number of links indicates greater landscape connectivity; (ii) Probability of connectivity (PC), which indicates the probability of functional connection between pairs of nodes and varies between 0 (lower connectivity; nodes are not connected to each other) and 1 (higher connectivity; when the entire landscape is occupied by suitable habitat); (iii) Equivalent Connectivity (EC_IIC), defined as the size of a single maximally connected habitat fragment that would provide the same IIC metric value as the actual habitat pattern in the landscape; (iv) Percentage of the total habitat attribute (in this case, area) (dA) that corresponds to the attribute at that node; and (v) Integral Index of Connectivity (dIIC), which is a binary index that considers the existence or non-existence of connectivity between two fragments, allowing the evaluation of a fragment's importance for overall landscape connectivity or for connectivity between fragment combinations. The dIIC ranges from 0 to 1 and increases with connectivity. The values of its three fractions, dIICintra, dIICflux, and dIICconnector, were also calculated. dIICintra corresponds to the contribution of the fragment in terms of connectivity within the fragment itself (interpatch); dIICflux represents how well the fragment is connected to other fragments in the landscape; dIICconnector assesses the contribution of a fragment or link to connectivity between other fragments, acting as a connecting element or stepping stones.

Focused species

Tapirus terrestris (tapir) was the selected species for determining the probable connections between fragments based on its ability to move through the matrix.

The tapir is among the main mammals occurring in PEMG and is an important landscape species (COPPOLILLO *et al.*, 2004) since it possesses a set of complementary ecological characteristics, uses large ecologically diverse areas, has the ability to traverse the matrix in fragmented landscapes, and plays significant roles in ecosystem structure and function (VIDOLIN *et al.*, 2013).

From the forest fragment map, a distance map was generated in the numerical model, considering the daily travel distances of this tapir, which include movements ranging from the search for water and food resources to migration and nomadism.

The greatest average distance covered daily by tapirs for movement between PEMG and three adjacent fragments, which is approximately 1,850 meters in open fields in search of resources (VIDOLIN *et al.*, 2013), was used. To facilitate data processing by the program, this distance was rounded to 2,000 meters.

The default value of 0.5 was adopted to convert distance into dispersal probability, reflecting half of the maximum probability of movement considered for the species between the areas under analysis. This value reflects the probability of the species using or not using the patches near those identified as high priority.

RESULTS

The clip generated on the map of native forests in Paraná, considering the boundaries of PEMG and its buffer zone, resulted in the functional analysis of 266 patches of native vegetation (NP = 266), with a wide range of area sizes, totaling 28.75% (10,395.85 ha) of the studied landscape mosaic. Therefore, the matrix is predominantly anthropogenic. The area size of the classes (CA) and the percentage of occupancy in the landscape (PLAND) are presented in Table 1.

Table 1. Area of classes (CA) and their respective percentages of landscape occupancy (PLAND) in PEMG and its buffer zone.
Tabela 1. Área das classes (CA) e respectivos percentuais de ocupação na paisagem (PLAND) do PEMG e da sua zona de amortecimento.

Classes of mosaic composition	CA (ha)	PLAND (%)
Native Forest Formation	10.395,85*	26,69
Silviculture	566,22	1,45
Water	134,76	0,35
Anthropized Area	27.838,84	71,47
Built-up Area	14,78	0,04
Total	**38.950,45**	**100**

Legend: CA, area of all patches of the class in ha; PLAND, percentage of occupancy of patches of the same class in the landscape; NP, number of patches of the class existing in the landscape. * This class includes PEMG.
Silviculture/Anthropized Area/Built-up Area were kept as separate classes, according to the original database (IAT/ NGI, 2022), as *Tapirus terrestris* will exhibit different behavior in each of them, in terms of 'use' or 'restriction of use' of the area.

Of these 266 patches of native forest vegetation, 212 patches are smaller than 10 ha, and only two patches account for nearly 60% of the total area (Table 2).

Out of 35,245 link processes between patches, 2,142 links or connections were indicated (NL = 2,142). Out of the 266 habitat patches, 255 have at least one link to another habitat patch within this search radius, meaning that 95.86% of the patches have a strong probability of having functional connections for *Tapirus terrestris*.

Table 2. Distribution of the 266 patches of native forest vegetation in area size classes, area (ha) and percentage occupied in the studied landscape.
Tabela 2. Distribuição das 266 manchas de vegetação de floresta nativa em classes de tamanho de área, a área (ha) e a porcentagem ocupada na paisagem estudada.

Class (ha)	Area size (ha)	% of landscape occupancy
≤ 10	597,76	5,75
> 10 e ≤ 50	558,26	5,37
> 50 e ≤ 200	1.394,08	13,41
> 200 e ≤ 1000	1.623,83	15,62
> 1000	6.221,92	59,85
Total	**10.395,85**	**100**

Of these 266 patches studied, considering the five classes of connectivity importance categorization, 255 (95.86%) were categorized as low connectivity (classes I and II); 10 (3.76%) were classified as medium connectivity (classes III and IV), and only one (0.38%) as high connectivity (class V). For patches of low connectivity, the dIIC values ranged from 0.00000 to 1.567356; medium connectivity from 1.567357 to 23.282380, and high connectivity from 23.282381 to 78.505250 (Table 3).

REVISTA FLORESTA Engenharia Florestal
ISSN 1982-4688
Edição 54
Universidade Federal do Paraná
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Table 3. Integral Index of Connectivity (dIIC) applied in the study area, classifying the degree of connectivity of habitat patches into five classes.
Tabela 3. Índice Integral de Conectividade (dIIC) aplicado na área de estudo, classificando o grau de conectividade das manchas de habitat em cinco classes.

Classes	Classes of dIIC	NP	PLAND	dA	Area (ha)	dIIC	*Links*
I	0.000000 a 0.463760	246	92,48	11,12	1.156,01	0,46	1.569
II	0.463761 a 1.567356	9	3,38	6,27	651,82	1,56	129
III	1.567357 a 4.626343	8	3,01	14,26	1.482,45	4,62	191
IV	4.626344 a 23.282380	2	0,75	25,75	2.676,93	23,28	115
V	23.282381 a 78.505250	1	0,38	42,60	4.428,64	78,50	138
	Total	**266**	**100**	**100**	**10.395,85**	**-**	**2.142**

Legend: dIIC, Integral Index of Connectivity; NP, number of patches of the class present in the landscape; PLAND, percentage of occupation of patches of the same class in the landscape; dA, percentage of the total habitat attribute (in this case, area); Links, number of connections.

The most important habitat patch as a functional connector of the landscape, considering *Tapirus terrestris*' daily displacement capacity of 2,000 meters, is located in the central part of the landscape mosaic and encompasses the Mata dos Godoy State Park. This patch has a percentage of the total habitat area corresponding to dA = 42.60% and dIIC = 78.50, meaning it represents the most important node for connectivity and habitat availability (Table 3).

The partitioned values of dIIC into fractions measuring internal connectivity (interpatch), connections with other habitat patches, and patches acting as stepping stones resulted in dIICintra = 34.33 (81%), dIICflux = 40.00 (34.46%), and dIICconnector = 4.17 (72.46%), respectively. This habitat patch has 138 links with a probability of functional connection exceeding 50% (PC>0.5) with other patches, indicating its importance as a connector node.

Secondarily, the patches in the northern and southern portions also play a relevant role in landscape connectivity, but with less significant importance indices in terms of values. The patch located in the southern portion, indicated as having medium priority, covers 1,933.87 ha, dA = 17.25%, and dIIC = 23.28, with partitions of dIICintra = 5.63, dIICflux = 17.38, and dIICconnector = 0.27, contributing to 13.41%, 14.97%, and 4.69% to interpatch connectivity, connections with other habitat patches in the landscape, and connectivity between other fragments, respectively. This patch has 57 connection links.

The other patch indicated as having medium priority, located in the northern portion, covers 952.66 ha, dA = 8.49%, dIICintra = 1.37 (3.26%), dIICflux = 12.10 (10.42%), and dIICconnector = 0.03 (0.52%), totaling dIIC = 13.50. This patch has 58 connections links.

These two patches have a smaller number of links compared to the central patch, indicating that they are more isolated, with distances exceeding 2,000 meters from other habitat patches. The remaining patches, indicated in the other priority categories, obtained extremely low index values, close to 0. These patches add up to 1,698 links (Table 3).

Figure 2 outlines the prioritization of habitat patches in relation to landscape functional connectivity considering the five categories of dIIC categorization. In (A), you can see the prioritization of habitat patches in relation to landscape functional connectivity, considering the central patch and PEMG. In (B), it shows the prioritization of habitat patches in relation to landscape functional connectivity without considering the central patch but still including PEMG.

Regarding the EC_IIC index (which measures equivalent connectivity), the calculated value indicates that 8,150.20 hectares of continuous habitat would be required to achieve the same connectivity quality measured by the dIIC metric. The total sum of natural habitats in the studied mosaic is 10,395.85 hectares, and the highest-priority habitat patch covers 4,428.64 hectares.

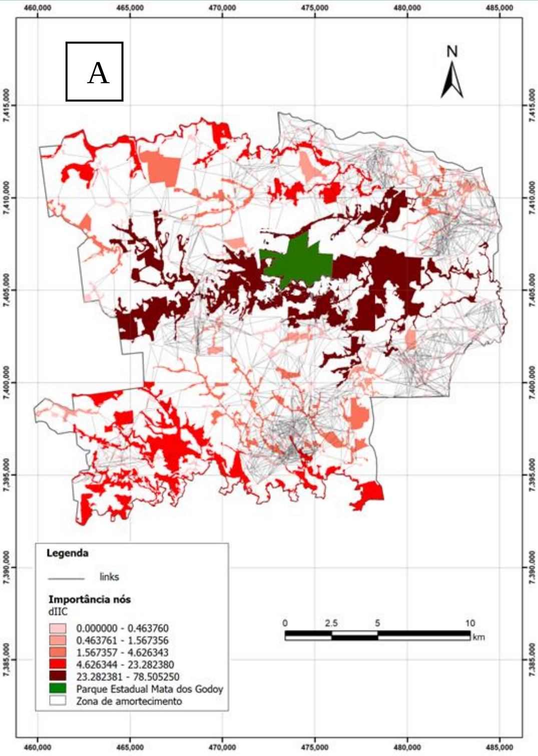

Figure 2 (A). Prioritization of habitat patches in relation to landscape functional connectivity, considering the central patch and PEMG.

Figura 2 (A). Priorização das manchas de habitat em relação à conexão funcional da paisagem, considerando a mancha central e o PEMG.

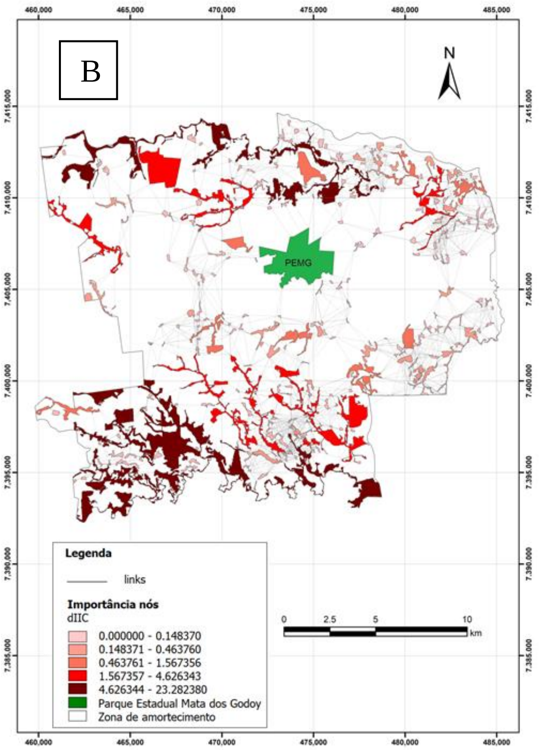

Figure 2 (B). Prioritization of habitat patches in relation to the functional connection of the landscape, without considering the central patch, but maintaining the PEMG.

Figura 2 (B). Priorização das manchas de habitat em relação à conexão funcional da paisagem, sem considerar a mancha central, mas mantendo o PEMG.

DISCUSSION

According to the results obtained for the dIIC index, even in a human-altered landscape with the current fragmented matrix, the scattered forest remnants in the study area are accessible to tapirs. This is considering that the distance between fragments in most cases falls within the daily displacement limit established for the species, estimated at a radius of 2,000 meters.

Based on the metrics, especially the EC-IIC (Equivalent Connectivity Index), it can be inferred that even though there are 10,395.85 hectares of natural habitats in the study area, they are not continuously connected to meet the needs of functional connectivity. Therefore, it can also be inferred that if there are landscape changes that result in increased isolation of habitat patches, then the loss of connectivity will be more significant than the loss of area, and consequently, the tapir is particularly more sensitive to the spatial arrangement and connectivity of these habitat patches than the presence of patches that do not have connectivity between them or are arranged in a way that the species cannot access them. (SAURA; RUBIO, 2010).

This is more evident when evaluating the value of the dIIC index, especially in the largest priority habitat patch that encompasses PEMG, totaling 4,428.64 hectares. This patch alone, although of maximum priority, is not large enough to provide the necessary connectivity between natural habitats (EC-IIC = 8,150.20 ha), but it is the one that maintains the functional landscape connectivity (dIIC = 78.50), thus contributing to maintaining the tapir population flow in the area. This patch contributes 81% to the connectivity within the patch itself (interpatch), is independent of connections between patches, dispersal distances of the focal species, and the patch's isolation in the landscape. It corresponds to 34.46% of connections with other habitat patches in the landscape and 72.46% for connectivity between other patches that act as connection elements or stepping stones (dIICintra, dIICflux, and dIICconnector, respectively).

Therefore, if transformations specifically occur in the central priority patch, which already acts as a corridor or stepping stone, providing functional connectivity to this landscape, there will be significant losses in habitat availability that could potentially be reached by the species.

The loss or fragmentation of this patch, with only the PEMG remaining, for example, would completely change the functional connectivity of the landscape, breaking several connection links and the possibility of the species reaching these habitats within the maximum travel distance (141 fewer links, NL = 2001). The patch of greatest importance would occupy the southern and northern portions of the landscape mosaic, with dIIC = 23.28% and dA = 37%, whereas in the original scenario, the most important patch has dIIC = 78.50% and dA = 42.60% (Table 2). According to the EC_IIC index calculated for this scenario, an equivalent habitat patch of 4,272.25 hectares would be required to reestablish the functional connectivity of the landscape, which is the area equivalent to the excluded central habitat patch. Landscape connectivity is thus facilitated by the flows enabled by this central habitat patch, which includes the PEMG.

Therefore, preserving this area with the highest values in all calculated indices is of utmost importance for the integrity of the landscape as a whole. Even when it is not physically close to the other areas, it still provides alternative routes, making it easier for tapirs to move between the areas of native vegetation located in the northern and southern parts of the landscape mosaicThis patch can be considered irreplaceable in the landscape, as it significantly contributes to the functional connectivity of the landscape. In other words, a patch with high irreplaceability like this should have a high priority for protection, either through the expansion of the existing conservation unit (PEMG) or the creation of a new conservation unit.

The remaining patches located in the north and south with low dIIC values indicate their low connectivity with surrounding areas, a result of the fragmentation of these blocks of native vegetation. However, according to García and Leonardo (2016), it should not be ruled out that these patches may act as stepping stones and potentially contribute to maintaining the overall landscape connectivity, considering the priority patch (dIICintra = 5.63 (13.41%), dIICflux = 17.38 (14.97%), and dIICconnector = 0.27 (4.69%) in the southern portion, and dIICintra = 1.37 (3.26%), dIICflux = 12.10 (10.42%), and dIICconnector = 0.03 (0.52%) in the northern portion).

The main pressures on the patches, considering land use and occupation, are in their surroundings characterized by agricultural cultivation areas. These anthropized areas contribute to the large number of patches with extremely low dIIC values (NP = 263, including patches from classes I, II, and III).

In terms of land planning, the central habitat patch can be seen as a core area or a conservation zone within the buffer zone of the protected area, with significant relevance for maintaining the local metapopulation scenario and, consequently, gene flow and habitat structure and availability. Human activities in this area should be subject to specific regulations and restrictions aimed at minimizing negative impacts not only on the protected area but also on the connectivity network provided by this habitat patch.

In this context, Hofman *et al.* (2018) suggested that defining core areas based on a combination of empirically derived habitat suitability and actual protection status would be ecologically more relevant than using the boundaries of protected areas.

This landscape genetics approach, where functional structure is established by identifying potential pathways or connections between habitat patches, has been increasingly used to provide parameterizations of landscape resistance based on movement and gene flow (ZELLER *et al.*, 2018). Thus, graph-theoretical approaches, such as those used in this study, have great potential for practical conservation because they are useful for estimating connectivity in the landscape scenario studied (TAMBOSI *et al.*, 2014), identifying key areas for functional landscape connectivity in the buffer zone of the Parque Estadual Mata dos Godoy (PEMG) based on a landscape species occurring in the area.

Furthermore, the information presented can be used in restoration projects aimed at enhancing connectivity between remaining habitat patches, considering the prioritization gradient of patch importance. This may include reestablishing permanent preservation areas to maintain or improve the ecological resilience of the landscape.

This resilience is maintained by the ecosystem services provided by Tapirus terrestris, including seed dispersal and predation, as well as their long-distance daily movements, allowing ingested seeds to be transported to distant locations from the parent plant. This makes them an important element in changing the composition and structure of forests. Thus, landscape connectivity is closely related to the maintenance of various ecological processes, including seed predation, seed dispersal, and nutrient cycling, which help maintain the integrity and functionality of ecosystems.

CONCLUSIONS

The analyses conducted lead to the following conclusions:

- The buffer zone of the PEMG, despite having a predominantly antropogenic matrix, shows indices that demonstrate it has a good degree of connectivity, primarly maintaned by a single habitat patch that includes the aforementioned conservation unit.

- This patch, along with those of moderate connnectivity importance accounts for 68,35% of the total area of remaining native vegetation in the mosaic. The smaller patches, despite obtaing low index values, are also importante for maintaning connectivity, acting as stepping stones, with the potential to alow *Tapirus terrestris* to access different patches na thereby increase habitat availbility. However, the loss or fragmentation oh these patches can compromisse the current condition of landscape connectivity, making it difficult or even impossibel for the studied espécies and other species to move effectively and be protected.
- The results and findings presented in the study through the analysis of connectivity conectividade índices, serve as na important tool for identifying priority areas for conservation, whose protection or increase of new areas, can enhance connectivity between habitat patches. In addition, this informations can be used to identify corridors and areas to be restored, which is of great utility na importance for the agencies reponsible for the conservation of protected areas and conservation área networks, or even, to define the limits of a buffer zone, when this has not yet been established around a conservation unit. It can also be useful for identifying the most important patches within the boundaries of an already estabilished buffer zone to ensure the movement of species between fragments, even when the landscape matriz consisit of antrhropized áreas.
- As a protective measure, it is necessary to intesify the monitoring of patches with remaining native forest in the buffer zone of the PEMG, in order to prevent fragmentation na safeguard connectivity between habitat patches.

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