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# Relationship between forest integrity, drainage headboards and patch-level metrics as subsidy for planning and conservation in fragmented Atlantic Forest areas

## Relação entre integridade florestal, cabeceiras de drenagem e métricas de manchas como subsídio para planejamento e conservação em áreas de Mata Atlântica fragmentada

## Relación entre integridad forestal, cabezas de drenaje y métricas de manchas como subsidio a la planificación y conservación en áreas de Bosque Atlântico fragmentado

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**Abstract**

Forests worldwide are essential goods for humanity as they provide support, provision, regulation, and cultural ecosystem services. In Brazil, the Atlantic Forest has lost much of its original cover, is currently represented by relatively small fragments in an anthropized matrix. Therefore, it is very relevant to analyze if forest fragments change in related the fragmentation of the original native vegetation and how they maintain their quality. This study aimed to analyze whether patch-level metrics are related to forest quality (biotic integrity) and whether relief features such as headboards are related to forest fragmentation patterns to provide subsidies for public planning and environmental conservation policies. The methodology involved mapping forest fragments (F) and drainage headboards (DH), calculating patch-level metrics (AREA, SHAPE, PROX), and the biotic integrity (BII) of the forest. Spearman's Correlation Coefficient was used to test the relationship between variables. The results showed a significative robust relationship between AREA and BII and significative medium relationship between SHAPE and DH, confirming partially the initial assumptions of the research. We concluded that the integrity of the forest fragment and the presence of drainage headboards must be considered in public planning and environmental conservation policies.

**Keywords**: Biodiversity; Environmental planning; Water resources; Forest conservation.

**Resumo**

As florestas em todo o mundo são bens essenciais para a humanidade, pois fornecem suporte, provisão, regulação e serviços ecossistêmicos culturais. No Brasil, a Mata Atlântica perdeu grande parte de sua cobertura original, atualmente é representada por fragmentos relativamente pequenos em uma matriz antropizada. Portanto, é muito relevante analisar se os fragmentos florestais mudam em relação à fragmentação da vegetação nativa original e como eles mantêm sua qualidade. Este estudo teve como objetivo analisar se as métricas em nível de mancha estão relacionadas à qualidade da floresta (integridade biótica) e se características do relevo, como cabeceiras de drenagem, estão relacionadas aos padrões de fragmentação florestal para fornecer subsídios para o planejamento público e políticas de conservação ambiental. A metodologia envolveu o mapeamento de fragmentos florestais (F) e cabeceiras de drenagem (DH), cálculo de métricas a nível de mancha (AREA, SHAPE, PROX) e a integridade biótica (BII) da floresta. O Coeficiente de Correlação de Spearman foi utilizado para testar a relação entre as variáveis. Os resultados mostraram uma relação robusta significativa entre AREA e BII e relação média significativa entre SHAPE e DH, confirmando parcialmente os pressupostos iniciais da pesquisa. Concluímos que a integridade do fragmento florestal e a presença de cabeceiras de drenagem devem ser consideradas no planejamento público e nas políticas de conservação ambiental.

**Palavras-chave**: Biodiversidade; Planejamento ambiental; Recursos hídricos; Conservação florestal.

**Resumen**

Los bosques en todo el mundo son bienes esenciales para la humanidad, ya que brindan soporte, provisión, regulación y servicios ecosistémicos culturales. En Brasil, la Mata Atlántica ha perdido gran parte de su cobertura original, actualmente está representada por fragmentos relativamente pequeños en una matriz antropizada. Por lo tanto, es muy relevante analizar si los fragmentos de bosque cambian en relación con la fragmentación de la vegetación nativa original y cómo mantienen su calidad. El objetivo de este estudio fue analizar si las métricas a nivel de mancha están relacionadas con la calidad del bosque (integridad biótica) y si las características del relieve, como las cabeceras de drenaje, están relacionadas con los patrones de fragmentación del bosque para proporcionar subsidios para la planificación pública y las políticas de conservación ambiental. La metodología implicó mapear los fragmentos de bosque (F) y cabeceras de drenaje (DH), calcular métricas a nivel de mancha (ÁREA, FORMA, PROX) y la integridad biótica (BII) del bosque. Se utilizó el Coeficiente de Correlación de Spearman para probar la relación entre las variables. Los resultados mostraron una relación robusta significativa entre AREA y BII y una relación media significativa entre SHAPE y DH, lo que confirma parcialmente los supuestos iniciales de la investigación. Concluimos que la integridad del fragmento de bosque y la presencia de cabeceras de drenaje deben ser consideradas en las políticas de planificación pública y conservación ambiental.

**Palabras clave**: Biodiversidad; Planificación ambiental; Recursos hídricos; Conservación forestal.

## 1. Introduction

Forests worldwide are essential sources of goods for humanity (Peterson et al., 2018), providing ecosystem services (MEA, 2005; FAO, 2020) as regulation (climate, disease control), provision (food, fiber, wood, medicines), cultural services (health, recreation, leisure). Even so, day after day forests have lost areas to other land uses such as agriculture (Farah et al. 2017) and urbanization (Ordóñez & Dunkier, 2012; Mello et al. 2016, Steenberg et al., 2019). Over the past 30 years, the rate of forest loss has slowed down (Miura, 2015, FAO, 2020), but nations have still been destroying their forests on a large scale (FAO, 2020).

In Brazil, the Atlantic Forest (Brasil, 2012 a) has lost much of its original cover (Tabarelli et al., 2010). Most of this forest is currently represented by small forest fragments (Ribeiro et al., 2009, Tabarelli et al., 2010). Even so, the fragments can still support important plant species in a highly anthropized matrix such as in agricultural (Farah et al. 2017) or urban (Steenberg et al. 2019). Anthropogenic disturbances arising from forest fragmentation disrupt the balance of the ecosystem, influencing the ecological integrity (Reza & Abdullah, 2011) and reducing its biodiversity (Haddad et al. 2015). These effects are more significant in smaller and more isolated fragments (Laurence & Vasconcelos, 2009; Haddad et al. 2015, Rocha-Santos et al. 2017).

Classically ecological studies on forest ecosystems have been carried out locally, with field data collection and great sampling effort (Cardoso-Leite et al. 2013, Mangueira et al. 2021), which allows to sampling exhaustively but, over small areas. On the other hand, landscape ecology studies using remote sensing can sample large areas (Mello et al. 2016, Ferreira et al. 2017), although often without sufficient detail for further ecological analysis. Ganivet & Bloomberg (2019) argued that remote sensing should be used to map and predict tree species diversity at regional scales, while field inventories provide accurate information at local scales and allow validation of remotely sensed data. Riedler et al. (2015) claim that integrating field data (e.g., information on understory vegetation) can help overcome the limitations of studies carried out only with remote sensing data.

On the other hand, few studies bring together biotic (forest integrity) and physical (landscape dynamics) knowledge relating to aspects of relief and water resources with the presence and quality of vegetation. Therefore, it is necessary to advance in this interdisciplinary meeting by joining data from different scales as Ganivet & Bloomberg (2019) proposed. In addition to uniting knowledge on forest integrity and water resources and producing analyses that can effectively contribute to conservationist planning and management in anthropic landscapes. The present study represents an effort in this direction.

Therefore, it is very relevant to analyze if forest fragments change in related the fragmentation of the original native vegetation and how they maintain their quality (Reza & Abdullah, 2011). So this knowledge can provide subsidies for territorial planning and management, both at a regional (states, regions, watershed) and local (municipalities) scales. However, to maintain itself over time, the forest must maintain its compositional, structural, and dynamic characteristics in a minimal condition.

The biotic integrity of a forest fragment (Medeiros et al. 2012, Medeiros et al. 2015) represents its probability of long-term sustainability (Graciano-Silva et al. 2018), in addition to the provision of ecosystem services. The biotic integrity index (BII) proposed by Medeiros et al. (2012) is helpful for this analysis as it contains species composition indicators (provision services), biomass (carbon sequestration services), litter (support service), in addition to other vital indicators.

In analyzing landscape dynamics, it is essential to correlate different aspects such as relief and river system. The drainage headboards, for example, reflect the current landscape evolution process, being a response to the work of natural erosion dissecting the relief. Drainage headboard refers to the concave area upstream of a first-order channel (Paisani et al. 2016). Different names have been traditionally used in geosciences and environmental sciences (Hack & Goodlett, 1960; Moura et al., 1991; Pelech, 2016) to refer to these features, such as zero-order basin, amphitheater, hollow and drainage headboards. In the present study we will adopt the term “drainage headboards”.

It is noteworthy that these features may not be intrinsically linked to a constant water depth due to seasonality. Yet, the presence of drainage headboards represents the possibility of the occurrence of springs since these mildly depressed areas create more surfaces near the water table, as discussed in Ferreira et al. (2017). Oliveira et al. (2014) carried out a study that integrating studies in the Mantiqueira Mountain Range Region concluded the interaction between area, soils characteristics and forest cover generated the best values for all indicators of the stremflow regime for the springs.

Native forests are closely related to soil conservation and consequently, agricultural production (FAO, 2020), human water supply, and other uses (Romero et al. 2018, FAO, 2020). In addition, to minimize the effects of climate change (Scarano & Ceotto, 2015) and to provide species for human use (Brockerhoff et al. 2017, Joly et al. 2019). Wu et al. (2017) point out that precisely riparian vegetation can provide multiple ecosystem services such as providing habitat for wildlife species, filtering sediments and nutrients, and stabilizing riverbanks and water temperature. Furthermore, drainage headboards facilitate forest fragments producing vegetated hills with great scenic beauty, providing cultural services (Cooper et al. 2016, Colley & Craig, 2019, Kosanic & Petzold, 2020) related to leisure, recreation, ecotourism.

Thus, this study aimed to analyze whether patch-level metrics are related to forest quality (biotic integrity) and whether relief characteristics, such as drainage headboards, are related to forest fragmentation patterns. We also analyzed the possible relationship between forest quality and drainage headboards. We start from the initial assumption that there should be a positive relationship between the biotic integrity of the forest and the patch-level metrics (AREA) and that larger fragments could have greater altimetric amplitude, which should be related to the number of headboards.

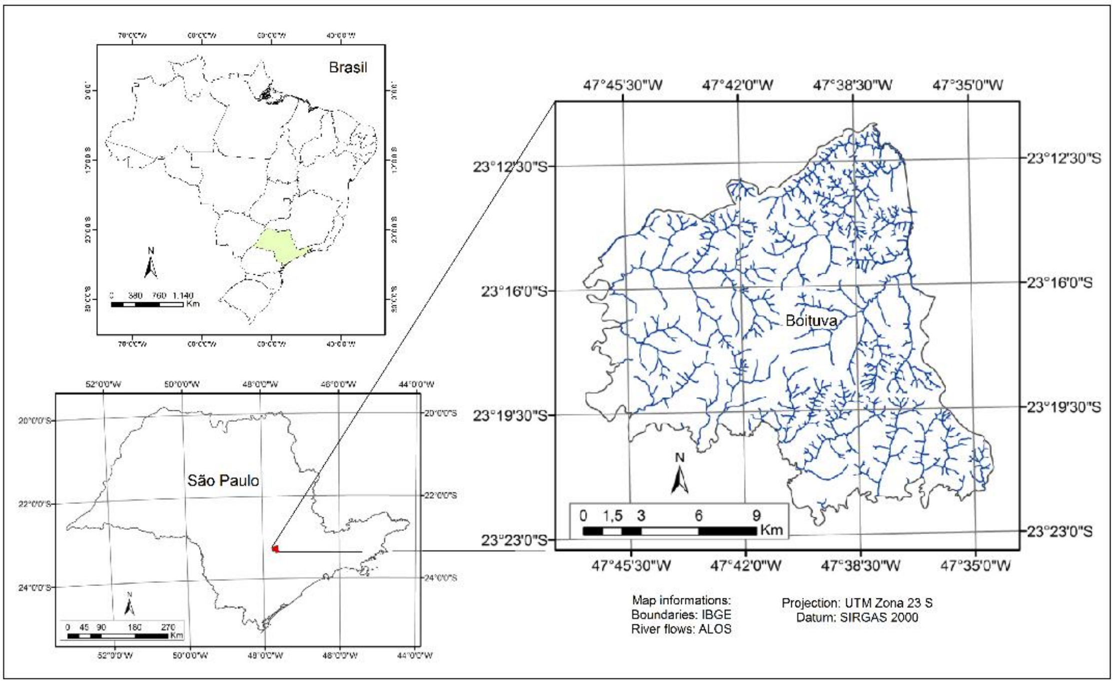
Few studies analyzed the relationship between forest biotic integrity and patch-level metrics. Galvani et al. (2020), which recorded a positive relationship between AREA and biotic integrity. Still, none of them analyzed the relationship between biotic integrity and drainage headboards, specifically for forests in hight degraded landscape (Graciano-Silva et al. 2018, Galvani et al. 2020). The results of this study may support public policies for landscape planning, including the conservation of forest biodiversity and water resources. Thus, the final objective of this study was to provide subsidies for public policies on environmental conservationist planning.

## 2. Material and Methods

### 2.1 The study area

The studied area (Boituva/SP) is located in southeastern Brazil in the Atlantic Forest Biome. Land use is predominantly rural, with large urban patches and smaller patches of native vegetation, which correspond to approximately 10% of the area (Cardoso-Leite et al. 2020). The vegetation is of the Submontane Seasonal Semideciduous Forest (FES) one phytophysiognomy of the Atlantic Forest (Brasil, 2012 a). The municipality is part of the Middle Tietê Sorocaba Watershed (SÃO PAULO, 1991), an important river that supplies water to several municipalities in this region of the state. The city's climate is characterized as Cwa - subtropical climate, while the relief is characterized by the Peripheral Depression of São Paulo with altitude ranging from 512 to 670 m. The municipality is part of the RMS - Metropolitan Region of Sorocaba (SÃO PAULO, 2014). The predominant economic activities are agricultural production (cattle, sugar cane), industry (beverages and others), and tourism (skydiving, ballooning).

**Figure 1**. Location of Boituva municipality in the State of São Paulo, Brazil.



Source: Authors.

### 2.2 Data collection and analysis

**Patch-level metrics - AREA, SHAPE, PROX**

The forest fragments map was based on CBERS-4 images (Pan 5m-resolution and 2R3G4B-resolution with 10m-resolution), obtained from the National Institute for Space Research (INPE) website. Based on these images, the forest fragments were digitized at a scale of 1:8000, which were later checked in the field (i.e., checking the accuracy of the map) through 25 randomly distributed points, stratified as proposed by Eastman (2009).

We considered only patches larger than 5 ha for this work, which is the minimum area for maintaining some biotic integrity in forest fragments (Graciano-Silva et al. 2018). We characterized the fragments through traditional patch-level metrics, called area (AREA), shape (SHAPE), and proximity between forest fragments (PROX), proposed by McGarigal et al. (2012), using the GIS through the V-LATE 2.0 plugin.

According to some authors, following Theory of Island Biogeography (Losos & Ricklefs, 2009), the AREA metric supports the discussion of biodiversity conservation within the fragment because the largest forest patches of the studied areas can sustain a higher level of biodiversity than the smaller patches (Almeida-Gomes et al. 2016). Rocha-Santos et al. (2017) highlighted that patch make the presence of certain species unfeasible.

The SHAPE metric supports the assessment of the influence of the edge on the forest fragment. The results for this metric can vary from 1 to n, where the most circular SHAPE is represented by value = 1, and higher values represent the most irregular one. Ries et al. (2004) mentioned that patches characterized by circular shapes are less influenced by edges (Murcia, 1995), with their original biodiversity being better preserved. On the other hand, irregularly shaped patches are exposed to matrix interference, and their biodiversity is affected by anthropogenic effects (Riedler et al., 2015; Silva et al. 2020, Mello et al., 2020 or Valente et al. 2021).

Concerning the PROX metric, it reflects the edge-to-edge distance between the forest patch and its nearest neighbor. By evaluating this metric, one can estimate the scenario of connected landscapes, which should be essential for the survival of some species (Thompson et al., 2017). According to Herrera et al. (2017), the proximity between forest fragments contributes to the maintenance of biodiversity, especially when smaller fragments make up most of the landscape.

### Drainage headboards -DH

The altitude data was obtained overlaying data from some mappings carried out during the research. The hypsometric map was the base for this, elaborated in the GIS from an MDE (Digital Terrain Model) image of the base ALOS/PALSAR. We also consulted the vectorized topographic maps of 1:10,000 (IGC-SP) during the process to clarify some doubts. In some fragments, measurements were also carried out using portable GPS devices, which minimized distortions in the data obtained from cartographic documents. For slope, we considered ALOS/PALSAR with a spatial resolution of 12.5m and the 3D Analyst Tools/Slope tool from Arcgis 10.5.

The drainage headboards (DH) were obtained from the mapping of the drainage network, making the extraction of river courses in the municipality, with vectorization from orbital images. The basic principles involved identifying river courses using traditional visual parameters of photo interpretation, as Arcanjo (2011) proposed. Such data were crossed with other products on the subject, obtained from a drainage network generated automatically from specific procedures using SRTM and ALOS images. We also based on Topographic maps of IGC 1:10,000 (IGC-SP) to correct any distortions. The term drainage headboard used in this work is based on the understanding proposed by Hack and Goodlett (1960) and Gomi (et al. 2002).

### Biotic Integrity Index- BII

From the 155 fragments mapped in the municipality (Cardoso-Leite et al. 2020), 15 fragments were chosen (10% of the total) with wide variation in AREA (Figure 2), with small fragments being considered fragments below 25 hectares, medium from 25 to 49.9 hectares, large from 50 to 74.9 hectares, and very large from 75 to 100 hectares. The method proposed by Medeiros and Torezan (2012) was used to calculate the BII, with some adaptations for the region (Graciano-Silva et al. 2018). This index contains 11 forest quality indicators (Table 1) including composition indicators (indicators 4,9,10,11), structure (indicators 7,8) and successional function or dynamics (1,2,3,5,6).

In each area, the indicators (Table 1) were registered in the field within 10x10 m plots, using 3 plots for small areas, 4 for medium-AREA areas, 5 for large areas, and 6 for very large areas. The BII value was calculated using the simple average of the values recorded in the field. The score assigned to each indicator varies from 1 to 5. As there are 11 indicators, the maximum possible score is 55. Therefore, an area with 11 to 19 points was considered very low integrity, 20 to 29 points low integrity, 30 to 39 points medium integrity, 40 to 49 points high integrity, and 50 to 55 very high integrity, as proposed in the original method (Medeiros and Torezan 2012). The final result was transformed into % for ease of understanding.

**Table 1**. Biotic Integrity Index (BII) employed in Boituva municipality, State of São Paulo, Brazil.

| Classes | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1- Litter Cover | 0 to 10% | 10 - 25% | 26 to 50% | 51 to 75% | 76 to 100% |
| 2- Gaps | <50% | 26 to 50% | 11 to 25% | Gift up to 10% | Absent |
| 3- Exotic Grass Coverage | <50% | 26 to 50% | 11 to 25% | Gift up to 10% | Absent |
| 4- Epiphytes | 0 | 1 - 2 (1 sp) | 3-6 (1 or 2sp) | 6-9 (2 to 3 sp) | 10 or + (4 or +sp) |
| 5- Standing Dead Trees | Five or + | 4 | 3 | two | 0 or 1 |
| 6 Vines | Thin only, four or + tangles | Thin only, 2 or 3 tangles | Thin only, one tangle | Thick and a few thin | Only thick woody |
| 7- Canopy height (m) | 0 to 8 | 8-12.5 | 12.5-17 | 17-21 | 21-25 |
| 8- Diameter of ind. of the canopy (cm) | > 6 | 6 to 14 | 14 to 22 | 22 to 30 | < than 30 |
| 9- Exotic woody species [1] | 5 or + | 3-4 | two | 1 | 0 |
| 10 – Late Individuals and Species in Understory [2] | 0 | 1-2 (1sp) | 3-5 (1 or 2 sp) | 6-9 (2 to 3sp) | 10 or + (3.4 or + sp) |
| 11 - Late Individuals and Species in Canopy [3] | 0 | 1 (1sp) | 2 (1 or 2sp) | 3 (2 to 3sp) | 4 or + (3, 4 or +sp) |

[1] *Eucalyptus, Pinus, Leucena , Citrus, Mangifera, Coffea.* [2] Individuals of the Rubiaceae , Myrtaceae, Meliaceae (*Trichillia* spp.) and Arecaceae (*Euterpe edulis*) families. [3]*Cariniana* sp. (Jequitibá), *Cedrela fissilis* Vell. (Cedro), *Copaifera langsdorffii* Desf. (Copaíba), *Aspidosperma polyneuron* Müll.Arg. (Peroba rosa), Laurarceae (several spp.). Source: Adapted from Medeiros and Torezan (2012).

### Data analysis

We tested the effect of patch-level variables (AREA, SHAPE, PROX) on the biotic integrity , and we discussed the number drainage headboards in relation to patch-level variables. All tests were performed using Spearman's Correlation Coefficient. Data organization was elaborated in tables using Microsoft Excel. Calculations and graphs with Spearman values were prepared using the R language (Zar, 2010; Mc Donald, 2014).

## 3. Results

The results are shown in Figures 2, 3, 4 and Table 2. Figure 2 shows the studied fragments, their location, and AREA classes. It can be seen that (Table 2) the AREA of the areas ranged from 5.5 to 97.7 hectares. It is noted that the small fragments (Figure 2, Table 2) are embedded in or adjacent to urbanized areas (Figure 2), and the other fragments (medium, large, or very large) present in the surroundings other land uses, in general agricultural.

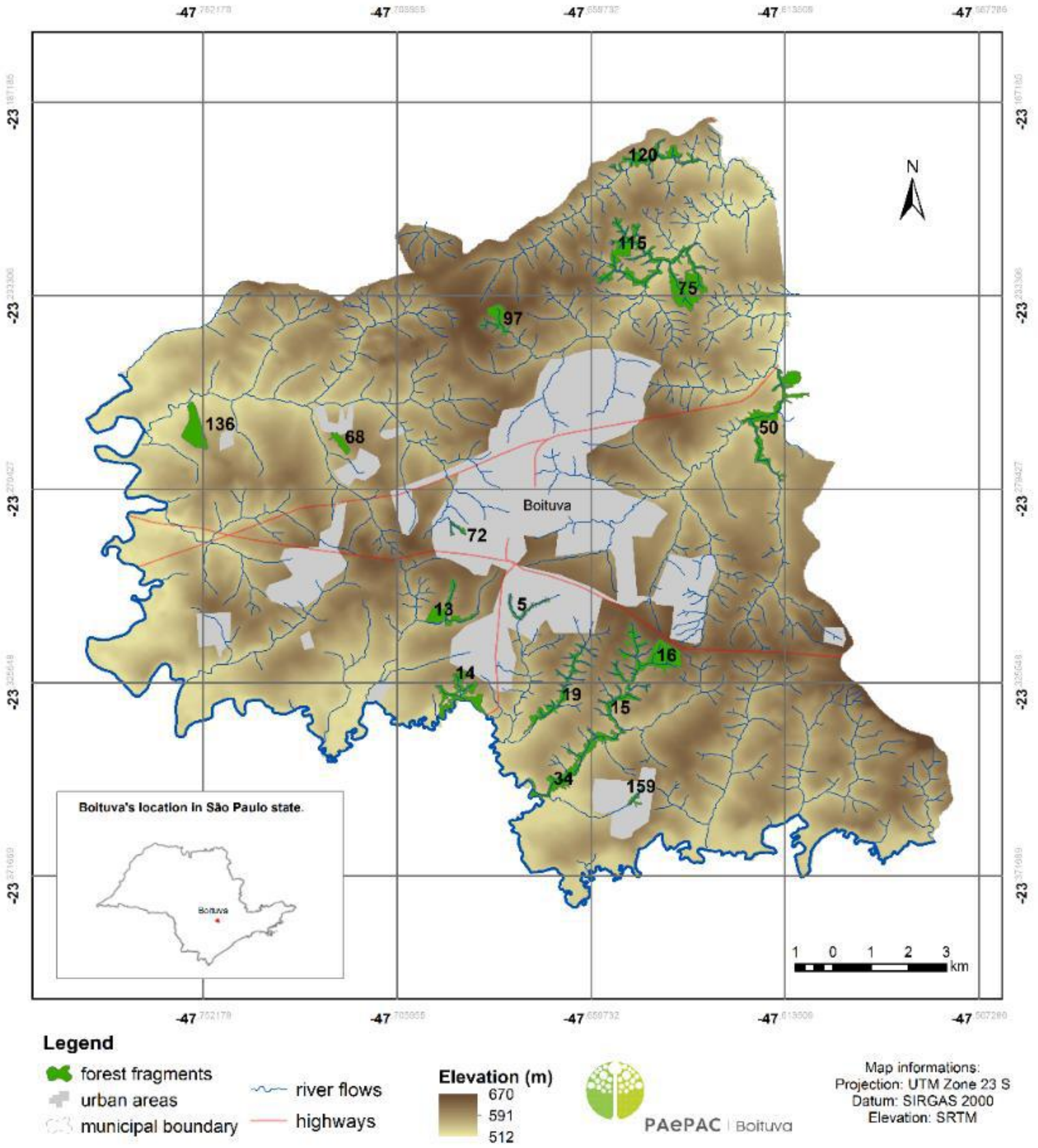
The SHAPE (remembering that more circular shapes should have values close to 1) ranged from 1.61 to 6.13 (Table 2), with most small fragments showing more circular shapes (values close to 1) and medium, large, or very large fragments and more irregular (values above 4).

The PROX ranged from 8.3 to 429.4 m, with some fragments being entirely connected to others, with low PROX values, as in fragments 19, 50,115 (Fig.2, Tab. 2). It is important to emphasize that AREA that the 155 fragments larger than 5 hectares mapped were used to calculate the PROX (Cardoso-Leite et al. 2020) and not just the 15 fragments sampled in this study, so this connectivity may not always be visible on the map (Figure 2).

The number of DH ranged from 0 (absence) to 20 (Table 2).

The BII ranged from 31 to 44 among areas (Table 2). Small fragments had regular integrity (generally less than 60% of the maximum possible), but none of the areas had low integrity. Among the four very large fragments, 3 showed high integrity (between 65% and 80%). There seems to be a direct relationship between the AREA of the BII fragment (Figure 3). The high scores for the indicators 4,10,11 (Table 1) positively influenced the high biotic integrity of the large and very large fragments and the low scores for the 2,3,6,9 indicators (Table 1).

**Figure 2**. The forest fragments studied in Boituva, SP, Brazil. The numbers represent the forest fragments.



Source: Authors.

**Table 2.** Patch-level metrics (AREA, SHAPE, PROX), DH and IBB for the 15 fragments analyzed, Boituva, SP, Brazil. F= identifier number of studied forest fragment, PROX = proximity to the nearest forest fragment, DH= drainage headboard, BII= biotic integrity index. S = small forest fragments, M= medium size forest fragments, L= large size forest fragments, VL= very large size forest fragments.

| F | AREA (ha) | SHAPE | PROX (m) | DH | BII | % BII | Biotic integrity |
|---|---|---|---|---|---|---|---|
| 72 | 5.5-S | 2.4 | 78.7 | 2 | 31 | 56.4 | regular |
| 159 | 5.8-S | 2.5 | 145.7 | 1 | 30.7 | 55.8 | regular |
| 5 | 10.8-S | 4.63 | 429.4 | 1 | 35.5 | 64.5 | regular |
| 68 | 10.9 - S | 1.61 | 55.5 | 0 | 31 | 56.4 | regular |
| 15 | 24.2 S | 4.14 | 16.6 | 4 | 33.7 | 61.3 | regular |
| 97 | 25.7-M | 2.82 | 12.18 | 4 | 39.3 | 71.4 | regular |
| 13 | 35.4-M | 3.3 | 252.6 | 1 | 34.6 | 62.9 | regular |
| 120 | 46.8 -M | 4.74 | 17.8 | 9 | 38 | 69.1 | regular |
| 14 | 50.6 - L | 4.5 | 174.5 | 3 | 38.7 | 70.3 | regular |
| 19 | 50.8 -L | 6.13 | 8.4 | 17 | 33.2 | 60.4 | regular |
| 34 | 61.4 L | 4.41 | 15 | 3 | 36.2 | 65.8 | regular |
| 50 | 75.3 - VL | 4.54 | 8.3 | 1 | 41.3 | 75.1 | high |
| 75 | 76.9 - VL | 3.7 | 12.7 | 4 | 44 | 80 | high |
| 115 | 90.9- VL | 5.52 | 9.9 | 20 | 36.7 | 66.7 | regular |
| 16 | 97.7 - VL | 5.66 | 50.9 | 17 | 42.5 | 77.3 | high |

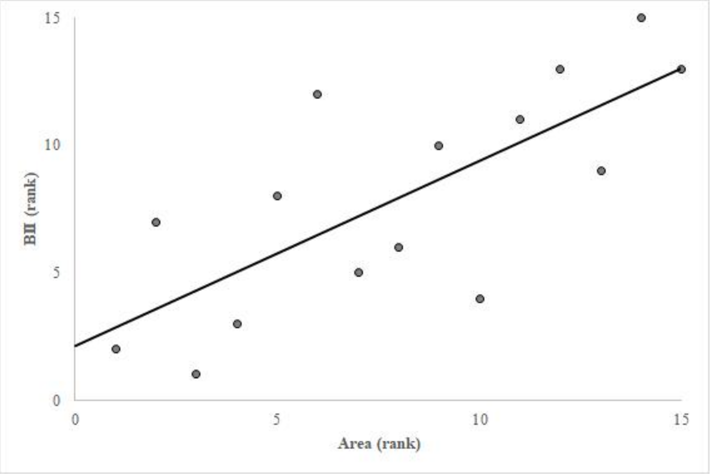
Source: Authors.

The results of correlation showed a positive and robust correlation (Spearman = 0.73977, p = 0.0016) between AREA and BII, positive and weak relationship (Spearman = 0.40086, p = 0.1387) between SHAPE and BII, and negative and weak between PROX and BII (Spearman = -0.36806, p = 0.1771).

The analysis also showed a positive and medium correlation (Spearman = 0.67970, p = 0.0053) between SHAPE and DH, also positive and medium (Spearman=0.65714, p = 0.0077) between AREA and DH. The relationship between the PROX and DH was negative and weak (Spearman = -0.53078, p = 0.04178).

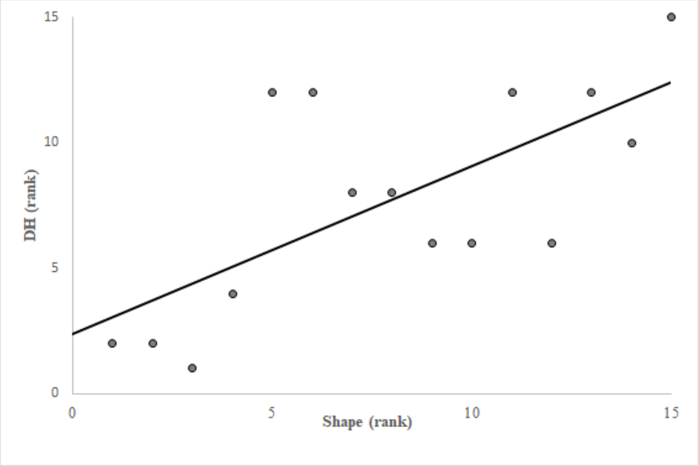
In other words, PROX not presented correlation with BII or DH. AREA presented significative correlation with BII (Figure 3), and SHAPE presented signiticative correlation with DH (Figure 4).

**Figure 3**. Spearman correlation graphs of SIZE and IBB in the 15 forest fragments analyzed, Boituva, SP, Brazil.



Source: Authors.

**Figure 4**. Spearman correlation graphs of SHAPE and DH in the 15 forest fragments analyzed, Boituva, SP, Brazil.



Source: Authors.

## 4. Discussion

### Area

The results show a clear relationship between fragment AREA and biotic integrity (Figure 3). In this study all small fragments had regular integrity (Table 2). Still, with % of BII below 60%, most fragments had regular integrity (and above 60% of the BII). Only 3 (F 16, 50, 75) of the four very large fragments had high integrity (% BII above 75%), in agreement with Haddad et al. (2015) and Rocha-Santos et al. (2017).

In some fragments (F 16, 50, and 75), a phytosociological survey was also carried out (Cardoso-Leite et al. 2020), which showed the existence of late species wich also provide wood (*Aspidosperma polyneuron, Cariniana legalis, Cedrela fissilis, Esenbeckia leiocarpa*) or late species with medicinal use (*Copaifera landsdorfii*) further showing that these larger fragments maintain a composition of regionally important species, which agrees with data from Farah et al. (2017) and Rocha-Santos et al. (2017).

The results also showed that only the very large fragments were able to prevent the edge effect (Murcia et al. 1995, Ries et al. 2004) canopy or late-species were more abundant there, while typical components of disturbed forests, such as exotic grasses or vines, were nearly absent. It was noted small fragments undergone more edge effect, as there were a higher amount of gaps, vines, grasses, and exotic woody trees (Indicators 2,3,6,9, Table 1). These results agree with those recorded by Magnano et al. (2014) for fragmented Atlantic forests. The authors reported that the edges of the fragments suffered species loss and changes in the community structure concerning the interior of the fragments.

Galvani et al. (2020) and Graciano-Silva et al. (2018) reported low integrity for small fragments (below 3 hectares) and a positive relationship between AREA and BII (Galvani et al. 2020) but obtained high integrity for a relatively small fragment AREA (20 hectares) in Ribeirão Preto/SP. In Medeiros and Torezan's (2012) study, although the correlation between AREA and BII was not analyzed, the results varied a lot; low BII values were registered for large areas, and vice versa. These data show that AREA influences biotic integrity, but this patch-level metrics alone does not explain all variations in integrity. Authors suggest that the existence of protection laws and the management of areas (Galvani et al. 2020) can influence even more than their AREA.

The relationship between AREA and DH was medium. All small areas and most of the medium ones presented between 0 to 4 headboards (Table 2). One medium area and the most of large or very large areas had 9 to 20 headboards (Table

2). In this sense, the presence of forest can be associated with the outcrop of the water table in these headboards, giving rise to first-order channels of river systems, something that was also addressed in the studies by Andrade (2008).

This result shows that larger areas are more likely to have headboards, and these may shelter springs, important points responsible for the formation of river courses. However, there were exceptions, such as a very large area (F = 50) that presented only one headboard. Dessie and Bredemeier (2013) studied forested and pasture springs in the Philippine, and obtained that riparian vegetation in the upstream region of the watershed is essential to promote better water quality and quantity, reduce the sediment load and turbidity, and regulate the flow, avoiding flooding in the downstream areas. Romero et al. (2018) studied urbanization's effects on forests in a watershed in a metropolitan region, obtaining that urban expansion and highways represent the most significant impacts on forest fragmentation and degradation, affecting negatively the availability and quality of water for supply. Therefore, in addition to the amount of DH (and possibly springs), the forest fragmentation recorded in Boituva, it must be also affecting negatively the quality and quantity of water in the watershed and the presence of aquatic fauna.

**Shape**

The forest fragments selected for this study generally have distinctive shapes (Figure 2, Table 2) as appears to be a pattern in forest fragmentation in the interior of São Paulo (Mello et al. 2014, Mello et al. 2016, Cardoso-Leite et al. al. 2020), where most of the fragments have an elongated and narrow shape. The relationship between the SHAPE and BII was positive but weak, contradicting the initial hypothesis. However, there seems to be a relationship between AREA and SHAPE. In general, even those with irregular shape, large or very large areas still have a core area where the edge effect (Murcia, 1995, Ries et al., 2004) is low or absent. Even those with a more regular shape, very small areas can suffer a lot from the edge effect due to their very small AREA, which must have occurred in fragments 68, 72, and 159 (Figure 2, Table 2). In other words, thinking about the edge effect, the influence of AREA seems to prevail over the influence of SHAPE in very fragmented landscapes, as also recorded by Galvani et al. 2020 for other Brazilian municipalities.

The relationship between SHAPE and DH (Figure 3) was positive and medium, however, the SHAPE of the fragment should not influence the number of drainage headboards. Still, the opposite can be seen with consistency. That is, the pattern of irregular and elongated forest fragments common in cities in the interior of the São Paulo State (Mello et al. 2014, Mello et al. 2016) suggests that the historically fragmentation process kept the forests close to drainage headboards and along watercourses (riparian forests) due to the existence of environmental legislation (Brasil, 2012b) that protects the forest preventing its destruction in these places, as also observed for a municipality neighboring the study area (Mello et al. 2014) where the authors recorded the occurrence of forest fragments associated with water bodies. This law (Brasil, 2012b) prevents land use for agricultural production and urban expansion on the banks of watercourses and within a radius of 50 m around springs, which are directly related to the drainage headboards addressed in this study.

This legislation is supported by scientific evidence (Dessie & Bredemeier, 2013; Goss et al. 2014; Romero et al. 2018, Mello et al. 2020), and authors such as Galvani et al. (2020) emphasized AREA that in some instances, legal protection is consequent conservation management influence the conservation of forest fragments more than patch-level or landscape metrics, such as AREA and, in this case, SHAPE.

## 5. Conclusions

The initial hypothesis was partially corroborated as the patch-area was strong related to the forest's biotic integrity and the patch-shape showed a medium relationship with the presence of headboards.

Thus, we can say that from biotic integrity standpoint, the results indicate that it is essential to conserve larger areas, which allow maintaining more ecosystem services related to support (nutrient cycling), provision (species of wood, food, medicines), regulation (carbon sequestration) and cultural services (scenic beauty, environmental education).

From the drainage headboards standpoint, it is essential to conserve larger areas that are currently irregular in shape (due to the historical process of fragmentation) as they maintain provision services (water for human supply and agricultural production), regulation (maintenance of hydrological cycles, avoiding landslides, silting and floods) and cultural (recreation, leisure in water bodies).

At a widespread discussion about water scarcity in tropical Brazil, especially in the State of São Paulo, with dam systems at low water levels for public supply. It would be important that more and more public policies also focus on municipal scales, seeking to understand local environmental systems, protecting their native vegetation and river courses, which can ensure the environmental quality of regional watersheds.

In addition, Boituva has a large part of its economy turned to ecotourism, with ballooning and skydiving activities. The region's scenic beauty is related to the relief, the presence of native vegetation, and watercourses, still existing within the remaining forest fragments amid the predominantly agricultural matrix. Thus, considering that riparian forests provide multiple ecosystem services,, they should be at the center of environmental planning and public policies to reconcile the sustainability of all services, integrating aspects of urbanization, agriculture, tourism, and the environment.

Thus, as a subsidy for local and regional public policies, the creation of specially protected areas is recommended in places with the largest fragments of vegetation remaining, combined with the existence of drainage headboards.

To provide more consistent subsidies for environmental planning, it is recommended that future studies carry out the mapping and analysis of perenniality of springs, as well as the study of forest biodiversity within patches.

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