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Fabricio Macedo Galvani[1a], Thais Graciano-Silva[1b], Eliana Cardoso-Leite[1c+]

IS BIOTIC INTEGRITY OF URBAN FORESTS REMANTS RELATED WITH THEIR SIZE AND SHAPE?

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HIGHLIGHTS

The size of urban forests has a direct relationship with the biotic integrity of the ecosystem.

There is a relationship between the shape of urban forests and their biotic integrity but it is weak.

In general, small urban forests exhibit low integrity and large urban forests exhibit high integrity.

Besides size and shape, other factors seem to affect the biotic integrity of urban forests, such as the history of disturbance and conservationist management.

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ABSTRACT

The Brazilian Atlantic Forest (BAF) is one of the biodiversity hotspots, but in the last decades, it has been fragmented due to agricultural and urban-industrial expansion, which has a strong impact on forest fragments. The goal of this study was to analyze the Biotic Integrity Index (BII) in fragments of BAF in two medium-sized cities in Southeastern Brazil and to analyze the relation between BII and landscape metrics (size and shape). The method (BII) has eleven indicators (litter, grass, dead trees, exotic species, vines, gaps, epiphytes, orchids, palms, later species in canopy and understory). The survey was carried out in nine forest fragments in Ribeirão Preto (SP) and 23 in Sorocaba (SP), with a size variation between 0.33 and 185 ha, all of them in urban influence. The relation between BII and landscape metrics were analyzed by the Pearson regression. BII value was registered from 28.7 to 40.0 to Ribeirão Preto and from 22.34 to 35.34 to Sorocaba. Pearson regression was strong between IBB and the size for both cities (p= 0.742 to Ribeirão Preto, and p= 0.679 to Sorocaba). Pearson regression between IBB and shape was medium to Ribeirão Preto (p= 0.47) and weak to Sorocaba (0.1838). The results showed that there is a strong relation between BII and size, and less correlation between BII and shape. However, only size is not able to explain all variation in integrity, suggesting that other factors such as disturbance history and conservation management should have greater influence than the fragment size.

+Correspondence:
elianacleite@gmail.com

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[1] Federal University of São Carlos, Sorocaba, São Paulo, Brazil- ORCID: 0000-0003-4556-0434[a], 0000-0003-0334-8750[b], 0000-0003-3152-2576[c]

INTRODUCTION

The Brazilian Atlantic Forest is one of the biodiversity hotspots in the world due to its great biodiversity, endemism and threat level (Myers et al., 2000). In Brazil this forest was significantly modified and fragmented, thus, 88.3% of the original Brazilian Atlantic Forest was lost and only 11.7% of the original vegetation remains (Ribeiro et al., 2009). Currently, it is distributed in 245,173 forest fragments, the largest of it is located in the Serra do Mar, mainly along the coastal mountains of São PauloState, but the small fragments (<50 ha) are currently the most of them (Ribeiro et al., 2009).

Changing in land use transforms areas with native vegetation into urban or agricultural areas and it destroys forests and other natural ecosystems, and it modifies their size, shape and, isolation degree in the landscape (Ferraz et al., 2014; Mello et al., 2016). As in the last decades human society has been concentrated in the cities, this has increased the pressure of destruction of natural ecosystems to occupy the space with urban expansion. Nowadays the urban population is 30% larger than the population of 50 years ago and the cities areas are gaining 67 million people a year (Picket et al., 2011).

The development of urbanization fragments natural ecosystems causes species homogenization (Aliberti and Marzuff, 2004) and increases the frequency of exotic species (Heckmann et al., 2008) due to the edge effects (Murcia, 1995; Pohlman et al., 2007; Haddad et al., 2015) and habitat degradation (Haddad et al., 2015), despite the importance of these forests in the urban matrix. Liu et al. (2018) in a recent review about this issue concluded that fragmentation can affect the ecosystem function modifying the community composition directly, as well as indirectly by changing environmental conditions in habitat patches.

Natural ecosystems are important because they provide ecosystem services for human societies. They not only provide services such as food, fiber, wood, pollinators, climate and, water regulation (avoiding heating zones in cities, avoiding floods and landslides), but also cultural services, such as recreation and aesthetics (Millenium Ecosystem, 2005; Pascual et al., 2017; Peterson et al., 2018). So, urban forests have been recognized as essential components of sustainable cities (Steenberg et al., 2015).

As an attempt to evaluate the biotic integrity of forest fragments in Paraná State, Medeiros and Torezan (2013) proposed a Biotic Integrity Index (BII) based on studies of Rapid Ecological Assessment (Sayer et al., 2000). This index (BII) is composed of a simple set, easily measurable variables that, when analyzed as a whole, can reveal much about the state of biotic integrity of the forest. As the original study (Medeiros and Torezan, 2013) was carried out in forest fragments inserted in a rural matrix, Graciano-Silva et al. (2018) adapted the BII method for forest fragments in an urban matrix, that is, in urban forests.

The urbanization is destroying the natural ecosystem, devastating biodiversity and ecosystem services (WU, 2010). Changes in the structural composition of urban forests can cause changes in certain ecosystem functions (LIU et al., 2018) that maximize human well-being in cities (Dobbs et al., 2011). Therefore, knowledge about the ecological dynamics and biotic integrity of forest fragments inserted in an urban matrix is essential to guide public policies and support decision-makers in the planning and management of territories.

In this way, the following questions are very relevant and they guided the present study: - “Do urban forests have any biotic integrity that can guarantee their survival over time?” - “Is the biotic integrity of urban forests related to their size and shape?”

This study aimed to analyze the Biotic Integrity in Atlantic Forest fragments inserted in an urban matrix, in medium-sized cities in the Southeast of Brazil (Ribeirão Preto/SP and Sorocaba/SP) and to analyze the relationship between biotic integrity and landscape metrics (size and shape of the fragments).

MATERIALS AND METHODS

The study area

This study was carried out in the municipalities of Ribeirão Preto and Sorocaba (Figures 1 and 2), two middle-sized cities located in the Southeast of Brazil, in São Paulo State. The original vegetation in the region is Atlantic Rain Forest. Another natural vegetation in this region is the Savanna, but the present study focused specifically on the forest fragments (Figures 1 and 2).

It was selected nine forest fragments in Ribeirão Preto (Figure 1) in the municipality area where they have some relation with the urban area. The choice of these fragments was based on a previous study (Konthetkoff-Henriques, 2003). The size of the analyzed areas varied from 1.3 to 185 ha. Therefore, the survey included two protected areas (Porto Ferreira and Vassununga State Park) as the “reference”, because these are well-preserved forests. Both state parks are located 100 km from Ribeirão Preto (Vieira et al, 1989).

It was selected twenty-three forest fragments in Sorocaba (Figure 2) in the municipality area, wherethey have some relation with the urban area, and the choice

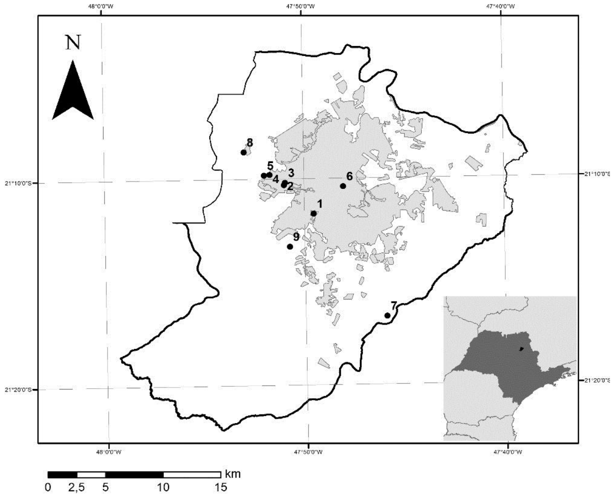

FIGURE 1 Sample units (forest fragments) analyzed in Ribeirão Preto/SP, Brazil. The area names are shown in Table 2.

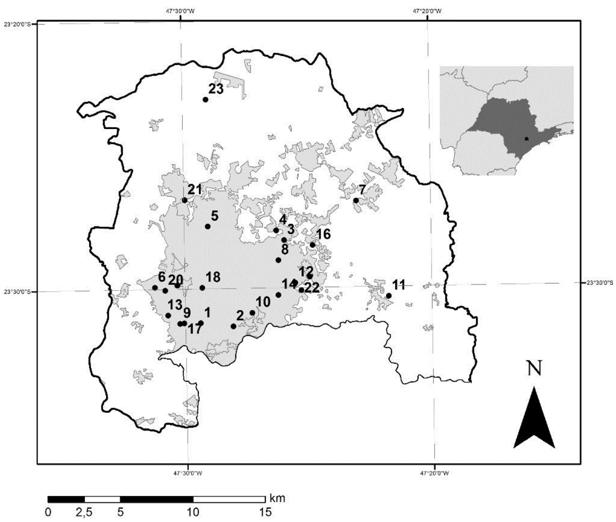

FIGURE 2 Sample units (forest fragments) analyzed in Sorocaba/SP, Brazil. The area names are shown in Table 2.

of these fragments was based on previous studies (Mello et al., 2016, Mota et al., 2016). The size of the analyzed areas varied from 0.33 to 31 ha. Therefore the survey included one protected area (Ipanema National Forest) as the "reference" because this is a well-preserved forest. This National Forest is located 10 km from Sorocaba (Albuquerque and Rodrigues, 2000).

Data collecting

Biotic Integrity Index

It was calculated the Biotic Integrity Index (BII), proposed by Medeiros and Torezan (2013) and adapted by Graciano-Silva et al., (2018), for each area. It was used 3 plots of 10x10m (or 100 meters square), inside each fragment.

BII contains eleven indicators (or ecological variables) and the selection of these indicators was based on literature review, most previous studies (Medeiros and Torezan, 2013; Gregorini, 2015; Graciano-Silva, 2016), with adaptations for species (Indicators 10, 11) using previous studies as Konthetkoff-Henriques (2003) to Ribeirão Preto, and Albuquerque and Rodrigues (2000) and Coelho et al. (2016) to Sorocaba. Table 1 shows these indicators and the possible value variation.

Each indicator received a score ranging from 1 to 5 (Table 1). The BII values were obtained through the sum of each of the indicators, with the maximum value of integrity of 55 representing a fragment with excellent biotic integrity and a minimum value of 11, representing a highly degraded fragment (very low integrity). The score obtained and the degree of integrity followed the proposal of Medeiros and Torezan (2013) where values from 11 to 19.9 are considered "Very Low Integrity", from 20 to 29.9 "Low Integrity", 30 to 39.9 "Medium Integrity", from 40 to 49.9 "Good (or High) Integrity" and, from 50 to 55 "Excellent (Very High) Integrity".

Landscape metrics

It was analyzed the size and shape of the forest fragments studied. These metrics were chosen based on ecological concepts. The first one was the Island Biogeography (Macarthur and Wilson, 1967) in which large areas should have greater biodiversity (Metzger, 1999; Mello et al., 2016). Then, the edge effect, in which the influence of the adjacent landscape is large and it depends on the shape of the patches (Murcia, 1995; Pohlman et al., 2007; Haddad et al., 2015).

The landscape metrics analyses were performed through image capture using the SAS Planet software. The source of the images is from Bing Maps Satellites, for the delimitation of the polygons and the land use mapping it was used ArcGis 9.2 software. Fragstats Software was used to calculate the metric variables. The analysis of the variables related to the landscape proposed for the present study is described below.

The size of the fragments was calculated from the drawing of the polygon occupied by the fragment, using the Esri ArcMap 10.2.2 Program, and the calculation was done using the Calculate Geometry Tool with the shapefiles open for editing of the same program.

The shape of forest patches is determined by the size and the perimeter of the area. A circular shape is the one that minimizes the perimeter/area ratio and generates edges with the same length from the patch center. The shape is a spatial attribute that is difficult

TABLE 1 Indicators and degree of biotic integrity (Adapted from GRACIANO-SILVA, 2016). 1 - *Copaifera langsdorfii*, *Aspidosperma* spp, Cariniana spp for both as areas, and *Cedrela fissilis* only for Sorocaba, 2 - Species of the genus *Trichilia* and species of families Myrtaceae and Rubiaceae.

INDICATOR	INTEGRITY DEGREE				
	1	2	3	4	5
1-Litter cover (%)	0 - 20%	20% - 50%	50% - 80%	100% - deep less 10cm	100% - deeep more 10cm
2-Standing dead trees (number of individuals)	4 or more	3	2	1	0
3-Exotic grass cover (%)	>70%	51-70%	21-50%	5-20%	Absent
4-Wood lianas and vine tangles	Just vine tangles (3 or more)	Just vine tangles (2)	Just vine tangles (1)	Wood and vine tangles	Just wood
5-Gaps in canopy (%)	More than 50%	From 25 to 50%	From 11 to 25	Present until 10%	Absent
6-Vascular epiphytes (number of individuals)	Absent	1	2	3	4 or more
7- Orchids (number of individuals)	Absent	1	2	3	4 or more
8-Palms (number of individuals)	Absent	Only youngs	1 adult + youngs	2 adults	3 adults or more
9-Exotics wood species (number of individuals)	4 or more	3	2	1	Absent
10-Later species in canopy (number of individuals) 1'	Absent	1	2	3	4 or more
11-Later species in understory (number of species) 2	Absent	1	2	3	4 or more

to be undertaken in a metric analysis because there are many possible ways to do it. So, for the evaluation, it is necessary to adopt an indexed constant (c), which takes different values to different formats, that allows assimilation from the form to the standard geometric shapes (circle, ellipse, square, etc.). A perfect circle has a shape value of zero, and shape values ≥ 6 are heuristically considered irregular. The shape was calculated by the analysis system program (McGarigalet al., 2015; Graciano-Silva, 2016). The shape of the fragments was calculated using Equation 1, also used by Graciano-Silva (2016). where: A – Size of study area; P – Perimeter of study area; c – Correction factor

$$\text{Shape} = A/\sqrt{P}/c \qquad [1]$$

Data analysis

In order to analyze the relationship between the BII and the fragment size, Pearson linear regression was calculated (Zar, 2010; McDonald, 2014) using the logarithm of the areas in hectares of the fragments. Using the logarithm for the areas aims to analyze how the relationship is established, once the oscillation of the values for the areas is much greater than the values of BII, especially data from Ribeirão Preto where the areas vary from 0.52 to 188.25, compared to values between 11 and 55 to BII.The Pearson linear regression (Zar, 2010; Mcdonald, 2014) was also used to analyze the relation between BII and the fragment shape.

The organization of the data was done with the elaboration of tables through Microsoft Excel software, the elaboration of the correlation graphs and the values of the Pearson regression were obtained through the language R (Zar, 2010; McDonald, 2014).

RESULTS

The results showed that the size of the areas in Sorocaba ranged from 0.32 to 31 ha (Table 2) and in Ribeirão it varied from 1.3 to 185 ha (Table 2). It means there was a greater variation in the size of the area in Ribeirão Preto.

The shape value can vary between 0 (circular) and 6 (irregular shape). For the most of fragments from Sorocaba were recorded shape values between 1 and 2 (Table 2), and only one area (Ouro Fino Park) presented a larger value, which is a more irregular shape. For Ribeirão Preto (Table 2) the shape values varied from 1.91 to 4.22, they presented more irregular forms.

The values of biotic integrity recorded an IBB ranging from 22.34 to 33.34 for fragments of Sorocaba and from 28.7 to 40.0 for fragments of Ribeirão Preto (Table 2). The results of the regression between area size and BII and between shape and BII are shown in Figure 3, where it is possible to see a stronger positive relationship between size and BII, and a weaker positive relationship between shape and BII.

DISCUSSION

About integrity Sorocaba (Table 2) presented a large part of the fragments (65.3%) with low BII and a small part of the areas (34.7%) with medium BII, whereas Ribeirão Preto (Table 2) presented a large part of the fragments (55.5%) BII medium and a small part (22.2%) BII low, as well as another small part (22.2%) BII high. That is, there are more fragments with low integrity in Sorocaba and a large part shows medium or high integrity in Ribeirão Preto.

Comparing these results to those obtained by Medeiros and Torezan (2013) they can be observed that the authors registered very high BII only for the reference area, high for 30% of the areas, medium BII for 50% of the areas and, low for only 20% of them. Therefore, we can say that the data from Ribeirão Preto are similar from those recorded by Medeiros and Torezan (2013) for forest fragments in the region of Londrina (PR). It must be considered that the study of Medeiros and Torezan (2013) was carried out in forest fragments inserted in a rural matrix and the present study in an urban matrix that could have affected the fragments even more, decreasing their integrity.

On the other hand, Graciano-Silva et al. (2018) considered as sustainable areas (forest ecosystems with long-term capacity) those with high or very high BII (over 40) or those which registered a minimum of 60% of the maximum possible value of the BII. Considering this percentage (60% out of 55, maximum value possible to BII),we could say that in Sorocaba 4, out of 23 analyzed areas, present some sustainability and in Ribeirão Preto 7, out of 9 analyzed areas, present some sustainability.

The Pearson regression between the size and BII data was positive (Figure 3A, 3B) and strong for both municipalities (0.742 for Ribeirão Preto and 0.679 for Sorocaba). It can be observed (Table 2) that very small areas (up to 2 or 2.5 ha) presented low integrity, just large areas (above 185 ha) presented high integrity. However, relatively small areas (Fabio Barreto - 21.8 ha) presented high integrity (Table 2) or relatively large areas (Petrochemical Terminal - 76.5 ha) showed medium integrity (Table 2) indicating that there is a relation between the size of the forest fragment and biotic integrity, but that only size is not able to explain all variation in BII.

The area "Fabio Barreto" (Figure 1) is a relatively small forest and its surroundings are completely urbanized, but it has been conserved as a "Municipal Forest" and it was inserted in an Environmental Preservation Area (Brasil, 2000) or Protected Landscape (IUCN, 1994) for the last 30 years.Thus, this conservationist management must have helped significantly in the preservation of the fragment, preventing common stressors in urban fragments such as the opening of clearings for the collection of wood, fire, waste disposal, drainage, among others. In this way, a fragment that presents a balanced forest structure and dynamics, between its strata, canopy and, the different groups of species (Connell, 1978; Ordóñez; Duinker, 2012), even with an occupancy of strongly anthropized environment, can keep high integrity.

The area "Petrochemical Terminal" (Figure 1) is relatively large (76.5 ha) and did not record high integrity. Signs of fire occurrence in the recent past have been observed in the area and this fact may justify the high rate of grasses and lianas (indicators 3, 4 (Table 1) at the edges of this fragment (Pohlman et al., 2007; Silva et al., 2017). In this area, there were few late understory and canopy species (Indicators 10 and 11, Table 1) indicating

TABLE 2 IBB results for areas analyzed in Ribeirão Preto and Sorocaba,SP, Brazil. * representsthe reference areas used for comparison. The location of the areas is shownin Figure 1 (Ribeirão Preto) and Figure 2 (Sorocaba).

Areas- Ribeirão Preto	Size- ha	Shape	BII	Integrity	% BII
1- Santa Tereza Hospital	1.3	2.15	28.7	Low	52.1
2- Coffe Museum - fragment 1	2.3	4.37	36.3	Medium	66.1
3- Caffe- fragment 2	2.7	3.49	29.3	Low	53.3
4- USP -São Paulo University –didatic center	3.5	3.76	34.7	Medium	63.0
5- USP- São Paulo University -– west fragment	4.8	3.26	34.0	Medium	61.8
6- Fábio Barreto	21.8	3.37	40.3	Hight	73.3
7- Santa Maria	47.2	4.22	38.3	Medium	69.7
8- Petrochemical Terminal	76.5	1.91	36.0	Medium	65.5
9- Ribeirão Preto Ecological Station	185.0	4.12	40.0	Hight	72.7
* Vassununga State Park	331.2	-	40.3	Hight	73.3
*Porto Ferreira State Park	611.6	-	40.0	Hight	72.7
Areas- Sorocaba	**Size- ha**	**Shape**	**BII**	**Integrity**	**% BII**
1- Agua Vermelha Park	0.32	1.79	23.67	Low	43.0
2- Carlos Alberto Souza Park	0.48	1.4	25.34	Low	46.1
3-Yves Ota Park	1.00	2.35	26	Low	47.3
4-Jardim Botânico Park	1.3	1.54	29.33	Low	53.3
5-Juraci A. Boaro Park	1.44	1.55	23.67	Low	43.1
6-Miguel Gregório Park	1.55	1.6	26	Low	47.3
7-Raul Bittencourt Park	2.38	1.9	22.34	Low	40.6
8-Armando Pannunzio Park	2.46	2.4	26.67	Low	48.5
9- Villa dos Inglezes	2.49	1.38	29	Low	52.7
10-Biquinha Park	2.63	2.14	31	Medium	56.4
11-Brigadeiro Tobias Park	2.99	2.18	30.66	Medium	55.7
12-Jardim Gonçalves	3.78	1	29.67	Low	53.9
13-Piazza di Roma II	4.72	2.3	28.67	Low	52.1
14-Quinzinho de Barros Zoo	5.06	1.54	32.67	Medium	59.4
15-Braulio Guedes Park	6.23	2.4	35.34	Medium	64.2
16-Chico Mendes Park	6.26	2	35.34	Medium	64.2
17-Piazza de Roma I	6.67	2.2	28.67	Low	52.1
18-Jardim Simus	7.52	2	29.34	Low	53.3
19-Ouro Fino Park	8.03	4.43	30.34	Medium	55.1
20-Wanel Ville	9.03	2	28	Low	50.9
21-Pedro P. Almeida Park	12.25	2.1	29	Low	52.7
22-Três Meninos Park	19.16	2	33.34	Medium	60.6
23-Corredores da Biodiversidade Natural Municipal Park	31.0	2	33.34	Medium	60.6
*Ipanema National Forest	5000	-	40.0	Hight	72.7

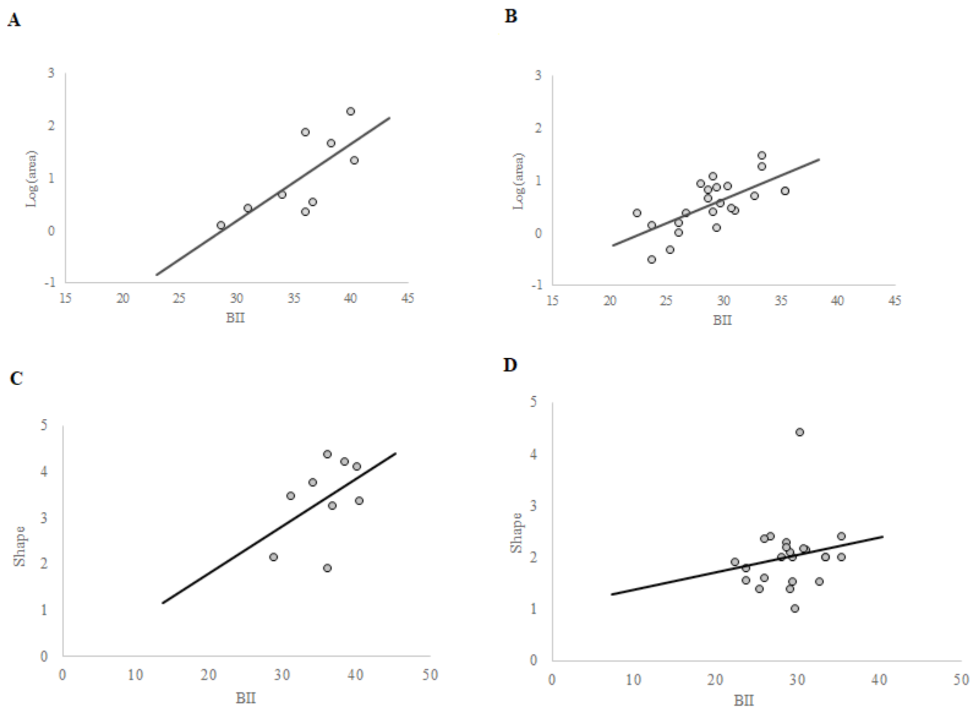

FIGURE 3 Pearson regression between BII and area size and between BII and shape. A) BII and area size to Ribeirão Preto (p = 0,742); B) BII and size area to Sorocaba (p = 0,679); C) BII and shape to Ribeirão Preto (p = 0,4614); D) BII and shape to Sorocaba (p =0,1838).

that the fire must have impaired the regeneration of late canopy species in both the canopy and understory strata. The fire must have provided an excess of disturbance (Connel,1987; Amenteras et al., 2013) and promoted the establishment of pioneer species.

These results show that sometimes the history of disturbances in the area influences negatively and more strongly than its size (Petrochemical Terminal area). On the other hand, it also shows that when conservationist management (Fabio Barreto area) avoids the possible anthropic disturbances it can positively influence the BII. So areas with reduced size can present good biotic integrity. Steenberg et al. (2019) draw attention to the importance of municipal management for the conservation and maintenance of urban forests.

Pearson regression between shape and BII (Fig. 3C, 3D) was positive for both municipalities but weak for Sorocaba and medium for Ribeirão Preto, contrary to expectations. Following previous studies (Ferraz et al. 2014; Mello et al., 2016) it was expected a strong relation because circular drawing should have a core area, where ecosystem structure and function should have been kept. The results showed a medium relation for Ribeirão Preto, where the areas varied in size and in shape. On the other hand, for Sorocaba, despite of the circular shape of the most fragments, the size of them was tiny, so the edge effect (Harper et al., 2005; Pohlman et al., 2007; Haddad et al., 2015) must have been strong for all fragments, regardless of their shape.

The results show that the exclusive effect of the shape on the biotic integrity is small or medium, but they seem to indicate that the shape and size of the area influence the maintenance of ecological processes when analyzed together (Muchailh, 2010; Mello et al. 2016). In fact, what influences or not the biotic integrity is the presence of edges, known as “edge effect” (Murcia, 1995, Silva et al., 2017) which increases the occurrence of light and wind, and this reduces shading and moisture (Silva et al., 2007). Also, there is an increase of the presence of dead trees, clearings, lianas and grasses. These indicators (mainly exotic grasses and dead trees) were present basically in all the studied areas of Sorocaba (Graciano-Silva et al., 2018) and most of them also in Ribeirão Preto (Galvani, 2018). Besides, the occurrence of the “vascular epiphyte” indicator and the absence of “orchids” were also registered for both municipalities, which must be related to the increase of the winds, and the decrease of the relative humidity of the air.

It is important to highlight that all areas used as “reference areas” are protected areas (Brasil, 2000; IUCN, 1994) where high BII were recorded (Table 2). This may be related to the size of these areas, which are usually much larger compared to urban forests. As they are large areas, the "edge effect" tends to decrease, even if the area drawing is irregular, because all of them can maintain a core area, regardless of the edges. Yet, high integrity may also be related to conservationist management, which is actually managing to avoid the occurrence of anthropic disturbances, thus maintaining them with high integrity.

CONCLUSIONS

The results allow concluding that the size of urban forests has a linear relationship with the biotic integrity of the ecosystem and that the shape of the fragment influences the integrity but with less intensity.

The results showed that very small urban forests (between 2 and 2.5 ha) generally exhibit low integrity and large urban forests (over 180 ha) exhibit high integrity. The results also indicated that there may be a minimum size for urban forests (around 20 ha) from which high integrity can be already expected, and this integrity can guarantee their survival over time. However, this will also depend on other factors, mainly historical disturbing elements and conservationist management.

Although the size and integrity are directly related, the results showed that factors such as disturbances, often caused by urbanization, influence negatively and more strongly than the size of the area itself. On the other hand, conservation management can help to maintain or enhance the integrity of urban forests, even if they are relatively small. This data is certainly relevant and it could be used in territorial planning and management by decision-makers in public policies elaboration.

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