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Association between urbanization and the biotic integrity of urban forest remnants

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Abstract: The disturbance of forest fragments has reduced environmental quality, ecosystem services and climate mitigation in several cities. The aim of the current article is to analyze the quality of native forest fragments close to urban areas. Seven forest fragments in Southeastern Brazil were selected for analysis based on two spatial scales: landscape and fragment. Analyses were structured by combining landscape diagnosis to the evaluation of the analyzed fragments, based on the application of an Index of Biotic Integrity. Data analyzed at landscape scale have shown association between the size of the analyzed urban forest fragment and its biotic integrity, as well as inversely proportional association between integrity and perimeter/area ratio. The fragment scale enabled corroborating the current study's hypothesis and evidenced association between quality of urban forest fragments and their proximity to urban areas. The adopted method has proved to be an important instrument to help developing environmental public policies focused on urban forests' planning and conservation.

Keywords: Urban landscape; Integrity Index; Conservation of Urban Fragments; Environmental Quality; Public Policies.

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1 Introduction

The world population has significantly grown in the last seventy years. According to estimates, approximately 70% of human populations will be living in urban areas by 2050 (UNITED NATIONS, 2018). This rate is even higher in Brazil, since approximately 85% of its population already lives in urban areas (FARIAS *et al.*, 2017; MACEDO; JACOBI, 2019).

This increase in humans' demand for ecosystem goods and services raises questions about limits and sustainability (DOBBS; NITSCHKE; KENDAL, 2017; MCGARIGAL *et al.*, 2018; FAO, 2018). Although urban areas only cover 3% of the Earth's surface, they account for more than 78% of global carbon dioxide emissions and for significant amounts of other greenhouse gases that contribute to climate change (FAO, 2018). Therefore, the urban environment is the place where a significant part of the planet's environmental crisis emerges (FERNÁNDEZ; WU; SIMONETTI, 2018; LIU *et al.*, 2019).

Among the events leading to the degradation of urban and peri-urban areas, one finds activities carried out without any planning and supervision type, such as occupations in permanent preservation and water-source areas, which result in land use incompatible to its potential capacity (WWF, 2018) and lead to habitat fragmentation (HADDAD *et al.*, 2015; MCGARIGAL *et al.*, 2018; LIU *et al.*, 2018). Such impacts, which arise from unplanned agricultural or urban expansion processes, change the size, shape and isolation level of native forest remnants (MELLO; TOPPA; CARDOSO-LEITE, 2016; WILSON *et al.*, 2020).

This scenario gives rise to the concept of Urban Forests, which are defined as remnants of forests modified by cities' expansion that can be found both in the urban perimeter and in the urban/rural transition (FORMAN; GODRON, 1986). The concept of urban forest should also include infrastructure (built landscape), people and institutions accounting for managing these environments (STEENBERG; DUINKER; NITOSLAWSKI, 2019).

Forested areas in urban environments provide ecosystem services, such as carbon sequestration, reduced heat islands and air pollution, as well as rainwater absorption. Nevertheless, they offer cultural ecosystem services, such as opportunities for leisure, education and contemplation - both outdoors and in the midst of nature -, as well as help improving human health and well-being (STEENBERG *et al.*, 2015; STEENBERG; DUINKER; NITOSLAWSKI, 2019; DOBBS; NITSCHKE; KENDAL, 2017; FERNÁNDEZ; WU; SIMONETTI, 2018). In addition, these areas are green infrastructure elements of paramount importance to help mitigating climate change (STEENBERG; DUINKER; NITOSLAWSKI, 2019; MACEDO; JACOBI, 2019) and preventing the emergence of epidemic diseases (AZEVEDO *et at.*, 2020).

Accordingly, the UN has established the 2030 Agenda (UNITED NATIONS, 2015), which covers 17 Sustainable Development Goals (SDGs), in order to guide the development of public policies in several countries worldwide (FAO, 2018) by establishing dialogues between global perspectives and national, regional and local realities (JACOBI; GIATTI, 2015). Among the aforementioned goals, SDG 11 focuses on "making cities and human settlements inclusive, safe, resilient and sustainable" (UNITED NATIONS, 2015).

Thus, sustainable development depends on the proper management of urban and peri-urban areas, as well as on their growth (STEENBERG *et al.*, 2015; STEENBERG; DUINKER;

NITOSLAWSKI, 2019; DOBBS; NITSCHKE; KENDAL, 2017; BARONA *et al.*, 2020); consequently, the role played by governance should be polycentric and multilevel (MACEDO; JACOBI, 2019). Management efficiency should be even higher in underdeveloped countries, where urbanization is fueled by real estate speculation (KUDO *et al.*, 2016) and rural-urban migrations, and where disorderly urban growth often precedes planned urban subdivisions, themselves (BENEVOLO, 2016). 2017; BARRERA *et al.*, 2018).

It is necessary performing an integrated forest remnant assessment (MEDEIROS *et al.*, 2015; LIU *et al.*, 2018) based on analyses conducted at landscape (e.g., region, municipality or watershed) and local (e.g., detailed analysis of each forest fragment) scale to achieve the desired efficiency (GRACIANO-SILVA, 2016; GALVANI, 2018). This integrated analysis can substantiate the development of strategies focused on the preservation of urban forests.

Intact forests have the ability to maintain their ecological features, composition elements, structure, function and ecological processes within their natural variation ranges, and it enables them to withstand and recover from most disturbances inflicted by natural environmental dynamics or by human actions (ORDÓÑEZ; DUINKER, 2012; GRACIANO-SILVA, 2016; MCGARIGAL *et al.*, 2018).

Among the environmental quality assessment methods, one finds the Index of Biotic Integrity (IBI) (MEDEIROS; TOREZAN, 2013), which uses environmental variables such as incidence of indicator species, forest structure, as well as incidence of gaps/dead trees, grass or exotic woody species. Therefore, one can assume that the greater the biotic integrity of a given fragment, the greater its resilience (GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018). However, studies of this nature carried out in urban environments remain scarce, mainly in Brazil (GREGORINI, 2015; GRACIANO-SILVA, MELLO AND CARDOSO-LEITE, 2018; GALVANI, 2018).

Accordingly, the hypothesis of the current study was that urban areas have negative effect on the quality of urban forest remnants, as well as that the closer the urban area is to a forest fragment, the stronger its effect on it, since changes in land use lead to the loss and degradation of forest fragments, worldwide (GUREVITCH *et al.*, 2009). The main aim of the current study was to assess the biotic integrity of urban forest fragments by taking into consideration the incidence and proximity of urban areas.

2 Method

The forest structure of the investigated landscape was analyzed to assess the quality of forest fragments. Then, Index of Biotic Integrity (IBI) was applied to seven of its remnants, which are located in urban and peri-urban areas, and present different land use and cover categories.

2.1 Study Site

The present research was conducted in an area of 3,707 hectares located in Boituva County, metropolitan region of Sorocaba City (MRS), Southeastern Brazil. The aforementioned area presents forest fragmentation driven by the advancement of agribusiness activities and by urban expansion; it is located next to Iperó County, which presents conurbation perspective.

Only one phytosociological survey was carried out in two forest fragments of the investigated county (GREGORINI, 2015); both fragments are inserted in the study site and present features that justify the implementation of measures focused on conserving them. Among them, one finds the incidence of threatened species and high species richness - which was also recorded for forest fragments in Sorocaba City (MELLO, 2012; MOTA *et al.*, 2016; GRACIANO-SILVA, 2016).

The remaining vegetation in this region lies on a area of ecological tension between the Atlantic Forest and Cerrado biomes; it mainly comprises the Seasonal Semideciduous Forest (SSF) and Savanna (IBGE, 2012) phytophysiognomies.

2.2 Land-use and landscape diagnosis

Land use and cover mapping was carried out through screen scanning (ANDERSON *et al.*, 1976) in Geographic Information Systems (GIS) environment, based on using ArcGIS 10.6 software (EASTMAN, 2006), standardization for Datum Sirgas 2000 and UTM23S coordinate systems.

An CBERS4 image (from 09/19th/2017; Orbit 156, point 126) - obtained free of charge at the National Institute for Space Research (INPE) website – was used as mapping basis. It presented 5-meter spatial resolution resulting from the fusion of its multispectral (10 m) and panchromatic (5 m) bands. The Zero Reflectance Principle (DUGGINS; ROBINOVE, 1990), the first-degree polynomial transformation model and the nearest neighbor interpolation method (JENSEN, 1996) were used for geometric correction purposes.

Then, a colored composition (3R, 4G, 2B) was generated on the screen to achieve mapping with overall accuracy of 95%, based on field verifications.

Four landscape ecology metrics were calculated for all seven selected fragments, namely: Area (AREA), perimeter-to-area ratio (PARA-Ratio), shape (SHAPE) and distance from the nearest neighbor (ENN). They were calculated in the V-Late landscape ecology software, in GIS environment, based on fragments in vector format. AREA expresses the area of each fragment in hectare (ha); the smaller the area of a given fragment, the higher its chance to have its biodiversity reduced, since floral and faunal species' maintenance require minimum area (ORDÓÑEZ; DUINKER, 2012; MELLO; TOPPA; CARDOSO-LEITE, 2016). PARA-Ratio and SHAPE refer to the shape of the investigated fragments; PARA-Ratio indicates to what extent its perimeter is elongated, whereas SHAPE expresses its complexity in comparison to a standard shape (perfect circle, with value equal to 1). The farther away from 1, the more irregular the shape (MCGARIGAL, 2015); thus, fragments with SHAPE index higher than 6 are considered too irregular (MELLO; TOPPA; CARDOSO-LEITE, 2016). ENN expresses the edge-to-edge Euclidean distance within the fragment; it was used to investigate landscape connectivity (MCGARIGAL, 2015).

Finally, GIS, itself, was used to calculate the shortest distance from the consolidated urban area (NEAR CUA), from the non-consolidated urban area (NEAR NCUA) and from the highway (NEAR HIGH), based on using their respective features as reference.

2.3 Selection of, and data collection in, the investigated fragments

Since the association between biodiversity and ecosystem functions depends on fragment size (LIU *et al*., 2018; GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018; GALVANI, 2018; WILSON *et al*., 2020), forest fragments with sizes ranging from 5.82 ha to 97.69 ha were herein sampled. Minimum size of 5 ha was adopted for analysis purposes, since previous studies (GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018; GALVANI, 2018) recorded low biotic integrity for fragments smaller than 5 ha.

Three sample plots (20 m x 20 m) were demarcated in each forest fragment for evaluation purposes: one close to the center of the fragment, one close to the edge of it, and one in an intermediate region. Environmental variables were surveyed in each plot by teams comprising three to five previously trained evaluators, similar to what was done by Medeiros and Torezan (2013) in the application of the original method.

Eleven environmental variables (Table 1) were selected, based on review applied to previous studies that adopted the same method (MEDEIROS; TOREZAN, 2013; GREGORINI, 2015; GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018; GALVANI, 2018). These variables were included in a matrix filled with data collected in the plots of the seven analyzed fragments, between June 2018 and June 2019. Each variable was assigned an integrity value (Table 1) that ranged from 1 (low integrity) to 5 (high integrity).

Table 1 – Variables collected in the field, in each of the seven analyzed forest fragments, whose integrity value ranged from 1 (low integrity) to 5 (high integrity). Boituva County, Metropolitan Region of Sorocaba City (MRS), São Paulo State, Brazil

VARIABLE	INTEGRITY VALUE				
	1 (low)	2	3	4	5 (high)
1 Litter cover	0% - 10%	10% - 25%	26% - 50%	51% - 75%	76% - 100%
2 Gaps	Higher than 50%	26% - 50%	11% - 25%	Present up to 10%	Absent
3 Exotic Grass Cover	Higher than 50%	26% - 50%	11% - 25%	Present up to 10%	Absent
4 Epiphytes (upper)	Absent	1 – 2 (1 sp)	3-6 (1 or 2sp)	6-9 (2 - 3 sp)	10 or + (4 or +sp)
5 Standing Dead Trees	5 or +	4	3	2	0 or 1
6 Vines	Only thin, 4 or + entangled	Only thin, 2 or 3 entangled	Only thin, 1 entangled	Thick and few thin	Only woody, thick
7 Canopy height	0 a 8	8-12,5	12,5-17	17-21	21-25
8 Diameter of individuals in the canopy	Smaller than 6 cm	6 - 14 cm	14 - 22	22 - 30	Larger than 30 cm
9 Other Exotic Species [1]	5 or more	3-4	2	1	Absent
10 Late individuals and species in the canopy [3]	Absent	1 (1sp)	2 (1 or 2sp)	3 (2 - 3sp)	4 or + (3, 4 or +sp)
11 Late individuals and species in the understory [2]	Absent	1-2 (1sp)	3-5 (1 or 2 sp)	6-9 (2 - 3sp)	10 or + (3,4 or + sp)

[1] *Eucalyptus, Pinus, Leucena* individuals (fruit trees - *Citrus, Mangifera, Coffea*, among others).
[2] Individuals belonging to families Rubiaceae, Myrtaceae, Meliaceae (*Trichillia* spp.) and Arecaceae (*Euterpe edulis*).
[3] *Cariniana* spp. (*Jequitibá*), *Cedrela fissilis* Vell. (Cedar), *Copaifera langsdorffii* Desf. (diesel tree), *Aspidosperma polyneuron* Müll.Arg. (*Peroba-rosa*), Laurarceae (several spp.).

Source: CARDOSO-LEITE, 2017.

2.4 Index of Biotic Integrity (IBI)

The environmental quality of urban and peri-urban forest fragments was evaluated based on using the method called Index of Biotic Integrity (IBI), which was developed by Medeiros and Torezan (2013), based on Rapid Ecological Assessment methods (SAYER *et al*., 2000).

The sum of scores attributed to all 11 selected variables (Table 1) provided the biotic integrity value of the analyzed plots. Thus, IBI of each forest fragment was calculated by taking into consideration the simple average of values measured in each plot; it ranges from 11 to 55 points. Based on the result of this calculation, it was possible finding values that indicated areas showing excellent (50 to 55), good (40 to 49.9), regular (30 to 39.9), poor (20 to 29.9) or significantly poor (11 to 19.9) integrity (CARDOSO-LEITE, 2017).

2.5 Data analysis at landscape and fragment scales

Analyses were structured by combining land use to cover survey, landscape indices (metrics and factors) to Index of Biotic Integrity (IBI) of the analyzed fragments, based on taking landscape as complex information unit formed by the association between forested and anthropized areas (FERNÁNDEZ; WU; SIMONETTI, 2018; STEENBERG; DUINKER; NITOSLAWSKI, 2019; MACEDO; JACOBI, 2019). Two analysis scales were adopted for such a purpose, namely: (1) landscape and (2) fragment (or local) scale.

Non-parametric test was performed to analyze the degree of association among variables measured at landscape scale (AYRES et al., 2007). It was done to investigate the correlation of results recorded for AREA, PARA-Ratio, SHAPE, ENN and landscape factors (NEAR) to IBI, based on calculating the Spearman's linear correlation coefficient, which was used due to non-normality of the data set (GOTELLI; ELLISON, 2011). This analysis assumed 15% probability of error ($p=0.15$), based on the number of fragment samples. Calculations were performed in the BioEstat 5.3 software (AYRES *et al*., 2007).

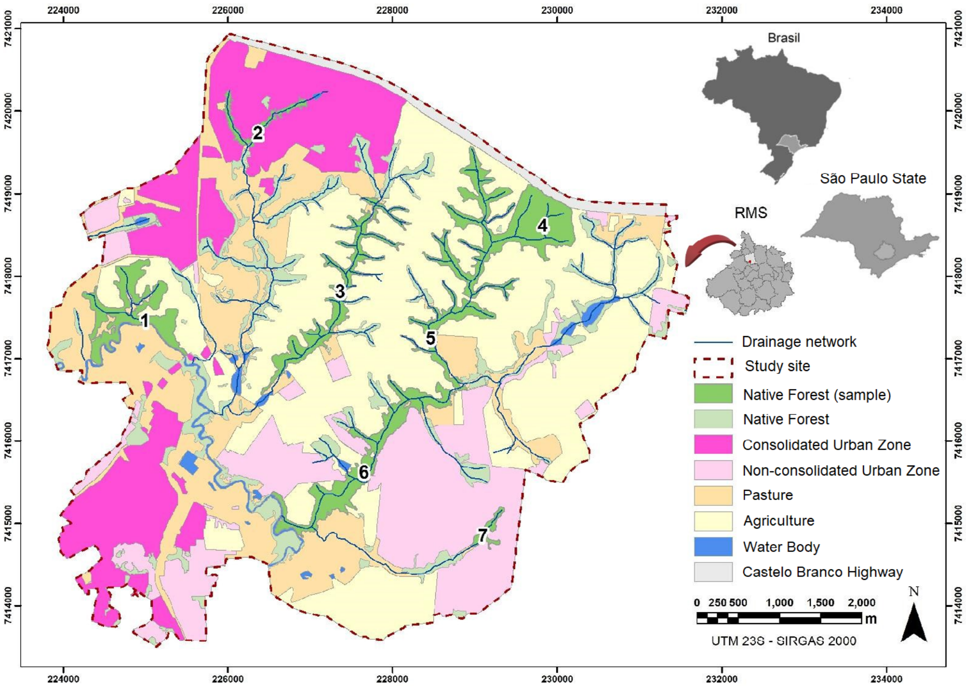
The performance of each sample N (plot), the respective results recorded for IBI variables and their association with the proximity to the edge of the fragment and to the urbanized area, were analyzed at fragment scale. Multivariate analysis, known as Principal Component Analysis (PCA), was used for this purpose. Calculations were performed in the Fitopac2 software (SHEPHERD, 2010).

3 Results and Discussion

3.1 Land-use and landscape diagnosis

The study site has 16% of its total area covered by native forest, 2% of it accounts for water bodies, approximately 34% of it is used for agricultural purposes, 18% is covered by pasture, and 30% of it corresponds to urban areas (15% of consolidated and unconsolidated urban area, each), as shown in Figure 1. According to the herein conducted analysis, the study site has 82% of its total area covered by anthropic land use.

Figure 1. Land use and cover in the study site, and its location in Boituva County, Metropolitan Region of Sorocaba City (MRS), São Paulo State, Brazil. Numbers 1 to 7 represent the investigated forest fragments



Source: Land use and cover mapping carried out by the authors, July 2019.

The effects of this configuration on native forest fragments stand out when one analyzes their shape, which is mostly elongated, narrow or irregular; this finding shows that their preservation was maintained and that it almost exclusively followed the Permanent Preservation Areas (PPA) provided on Law n. 12,651 (BRASIL, 2012). The exceptions lie on fragment 4, which was the only fragment of partially public domain analyzed in the current study (GREGORINI, 2015; CARDOSO-LEITE, 2017) and presented a more rounded shape; as well as on fragment 1, which maintained its shape due to the rugged topography of the area (checked in the field) that, in its turn, made it hard to establish settlements or other processes capable of degrading this fragment.

The literature reported negative effects for narrow fragments like the ones observed in this landscape. According to SCHINDLER *et al.* (2013), rounded natural fragments are the ones mostly suitable to maintain ecosystem services in the landscape, since they suffer lower edge effect (MCGARIGAL, 2015; HADDAD *et al.*, 2015). On the other hand, elongated fragments face increased edge effect, which leads to high incidence of light and temperature, low relative humidity, and favors the incidence of invasive species adapted to these conditions. Besides, this effect changes nutrient availability in the soil and sediments' flow, as well as reduces the size of forest remnants. It is the reason why it is often impossible maintaining certain fauna and flora populations in these fragments; sometimes they even disappear from these environments (MCGARIGAL, 2015; MELLO; TOPPA; CARDOSO-LEITE, 2016; SILVA *et al.*, 2017).

The edge effect on forest fragments subjected to these conditions can range from 20 to 400 meters. Sometimes it can reach kilometers into the fragment and make it impossible preserving its inner part; consequently, it leads to fragment degradation (MURCIA, 1995; RODRIGUES; NASCIMENTO, 2006), affects its energy and biomass flow, increases the effect of winds on it and predisposes it to the incidence of wildfires (SILVA *et al.*, 2017; WILSON *et al.*, 2020).

Observing the landscape in the study site (Figure 1) allowed perceiving an urban expansion gradient; fragments appeared smaller and isolated as urban intervention changed from non-consolidated to consolidated. This finding has evidenced that the urbanization process in this area did not conserve native forest fragments; consequently, it affected the maintenance of ecosystem services and hindered biodiversity preservation (FERNÁNDEZ; WU; SIMONETTI, 2018; STEENBERG; DUINKER; NITOSLAWSKI, 2019).

3.2. Landscape Analysis & Index of Biotic Integrity

Table 2 shows the results recorded for all seven fragments, whose size ranged from 5.81 to 97.69 ha, whereas IBI values ranged from 31 (regular integrity) to 41 (good integrity).

Table 2 – Results of metrics, landscape proximity factors and IBI, in Boituva County/SP, Brazil; wherein ID=fragment identifier number, AREA(ha)=area, PARA=perimeter/area ratio, SHAPE=shape index, ENN(m)=distance from the nearest neighbor, NEAR NCUA(m)=shortest distance from non-consolidated urban area, NEAR CUA(m)= shortest distance from consolidated urban area, NEAR HIGH (m)= shortest distance from highway, and IBI = Index of Biotic Integrity

ID	AREA (ha)	PARA	SHAPE	ENN (m)	NEAR NCUA (m)	NEAR CUA (m)	NEAR HIGH (m)	IBI
1	50.61	0.022	4.50	10.5	68.08	10.5	2,834.1	38
2	10.80	0.05	4.63	35.50	1,449	0.00	423.29	35
3	50.82	0.03	6.13	8.39	109.25	300.7	1,084.7	32
4	97.69	0.017	4.67	50.86	151.13	772.1	0,00	41
5	24.20	0.03	4.14	16.89	0.00	1,469	1,552	34
6	61.41	0.02	4.41	15.01	0.00	822.9	2,606	35
7	5.81	0.037	2.50	145.72	0.00	3,227	3,724	31

Source: Elaborated by the authors, 2019.

The degree of correlation between IBI applied to native forest fragments and the landscape metrics/factors - based on calculating the Spearman's linear correlation coefficient - has indicated association between IBI and the size of the analyzed fragments, which recorded positive mean value correlation (Spearman =0.61; p=0.14); in other words, the larger the fragment size at landscape scale, the higher the IBI.

Despite the considerable variation in size among samples and the regular integrity (average) observed for six of the seven investigated fragments, it was possible seeing (Table 2) that the only fragment presenting good (high) integrity was the largest one (fragment 4 - 97.69 ha). The smallest fragment (5.81 ha) recorded the lowest integrity score, which bordered poor (low) integrity.

There was inversely proportional correlation of the mean value recorded for the PARA-Ratio metric (Spearman=-0.65; p=0.11). Therefore, the larger the perimeter extension (i.e., the larger the edge extension), the lower the IBI. Fragments 2 and 7 (Table 2) - both interspersed in the urban area - recorded the highest PARA-Ratio value, and it indicated that they were the most elongated fragments. Fragment 4 (the only one presenting good integrity) recorded the lowest PARA-Ratio value, and it indicated that it was the least elongated fragment among the analyzed ones. This finding has shown that the fragment's nuclear area must be protected from anthropogenic stress in order to enable maintaining its biotic integrity (MCGARIGAL, 2015; GALVANI, 2018). SHAPE did not show significant positive correlation (Spearman=0.39; p=0.37) to IBI, since the rejection limit (p) exceeded 0.15. However, assumingly, it happened because the sample did not comprise a number of fragments large enough to support significant variation in shape complexity.

Metrics adopted to analyze connectivity did not show correlation to biotic integrity. ENN did not show significant correlation to IBI (Spearman=-0.03; p=0.93). With respect to proximity factors, although NEAR NCUA (Spearman=0.46; p=0.26), NEAR CUA (Spearman=-0.49; p=0.25) and NEAR HIGH (Spearman=-0.45; p =0.31) recorded significant coefficient values, the rejection threshold (p) exceeded 0.15. This outcome invalidated the correlation of distances from the unconsolidated urban area, from the consolidated urban area and from the highway to IBI, partly due to the feature of the investigated peri-urban landscape, which comprises fragments close to other habitats and helps maintaining the regularity of its integrity.

Therefore, it is possible saying that results recorded at landscape scale have evidenced directly proportional association between urban forest size and its biotic integrity; this outcome corroborates the ones reported by previous studies based on similar methods (GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018; GALVANI, 2018). There was inversely proportional association between integrity and edge-perimeter ratio, as well as lack of association of fragment shape and distance from the nearest neighbor with biotic integrity; this outcome corroborates the ones reported by Graciano-Silva (2016) and Galvani (2018).

It was not possible observing the influence of distance from the non-consolidated urban area, from the consolidated urban area and from the highway on the analyzed fragments at this scale, and it indicated the need of changing from landscape scale to fragment's local scale in order to enable a more detailed analysis.

3.3 Fragment Analysis & Index of Biotic Integrity

Multivariate statistics (PCA = Principal Component Analysis) was used for the analysis conducted at fragment scale; results were ordered based on sample, IBI and on plot variables, as shown in Table 3.

Table 3 – Differentiation of results based on sample (plot), Index of Biotic Integrity (IIB), as well as on variables such as shortest distance (plot) from the edge (Dist. Edge) and from the urban area (Dist.Urb), and the result recorded for individual IBI variables duly adjusted for analysis purposes; wherein: Lit.=Litter cover; Gap=Gaps; Gra. =Grass Cover; Epi. =Epiphytes; Dead=Standing dead trees; Vin.=Vines; Heig.=Canopy height; Diam. =Diameter of canopy individuals; Exo=Other exotic species; Can Lt. =Late individuals and species in the canopy; and Und Lt= Late individuals and species in the understory represent all 11 variables in Table 1 Boituva County, Metropolitan Region of Sorocaba (MRS), São Paulo State, Brazil

Par.	IBI	Dist. Edge (m)	Dist. Urb. (m)	Lit.	Gap	Gra	Epi.	Dead	Vin.	Heig.	Diam.	Exo	Can Lt	Und Lt
1A	40	54.4	457	5	2	1	4	4	2	2	4	1	2	3
1B	37	41.1	588	5	3	2	5	5	3	3	3	1	1	4
1C	37	29.7	398.2	5	4	2	2	5	3	3	3	1	2	5
2A	34	23.3	23.31	5	2	4	3	5	5	3	3	1	2	5
2B	29	9.88	9.98	5	2	5	1	5	5	2	3	1	1	5
2C	43	7.25	1.566	5	2	3	5	4	2	3	4	1	3	5
3A	35	58.4	289.1	5	4	2	2	2	3	2	2	1	1	5
3B	29	37.9	472.4	5	5	2	4	5	5	2	2	2	1	4
3C	33	32.6	631.8	5	4	2	4	5	4	3	3	3	2	4
4A	42	168	668.2	5	2	2	2	1	2	4	3	3	3	5
4B	48	115	326.3	5	2	2	5	1	2	4	4	1	3	5
4C	32	84.2	801.6	5	3	2	1	5	5	2	2	1	3	5
5A	39	38.8	879.5	5	2	3	5	2	3	3	3	5	3	5
5B	31	34.7	890.3	5	4	4	4	2	4	3	2	5	1	5
5C	31	32.9	871.8	5	4	4	3	1	4	2	2	4	1	5
6A	38	81.5	93.38	5	2	2	3	4	2	2	3	1	1	5
6B	38	50.3	166.3	5	2	2	3	1	5	2	3	1	1	5
6C	29	42.1	132.4	5	4	3	1	4	5	2	2	2	2	5
7A	34	36.9	37.11	5	4	4	3	1	5	3	3	1	2	3
7B	27	15.6	15.88	4	4	4	3	1	5	2	3	4	1	2
7C	31	6.90	6.64	5	4	4	2	2	4	2	3	2	1	4

Source: Elaborated by the authors, 2019.

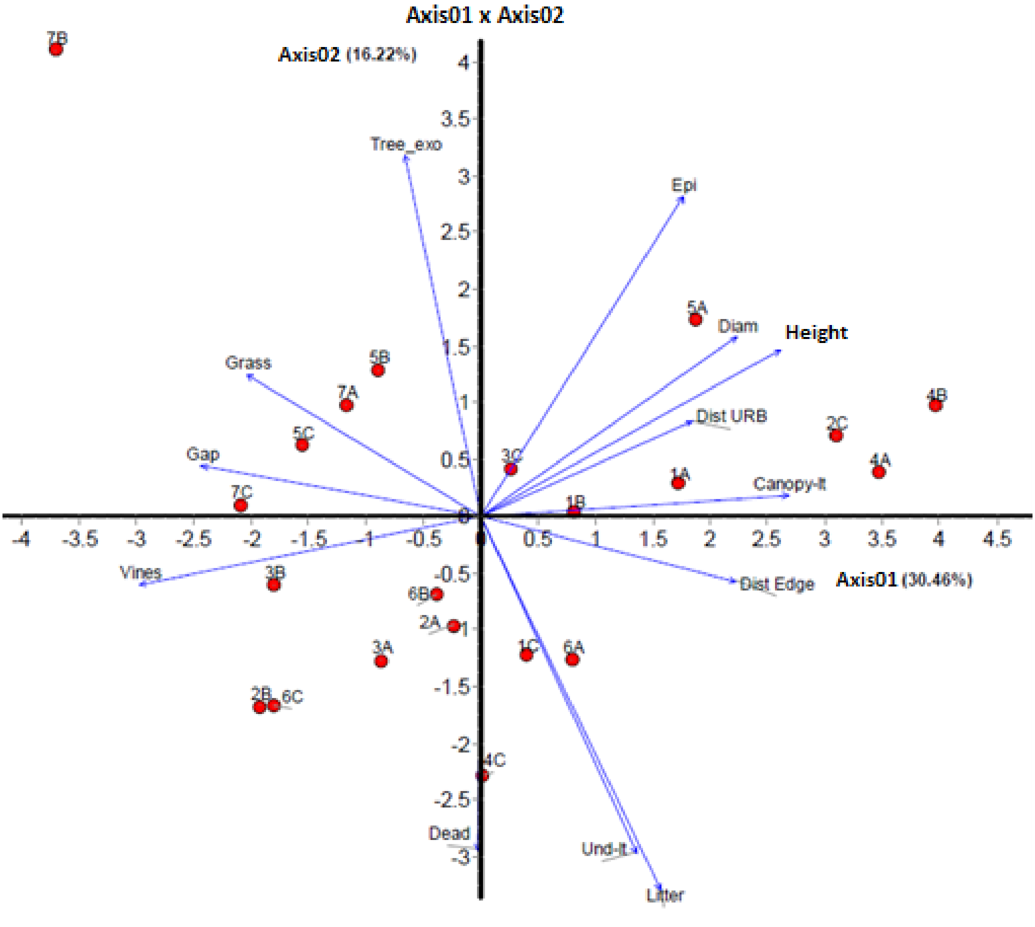
PCA resulted in spatialization of sample units in the principal component named Axis 1 and Axis 2 (axes x and y). Axis 1 recorded variance of 30.46%, whereas Axis 2 recorded 16.22%; this component recorded the highest accumulated-variance rate (eigenvalue), which accounted for 46.67% of data set variation, based on Table 4 and Figure 2, respectively. The most explanatory variables for each principal component are identified through eigenvector values described in Table 4.

Table 4. Eigenvector values of variables in the Principal Components (PCA) and explanatory percentage of each axis; wherein: Dist. Edge=shortest distance (plot) from the edge; Dist.Urb= shortest distance from the urban area; Litter=Litter cover; Gap=Gaps; Grass=Grass cover; Epi. =Epiphytes; Dead=Standing dead trees; Vines=Vines, Height=Canopy height, Diam. =Diameter of canopy individuals; Tree_exo= Other exotic species; Canopy-lt. =Late individuals and species in the canopy; Und-lt= Late individuals and species in the understory. Boituva County, Metropolitan Region of Sorocaba (MRS), São Paulo State, Brazil

Lines	Axis 01	Axis 02	Axis 03	Axis 04	Axis 05
Dist Edge	0.3015	-0.0775	0.1068	-0.5696	-0.2801
Dist URB	0.2514	0.1141	0.4068	0.4228	-0.0875
Litter	0.2143	-0.4472	0.2112	0.1619	0.0781
Gap	-0.3315	0.0597	0.2275	0.1099	-0.4323
Grass	-0.2768	0.1697	0.1390	0.0127	0.6844
Epi	0.2388	0.3827	-0.0341	0.4246	-0.1182
Dead	-0.0032	-0.4000	-0.1610	0.5036	-0.0566
Vines	-0.4038	-0.0828	0.0644	-0.0227	0.2047
Height	0.3552	0.1999	0.1368	-0.1007	0.1706
Diam.	0.3024	0.2139	-0.4900	0.0912	0.2459
Tree_exo	-0.0898	0.4317	0.4918	0.0010	-0.0131
Can-Lt	0.3650	0.0249	0.0983	-0.0695	0.1603
Und-Lt	0.1857	-0.4032	0.4072	-0.0255	0.2793
Variance rate	30.46%	16.22%	13.32%	10.75%	8.81%
Accumulated rate	30.46%	46.67%	59.99%	70.74%	85.63%

Source: Elaborated by the authors, 2019.

Figure 2. Principal Component Analysis (PCA) applied to data based on sample (plot), Index of Biotic Integrity (IIB), on variables such as shortest distance (plot) from the edge (Dist. Edge) and from urban area (Dist.Urb), and on results recorded for individual IBI variables properly adjusted for analysis purposes; wherein: Litter=Litter Cover; Gap=Gaps; Grass=Grass Cover; Epi. =Epiphytes; Dead=Standing dead trees; Vines=Vines; Height=Canopy height; Diam. =Diameter of canopy individuals; Tree_ exo=Other exotic species; Canopy-lt. =Late individuals and species in the canopy; and Und-lt=Late individuals and species in the understory represent all 11 variables in Table 1. Boituva County, Metropolitan Region of Sorocaba City (MRS), São Paulo State, Brazil



Source: Elaborated by the authors, 2019.

Based on the analysis of Axis 1 (Figure 2), the group was influenced by "Dist. Urb" and "Dist. Edge", i.e., by the highest values recorded for the shortest distance from the edge of the fragment and from the urbanized area. These plots recorded the highest values for canopy diameter, height, late species in the canopy and incidence of epiphytes (indicators of best integrity area).

Results have evidenced biotic integrity gradient ranging from regular to high. Plots 4B, 2C, 4A, 1A have shown high integrity, whereas plots 5A, 6A, 1B, 1C, 3C have shown regular integrity; all these plots were far from the urbanized area (Figure 2), except for plot 2C that, based on punctual analysis, presented high integrity despite its proximity to the consolidated urban area. The outcome observed for plot 2C may have been influenced by the disturbance history of both this fragment and its surroundings, since one can see public domain fragments at regeneration stage to the South of it (GREGORINI, 2015).

It is important emphasizing that the group (positive values in Axis 1) included many A and C plots, i.e., plots located inside the fragment and those close to its edge. This outcome corroborated PARA-Ratio results, which indicated that theses fragments were elongated and prone to edge effect; in other words, regardless of the plot position, these fragments were fully under the edge effect (MCGARIGAL, 2015; HADDAD et al., 2015; SILVA et al., 2017). Despite this condition, fragments presenting lesser elongated shape, which were farther away from the urbanized area (Fragments 1 and 4), had all their plots included in this group (positive values for Axis 1).

Based on the comparison of current results to those reported by Galvani (2018) and Graciano-Silva, Mello and Cardoso-Leite (2018), it was possible seeing that fragments recording good scores for variables associated with individuals belonging to late-stage canopy species, litter cover and canopy cover have shown higher biotic integrity. This outcome has indicated that the analyzed variables were sensitive to show that "distance from urbanization" can help preserving biotic integrity.

The incidence of late-stage canopy species with preserved structure (height and diameter) can lead to low light penetrability and assure lower direct sunlight incidence in the lowest strata. This process mitigates weather-related effects and preserves humidity inside the forest; consequently, it ensures epiphytes' maintenance and balanced species development (HECKMANN; MANLEY; SCHLESINGER, 2008; GRACIANO-SILVA; MELLO; CARDOSO-LEITE, 2018; GALVANI, 2018).

At the other extreme of this axis (negative values in Axis 1), one finds plots 7 (A,B,C) and 2 (A,B) (Figure 2), which were the ones closest to the urbanized area and belonging to the closest fragments to the urbanized area (Figure 1). These plots were associated with variables "Gap", "Vines" and "Grass". In other words, plots and fragments closer to the urbanized area presented increase in low integrity indicators, such as gaps, lianas and grasses; it affected the biotic integrity of these fragments. It happened because this group has shown biotic integrity gradient ranging from regular to poor - with emphasis on plots 7B, 2B, 3B, 6C - as well as the most elongated fragments (2 and 7). This outcome confirmed the association between elongated shape (PARA-Ratio) and decreased biotic integrity, since this shape enables higher incidence of wind, light and heat, as well as favors the incidence of invasive species adapted to these conditions (HECKMANN; MANLEY; SCHLESINGER, 2008; LONDE, 2020).

Galvani (2018) observed these very same variables associated with low integrity, in addition to "standing dead trees", which are seen by several scholars as disturbances resulting from the edge effect and from urban occupation. Assumingly, the incidence of gaps (Gap) increases the incidence of lianas and grasses, a fact that indicates degradation (HECKMANN; MANLEY; SCHLESINGER, 2008; MEDEIROS *et al*., 2015; LONDE, 2020). Graciano-Silva (2016) has also attributed high incidence of lianas to the most degraded environments, whose species were not capable of closing the canopy, when there were gaps and opened room for liana tangle formations.

The analysis of Axis 2 (Figure 2) has evidenced that high explanatory value was recorded for variables such as Litter (litter), Dead (dead trees), Tree-exo (exotic woody species), Und-lt (Understory) and Epi (epiphytes). It was possible seeing (Figure 2) that exotic species (tree_exo) were mostly associated with plots 7 (A, B, C) and 5 (B, C). This finding has shown that plots that were under the edge effect and close to urbanized areas presented more exotic species, a fact that can change ecosystem functions, such as hydrological conditions and nutrient cycling (HECKMANN; MANLEY; SCHLESINGER, 2008), which are linked to low biotic integrity. These species can enter these fragments just by being planted close to their edges or due to the dispersion of species used for the afforestation and ornamentation of streets and houses close to these fragments (GRACIANO-SILVA, 2016).

On the other hand, variable “Dead” (dead trees) did not appear to be associated with urbanization, i.e., the incidence of dead trees in the investigated area appears to have resulted from the natural forest dynamics, which may have influenced the observed “Litter” (litter) increase (MEDEIROS; TOREZAN, 2013). This finding corroborates the analysis of principal component 1, which evidenced the same low integrity fragments (2B, 3B and 6C) and indicated association of such an integrity level with the incidence of Vines (Lianas), Dead (dead trees) and Und-It (late species in the understory).

4 Conclusions

4.1 Theoretical-academic conclusions

Data analyzed at landscape scale in the current study have shown positive correlation between forest fragment size and its biotic integrity, as well as inversely proportional association between integrity and perimeter/area ratio. Lack of association between variables “fragment shape” and “distance from the nearest neighbor”, and biotic integrity can be attributed to the configuration of the investigated landscape, which comprised fragments without significant variation in shape and in distance between them.

The hypothesis of the current study was corroborated at fragment scale, since there was association between the quality (biotic integrity) of forest fragments and urbanized area. Results have shown that the distance from the urbanized area has influenced the increased epiphytes, tree diameter and height, as well as the incidence of late species in the canopy, which are variables indicating good biotic integrity. On the other hand, fragments near the urban area and the edge of the forest presented increased incidence of gaps, lianas, grasses and exotic species, which are variables indicating low biotic integrity that are also capable of harming local biodiversity preservation and ecosystem services’ maintenance.

4.2 Implications for public policies

Results in the current study can be used to help developing public local environmental and urban planning policies focused on fulfilling regional, national and international goals and agreements.

At local level, these data can be used to review the Municipal Master Plan. The Boituva County's Master Plan currently in force was published in 2006 (BOITUVA, 2006) and is currently under review. The Bill to amend the current Master Plan (BOITUVA, 2020) only has proposed two environmental interest macro-zones, one in the Northern sector of the county and the other one in the Southern sector of it, on the banks of Sorocaba River. It has also proposed urban expansion (small farm area) in a strip parallel to Castelo Branco Highway. However, its approval could lead to the destruction of forest fragment 4, which is one of the largest and best-preserved forest fragments in Boituva County. Thus, it is necessary establishing dialogue between the Public Power and Civil Society in order to observe academic studies previously carried out and to incorporate them in the formulation of Public Policies, such as the Master Plan under review.

Results in the present study can be used to elaborate a Municipal Environmental Policy to provide guidelines for the creation and maintenance of conservation units (BRASIL, 2000; BRASIL, 2019) and green areas, as it happens in other counties in the investigated region (SOROCABA, 2012). The investigated county could also expropriate areas for conservation purposes or encourage rural landowners to create Private Reserves. Fragment 4 stands out as priority area to create a Conservation Unit (BRASIL, 2000, BRASIL, 2019) due to its size and high biotic integrity.

If one takes into consideration the existence of *Programa Município VerdeAzul* (Green-Blue Municipality Program) developed by São Paulo State (SÃO PAULO, 2021), results in the current study can be used at state level to help improving Boituva County's score in the next evaluations, mainly in Directives 4 (Biodiversity) and 7 (Land Use). This county ranked 134th in the state ranking in the last assessment (SÃO PAULO, 2021); it was far below other counties in the same region, such as Sorocaba and Itu, which ranked 11th and 6th, respectively.

With respect to international goals and agreements, Brazil is signatory to the Convention on Biological Diversity (CBD, 2014); the document called "Aichi Biodiversity Targets" (CBD, 2020) was issued at the 10th Conference of the Parties. During this Conference, it was agreed that CBD-participating countries should reduce by 50%, or bring to zero, the habitat loss rate, including forests (target 5); use at least 17% of their continental territory as areas protected by law (target 11); as well as preserve and restore ecosystems accounting for providing ecosystem services (target 14). Thus, the conservation of forest fragments and the creation of protected areas in them would contribute to the compliance with this agreement and enable Boituva County to get a prominent place in the national scene.

According to the "UN Sustainable Development Goals" (UNITED NATIONS, 2015), Goals 11 (Sustainable Cities and Communities) and 15 (Terrestrial Life) address cities and forests, respectively. Using data deriving from the present study in the protection and sustainable use of forest remnants (goal 15) would also contribute to fulfill goal 11, i.e., it could turn Boituva into a more resilient and sustainable county, which could serve as example to the other counties.

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SciELO

Relação entre urbanização e integridade biótica de remanescentes de Florestas Urbanas

Vanessa Peixoto Giacon
Roberta Averna Valente
Eliana Cardoso-Leite

São Paulo. Vol. 25, 2022

Artigo Original

Resumo: A perturbação dos fragmentos de florestas tem reduzido a qualidade ambiental, serviços ecossistêmicos e atenuações climáticas nas cidades. O objetivo deste artigo foi analisar a qualidade dos fragmentos de floresta nativa próximos às áreas urbanas. Foram selecionados sete fragmentos, no Sudeste do Brasil, para análise em duas escalas espaciais: paisagem e fragmento. Estruturaram-se as análises combinando o diagnóstico da paisagem e a avaliação dos fragmentos analisados a partir da aplicação de um Índice de Integridade Biótica. Na escala da paisagem, os dados demostraram existir relação entre o tamanho do fragmento de floresta urbana e sua integridade biótica e relação inversamente proporcional entre integridade e razão perímetro/área. Na escala do fragmento, corroborou-se a hipótese deste artigo, demonstrando haver relação entre a qualidade dos fragmentos florestais urbanos com a proximidade da urbanização. O método mostrou-se um instrumento importante para elaboração de políticas públicas ambientais de planejamento e conservação de florestas urbanas.

***Palavras-chave*:** Paisagem Urbana; Índice de Integridade; Conservação Fragmentos Urbanos; Qualidade Ambiental; Políticas Públicas.

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Relación entre urbanización e integridad biótica de remanentes de Bosque Urbano

Vanessa Peixoto Giacon
Roberta Averna Valente
Eliana Cardoso-Leite

Resumen: El objetivo de este artículo es analizar la calidad de los fragmentos forestales nativos con la proximidad de la urbanización. Siete fragmentos de bosques nativos en el sureste de Brasil fueron seleccionados para su análisis a dos escalas: paisaje y fragmento. Los análisis se estructuraron combinando el diagnóstico de uso y cobertura del suelo, índices paisajísticos y el Índice de Integridad Biótica (IIB) de los fragmentos analizados. En la escala paisajística, los datos mostraron que existe una relación entre el tamaño del fragmento del bosque urbano y el IIB, así como una relación inversamente proporcional entre la integridad y la relación perímetro/área. En la escala del fragmento, se corroboró que existe una relación entre la calidad de los fragmentos del bosque urbano con la proximidad de la urbanización. El método resultó ser un instrumento para la elaboración de políticas públicas ambientales para la planificación y conservación de los bosques urbanos.

Palabras-clave: Paisagem Urbana; Índice de Integridade; Conservação Fragmentos Urbanos; Calidad del médio ambiente; Políticas Públicas.

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