



Urban landscape influences the composition of butterflies in public parks and fragments in Southern Brazil

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Abstract: Terrestrial ecosystems across the world experience large-scale and widespread urbanization, causing a sharp decline, fragmentation and segregation of natural landscapes. Nevertheless, fragments of natural habitats that are found within the largest cities may still be capable of preserving high species diversity that amount to a large portion of the regional biodiversity. Knowing which variables of the urban landscape promote the conservation of species' assemblages in large cities helps us to implement measures that support biodiversity conservation. We sampled the butterfly assemblages of eight urban forest fragments in Curitiba (Southern Brazil), from September 2015 to April 2016. At each site, richness, diversity and composition of butterflies were estimated and then correlated to nine landscape variables measured at two spatial scales (buffers of 250 and 750m). A total of 298 species were recorded in these fragments, representing 53.7% of all species known to occur in the city. Despite of great difference in the size of the fragments (between 27 and 56.3 ha), there were no significant differences in species richness among the fragments. On the other hand, some significant correlations were observed between landscape variables and butterfly composition other than the fragment itself, such as the paved area and total forested area present around the fragments. These results reinforce the idea that the conservation of natural fragments in urban areas requires public policies that enhance not only the habitat quality of the fragment itself, but also enrichment of the landscape around them.

Abbreviations: BA–Bosque do Alemão; BCI–Bosque Capão da Imbuia; BTr–Bosque dos Tropeiros; BJII–Bosque João Paulo II; BRM–Bosque Reinhard Maack; BTa–Bosque Tatuquara; CCA–Canonical Correspondence Analysis; FoA–Forest area; D–Fractal dimension; Dist–Fragment and the green belt around the urban matrix; FrP–Fragment perimeter; FrA–Fragments area; ISTF–Mean fragment isolation index; OGA–Open green area; PB–Parque Barigui; PaA–Paved area; CON–Proportion of the connection area; ZM–Zoológico Municipal.

Introduction

Urbanization is currently recognized as one of the main causes of habitat loss, mostly promoted by the rapid growth and concentration of human populations in large urban centers (Grimm et al. 2008). Consequently, large cities experience shrinking, fragmentation, and isolation of their natural ecosystems (Hardy and Dennis 1999, Pickett et al. 2001), resulting in highly altered landscapes.

Although isolated green areas, parks or fragments in urban landscapes are usually easily accessible for humans, biodiversity studies in urban ecosystems are still comparatively scarce (Bolund and Hunhammar 1999, Koh and Sodhi 2004, Ramírez-Restrepo et al. 2007, McKinney 2008, Ramírez-Restrepo and Halffter 2013). This obstructs an accurate evaluation of which variables are more intrinsically associated with biodiversity loss, such as size, shape, isolation, and connectivity of natural habitats, as well as the quality of the matrix (Dennis and Hardy 2001, DeSouza et al. 2001).

Since different organisms have particular biological characteristics, a variety of responses to the same anthropomorphic change may be expected by different taxa (Didham et al. 1998, DeSouza et al. 2001, Hill and Curran 2003). Butterflies

have often been used as model organisms for biodiversity monitoring because included are both groups of species which increase and decrease their population sizes in response to habitat modification (McDonnell and Pickett 1990, Ramírez-Restrepo and Halffter 2013). This makes them an ideal group to study the fragmentation caused by urbanization (Ruszczyk 1986, Blair and Launer 1997, Brown and Freitas 2000, Hogsden and Hutchinson 2004). Butterflies may be attracted to flowers and use host plant species that are cultivated either in home gardens or urban and park areas (Blair and Launer 1997, Bergerot et al. 2011).

Hence, this relationship directly affects their assemblage structure across the urban landscape, as the vicinity of forest fragments varies, e.g., being highly isolated by buildings, or partially connected by tree lines along street sidewalks, or by private backyard gardens (McDonnell and Pickett 1990, Felson and Pickett 2005, Grise et al. 2016). Therefore, the butterfly assemblages present in fragments isolated by an urban matrix are not only subjected by the quality of the fragments they inhabit, but also by factors that are external to the fragment itself. Knowing which urban landscape variables influence the patterns of butterfly assemblages may help to implement measures that support biodiversity conservation in large cities around the world. Aiming this goal, the cur-

rent study sampled the butterfly assemblages of eight forest fragments located in a large urban matrix in Southern Brazil, expecting to find more diverse assemblages related to both larger fragments and fragments less isolated by paved areas. Similarly, we also hypothesized that these landscape measurements affect assemblage composition, thus revealing that larger and less isolated fragments have more similar species composition compared to smaller and more isolated fragments. Finally, we compared the total butterfly richness collected in these fragments with the total richness already recorded for the city.

Material and methods

Study area

The city of Curitiba is located in the state of Paraná, Southern Brazil (Fig. 1) at 900-1000 m asl, Curitiba was originally covered by mixed Ombrophilous Forest (*Araucaria* Forest). The annual temperature ranges from 12.9°C to 22.5°C, with 16.4°C mean temperature. The climate is temperate oceanic climate (Cfb), according to the Köppen classification (García 1973), and annual average precipitation is

around 1600 mm (IPPUC 2012). Curitiba has 16 forests, 393 gardens, 54 lakes, 21 parks, 418 environmental parks, and four private reserves of municipal natural heritage (Grise et al. 2016). These green areas are present all over the city, although they are more concentrated in the northern and western zones (Vieira and Biondi 2008).

Butterfly sampling

We sampled butterflies using insect nets in eight fragments in the city: Bosque do Alemão (BA), Bosque Capão da Imbuia (BCI), Bosque dos Tropeiros (BTr), Bosque João Paulo II (BJII), Bosque Reinhard Maack (BRM), Bosque Tatuquara (BTa), Parque Barigui (PB), and Zoológico Municipal (ZM) (Fig. 1).

Four samplings were performed by two researchers in each fragment between September 2015 and April 2016, from 09:30 to 16:30. Specimens were identified with the assistance of specialists and/or by comparison with type specimens (Warren et al. 2009). Species' nomenclature follows Lamas (2004) for Papilionoidea, and Mielke (2005) for Hesperidae. Voucher specimens were deposited in the Entomological

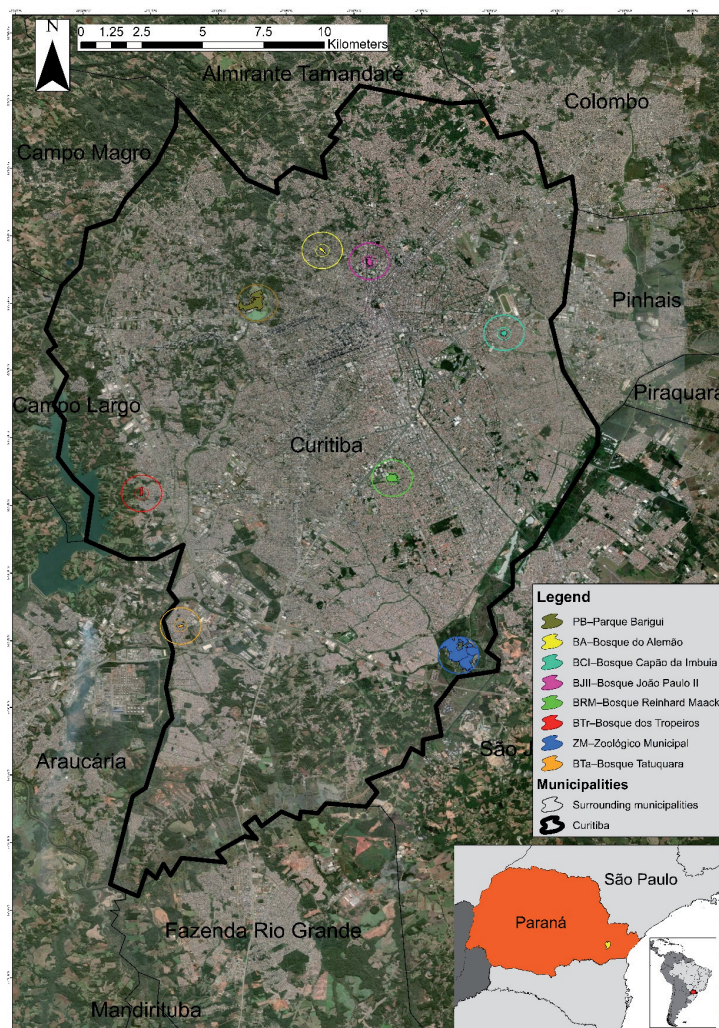


Figure 1. Geographical location of fragments sampled in the city of Curitiba, Paraná, Brazil. 750 m and 250 m buffer.

Table 1. Geographical and landscape metrics for the eight sample sites where butterfly assemblages were sampled in Curitiba, Paraná, Brazil.

	Bosque do Alemão	Bosque Capão da Embuia	Parque dos Tropeiros	Bosque Joao Paulo II	Bosque Reinhard Maack	Bosque do Tatuquara	Parque Barigui	Jardim Zoologico
Latitude	-25.41	-25.44	-25.50	-25.41	-25.49	-25.54	-25.43	-25.56
Longitude	-49.29	-49.22	-49.35	-49.27	-49.26	-49.34	-49.31	-49.24
Area (ha)	3.1	3.9	1.4	5.5	9.8	1.8	29.1	103.4
Perimeter	868	756	585	986	1343	687	3417	7363
Distance to greenbelt	2180	4960	0	3392	4817	610	0	0
(250 m scale)								
Forested areas	0.5	0.1	0.6	0.6	0.2	0.5	0.2	0.0
Open green areas	3.6	3.6	6.7	4.4	2.3	3.0	1.6	0.4
Paved areas	12.8	12.5	7.2	9.6	8.3	14.4	3.5	0.2
(750 m scale)								
Forested areas	15.1	1.4	22.1	6.8	6.3	19.0	18.5	12.1
Open green areas	39.8	36.7	51.9	36.8	32.5	53.8	47.3	15.1
Paved areas	119.0	134.8	91.9	127.3	129.0	101.1	56.0	9.4

Collection of *Pe. Jesus Santiago Moure* (DZUP), at the Universidade Federal do Paraná.

Data analysis

Hill numbers were used to estimate butterfly assemblage diversity for each sampled fragment (Hill 1973). This method has two major benefits compared to conventional diversity metrics: 1. A better appreciation of how the weight assigned to rare species alters the diversity estimations; 2. The possibility to directly compare different diversity profiles. Traditionally, Hill numbers are represented by weights (q) equal to 0, 1 or 2. When $q = 0$, the differences in the abundance of the species are ignored, which means that only the value of species richness is taken into account to designate the diversity in a sample. When $q = 1$, the index is equal to that of Shannon diversity (H'), allocating a low weight to discern the differences in the abundances of rare species. When $q = 2$, the index is equivalent to the Simpson diversity (λ) index, giving greater value of importance to rare species (Leinster and Cobbold 2012).

Because Hill numbers are also sensitive to sample size (Chao et al. 2014), interpolation and extrapolation curves were drawn to make fair comparisons between incomplete samples (Chao and Jost 2012), according to the methodology proposed by Chao et al. (2014). In each fragment sampled, the diversity calculated based on the interpolation and extrapolation method was compared with one another and with the total number of butterfly species already recorded from Curitiba (Pérez et al. 2017a). The curves were calculated using the iNEXT package for R environment (R Core team 2016).

To test the influence exerted by the urban landscape on butterfly diversity, nine categories of the surrounding landscape structure were measured: Forest area (FoA), Open green area (OGA), Paved area (PaA), other Fragments area (FrA), and Fragment perimeter (FrP). Additionally, we measured the distance between the center of the fragment and the green belt around the urban matrix (Dist), to represent how distant the fragment is from the more continuous natural landscape present around the city. We also measured the mean fragment isolation index (ISTf), which is the average of the distances from the fragment being investigated and all the neighboring fragments; proportion of the connection area (CON), calculated by dividing the number of pixels representing forested areas by the total number of landscape pixels; and fractal dimension (D), which is the slope of the regression line between the logarithm of the area by the logarithm of the perimeter, considering all the fragments that compose the landscape mosaic. Additionally, we tested the effect of spatial scale in our results by calculating the landscape metrics using two different buffer sizes (250 and 750 m). All the geographic information was processed and analyzed using QGIS 2.14.3 (Quantum GIS 2016) and Google Earth Pro (2016).

To confirm the correlations between the urban landscape and butterfly diversity, all landscape variables were fitted onto an ordination of butterfly composition produced by Canonical Correspondence Analysis (CCA) using the “envfit” function available in the “vegan” package (Oksanen et al. 2015). Through this procedure, the predictive power of all landscape variables under investigation can be assessed at the same time on the composition of the assemblages. The same procedure was used to test if different subsets of butterfly groups (e.g.,

families and subfamilies) responded similarly to the results obtained by all species.

Results

A total of 5,655 individuals were collected from all eight fragments sampled, representing 298 butterfly species (Table 1). Although fragment samples differed in the numbers of butterflies collected (between 561 and 997 individuals), no significant differences were observed in terms of species richness (from 116 to 143 species, Table 2, Fig. 2a) among the fragments.

All fragments displayed similar sample coverage, although a unique shape in the curve of BA was observed in comparison to all other interpolation-extrapolation curves (Fig. 2a). The confidence intervals showed a large overlap when $q = 0$, lending support to the non-detection of significant differences in terms of species richness among the fragments. However, the greater the weight assigned to the occurrence of a rare species, the higher the diversity estimated for BA, unlike ZM, whose diversity is clearly less than all

the other localities (Figs. 2b,c). Therefore, urban fragments revealed no differences in their richness, despite their contrasting abundances.

Several correlations between the landscape variables and butterfly composition were found, especially for family subsets, such as Hesperidae, Lycaenidae and Riodinidae (Tables 3,4). Paved area (PaA) was the landscape factor which showed more significant correlation with distinct families of butterflies, although the Fragment area (FrA), Fragment perimeter (FrP), distance between fragment and the green belt around the urban matrix (Dist), Proportion of the connection area (CON) and Fractal Dimension (D) also showed significant results to specific butterfly taxa. Also, we could not find any particular scale size showing more frequent correlations with the composition of butterflies. distinct results of correlations measured at distinct geographical scales (250 and 750 m, Figs. 3a,b). Although some correlations do change at different scales, they represent that different taxa/landscape relationship are sometimes better observed in smaller or larger scales.

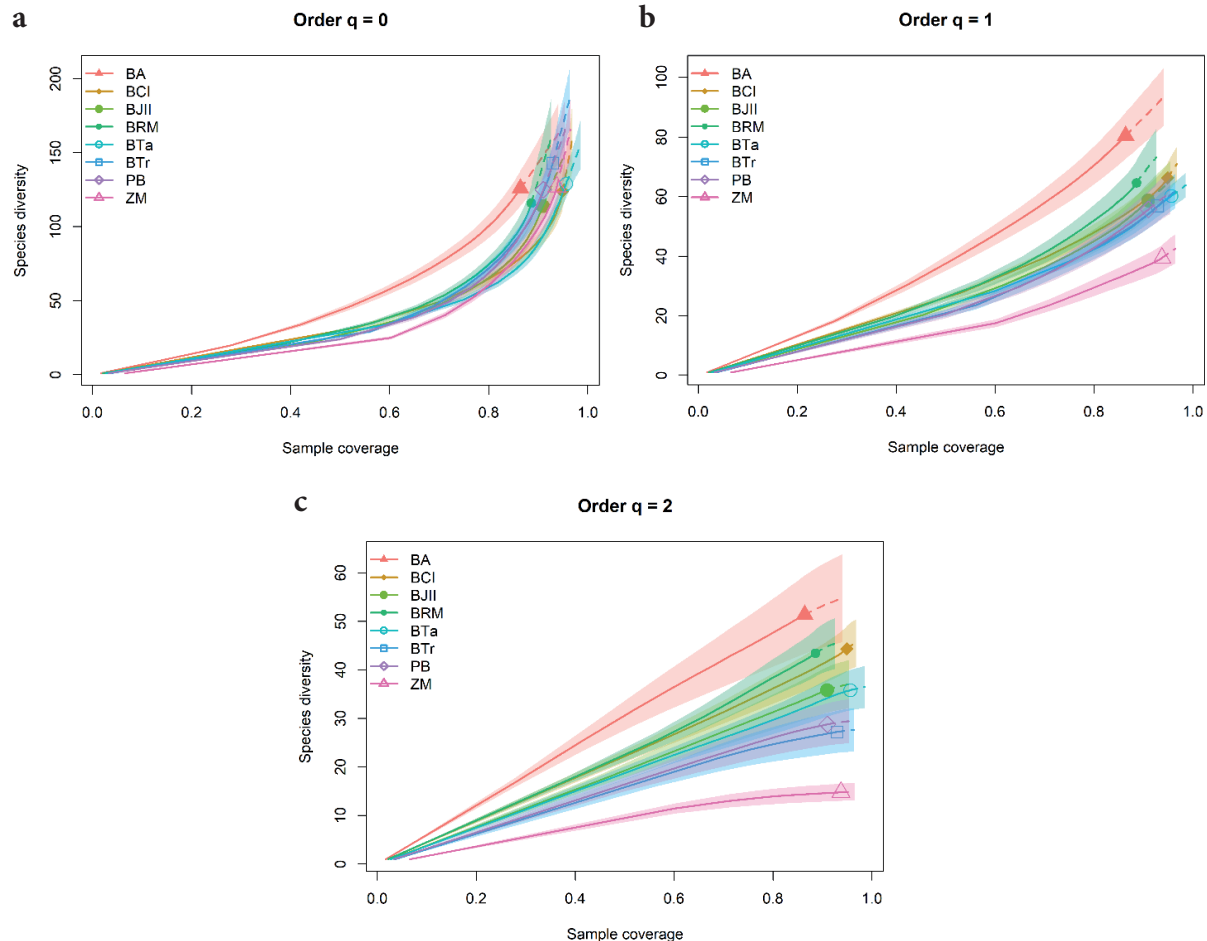


Figure 2. Butterfly diversity in eight urban forest fragments using Hill numbers: (a) $q = 0$ - total number of richness, (b) $q = 1$ - number of abundant species (H^{-1}) and (c) $q = 2$ - number of very abundant species in the sample (λ) with 95% confidence intervals. Interpolation based on the coverage, continuous lines (interpolation) and discontinuous lines (extrapolation).

Table 2. Abundance (N) and Species richness (S) total per park and families of the butterfly community, species represented by a single individual “singletons”, q = 0 total number of species richness extrapolated, q = 1 number of extrapolated abundant species and q = 2 number of very abundant species extrapolated in the sample, present in the eight urban forest fragments of Curitiba, Paraná, Brazil. The observed number of individuals is represented in parentheses.

	Bosque Alemão	Bosque Capão da Imbuia	Bosque dos Tropeiros	Bosque João Paulo II	Bosque Reinhard Maack	Bosque Tatuquara	Parque Barigui	Zoológico Municipal
N	414	845	864	561	501	997	633	840
S	126	124	143	114	116	129	125	127
Hesperiidae	40 (112)	46 (283)	48 (169)	41 (194)	48 (150)	45 (244)	43 (165)	42 (132)
Lycaenidae	12 (16)	9 (31)	5 (8)	9 (20)	6 (16)	12 (27)	6 (14)	5 (12)
Nymphalidae	56 (209)	55 (472)	68 (622)	51 (290)	46 (310)	61 (625)	57 (402)	60 (495)
Papilionidae	5 (36)	5 (14)	2 (7)	1 (2)	2 (2)	1 (2)	4 (11)	2 (3)
Pieridae	8 (25)	6 (38)	8 (38)	9 (40)	9 (17)	6 (55)	6 (21)	9 (50)
Riodinidae	5 (16)	3 (7)	12 (20)	3 (15)	5 (6)	4 (44)	9 (20)	9 (148)
Singletons	8	7	12	7	12	13	7	9
q = 0	182	151	176	163	176	165	181	144
q = 1	92	70	62	65	74	63	61	44
q = 2	55	45	28	37	47	37	30	15

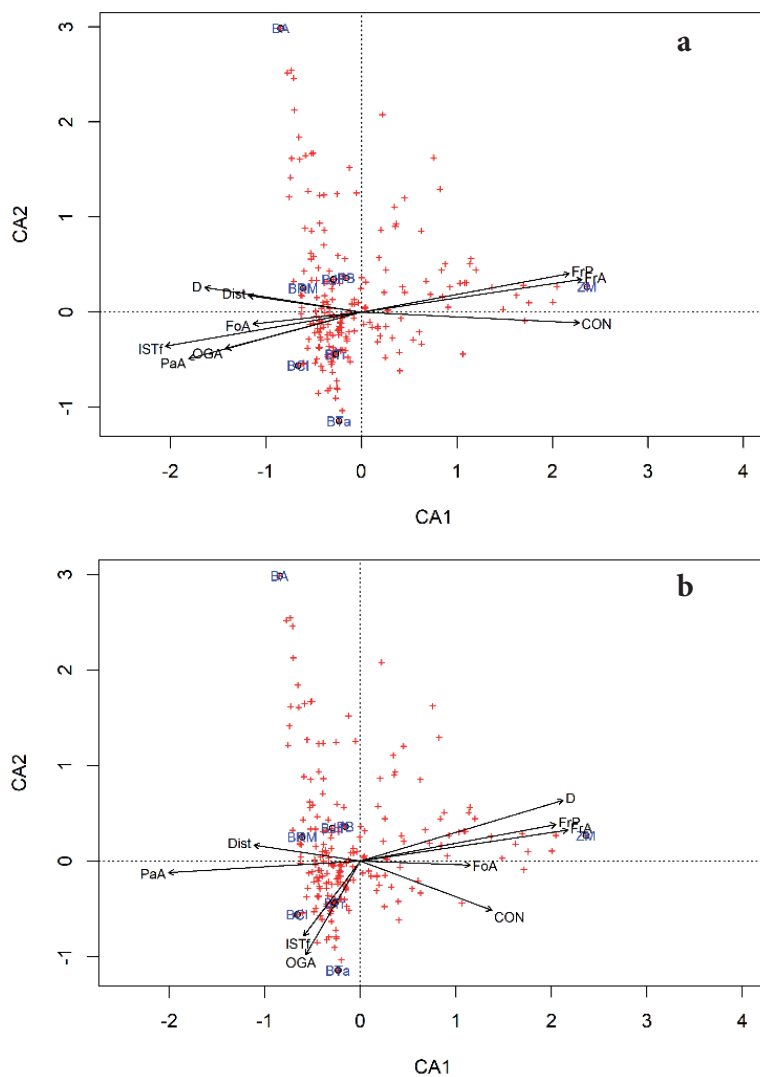


Figure 3. Canonical Correspondence Analysis (CCA), among the nine landscape variables and butterfly species (*) in eight urban forest fragments in Curitiba city. (a) 250 m buffer, (b) 750 m buffer.

Table 3. Canonical correspondence analysis (CCA) at a scale of 250 m, between the landscape variables and the community composition of butterfly families present in the eight fragments. $p < 0.05^*$.

	FoA		OGA		PaA		FrA		FrP		Dist		ISTF		CON		D	
	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P
	Hesperiidae	0.187	0.726	0.241	0.506	0.704	0.047*	0.786	0.137	0.816	0.049*	0.670	0.034*	0.481	0.255	0.468	0.249	0.374
Lycaenidae	0.167	0.673	0.388	0.321	0.399	0.279	0.817	0.089	0.630	0.121	0.573	0.047*	0.712	0.089	0.888	0.046*	0.587	0.101
Nymphalidae	0.100	0.767	0.042	0.857	0.263	0.399	0.372	0.346	0.296	0.383	0.192	0.534	0.350	0.282	0.686	0.103	0.306	0.276
Papilionidae	0.501	0.331	0.041	0.865	0.330	0.522	0.236	0.449	0.220	0.563	0.056	0.946	0.024	0.807	0.524	0.242	0.107	0.806
Pieridae	0.389	0.311	0.706	0.035*	0.221	0.585	0.412	0.205	0.394	0.321	0.417	0.281	0.574	0.138	0.287	0.454	0.622	0.107
Riodinidae	0.359	0.618	0.863	0.048*	0.866	0.036*	0.901	0.016*	0.896	0.038*	0.113	0.924	0.021	0.985	0.113	0.903	0.764	0.111

Table 4. Canonical correspondence analysis (CCA) at a scale of 50m, between the landscape variables and the community composition of butterfly families present in the eight fragments. $p < 0.05^*$.

	FoA		OGA		PaA		FrA		FrP		Dist		ISTF		CON		D	
	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P
	Hesperiidae	0.696	0.042*	0.511	0.176	0.828	0.034*	0.786	0.121	0.816	0.049*	0.670	0.037*	0.327	0.413	0.436	0.257	0.814
Lycaenidae	0.701	0.067	0.691	0.061	0.740	0.042*	0.817	0.071	0.630	0.102	0.679	0.072	0.040	0.915	0.356	0.301	0.786	0.122
Nymphalidae	0.197	0.506	0.007	0.971	0.362	0.292	0.372	0.362	0.296	0.407	0.192	0.516	0.046	0.868	0.267	0.366	0.341	0.392
Papilionidae	0.090	0.916	0.059	0.952	0.156	0.711	0.236	0.405	0.220	0.541	0.056	0.975	0.356	0.494	0.502	0.286	0.018	0.893
Pieridae	0.366	0.338	0.036	0.932	0.575	0.112	0.412	0.193	0.394	0.315	0.417	0.292	0.039	0.924	0.853	0.041*	0.332	0.274
Riodinidae	0.117	0.896	0.730	0.157	0.809	0.099	0.901	0.016*	0.896	0.034*	0.113	0.915	0.566	0.371	0.796	0.072	0.860	0.046*

Discussion

The total species richness recorded in this study corresponds to 53.7% of all butterfly species already recorded from Curitiba in almost 80 years (Pérez et al. 2017a). This percentage is particularly relevant, considering the restricted geographical and temporal sampling of this study. Furthermore, all species' extrapolation curves produced non asymptotic geometries, confirming the difficulties in sampling all species from a specific locality within a limited number of sampling hours (Brown and Freitas 2000, Iserhard et al. 2010, Fattorini 2013), even when habitats are extremely reduced (Brown et al. 2018) and/or intensely modified (Harvey and Villalobos 2007). Considering all these variables, it is reasonable to infer that small natural fragments present in tropical urban cities may serve as refuges for many butterfly species that inhabit the city, and therefore they have a primary role in preserving biodiversity.

Obviously, fragment size is an important parameter to estimate how many species a fragment can harbor, given that larger fragments have greater probability to encompass more heterogeneous and complex environments. This is highly relevant for Lepidoptera because both larvae and adults may use distinct plant species as their main food resource (Wilcox et al. 1986, Baz and Garcia-Boyero 1995, Connor et al. 2000, Matter 2000, Steffan-Dewenter and Tschamtkke 2000, Zschokke et al. 2000, Wettstein and Schmid 2001, Hamer et al. 2003, Krauss et al. 2004). However, the diversity pattern observed in the present study did not exhibit a positive relationship between fragment area and species richness. For instance, the highest diversity indexes were found at BA, despite the fact that it is the smallest fragment compared to all other sampled areas. This fragment corresponds to one of the most visited parks in the city, where some nectar-producing plants are cultivated annually, thus offering abundant nectar resources for butterflies. In fact, studies that quantified nectar resources have found a strong association between this variable and butterfly species richness or species incidence (Hardy and Dennis 1999, Hogsden and Hutchinson 2004, Clark et al. 2007). Because such gardening practices are common in urban parks, an increase in nectar resources in selected fragments may hinder species area relationships in urban landscapes, as more species will be attracted to parks that include flowers in their regular management.

But landscape variables also interact with the biological diversity, particularly when they interfere with the ability of organisms to disperse and colonize new regions (MacArthur and Wilson 1967). Therefore, apart from fragment size, the connectivity and isolation of fragments are also common mechanisms that strongly affect butterfly assemblage structure in urban ecosystems (Blair and Launer 1997, Clark et al. 2007, Bergerot et al. 2011). For example, the total size of the paved area (PaA) around a fragment is most likely the principal impediment for butterflies to disperse. In contrast, green spaces, such as side-street lawns, backyard gardens, and tree or shrub lines along streets and avenues could act as stepping stones for butterfly dispersal, or even be used as host plant or nectar resource by more generalist species (Bergerot

et al. 2011, Soga and Koike 2013). In general, the measurements of paved areas, buildings, lawns, trees and bushes have been used as surrogates to gradients of urbanization, thus being associated with the richness and incidence of butterflies (Blair and Launer 1997, Hardy and Dennis 1999, Hogsden and Hutchinson 2004). Beyond that, they also evidently play a role on how butterflies disperse across a urban landscape (Bergerot et al. 2012).

In our study, paved area (PaA) and open green areas (OGA) were the most common factors associated with butterfly assemblage structure, and different taxonomic groups of butterflies responded distinctly to these landscape variables. For instance, assemblage composition of Hesperiiidae, Lycaenidae and Riodinidae were more affected by the size of the paved area, while Heliconiinae and Ithomiinae assemblages showed more correlations with open green areas. This disparity is known to occur in butterflies because certain lineages conserve distinct ecological traits, hostplant lineages, number of generations per year and dispersal ability (García-Barros 2008). As these traits affect the way distinct species are distributed across urban landscape (Blair and Launer 1997, Clark et al. 2007, Bergerot et al. 2011), distinct butterfly taxa are expected to disperse more efficiently than others depending on the kind of matrix surrounding the fragment (Nowicki et al. 2014).

Besides the quality of the matrix, one additional landscape feature influenced butterfly assemblage structure in our case. The fragments sampled in this study also varied in their shape, some of them having more irregular perimeter than others, thus increasing the size of edge-related habitats, instead of interior environments. Edge habitats are known to influence butterfly dispersal (Schultz and Crone 2001), and to harbor distinct assemblages according to their ecological properties (Ries and Sisk 2008). In fact, several studies have reported unique butterfly assemblages related to these habitats, suggesting that light, type of vegetation cover and composition of edge habitats favor their presence (Hill et al. 1995, Laurance et al. 2002, Hamer et al. 2003, Ramírez-Restrepo and Halfpeter 2013, Lemes et al. 2015, Pérez et al. 2017b). As in the results of PaA and OGA, we found that the same butterfly families (Hesperiiidae, Lycaenidae and Riodinidae) are influenced by variations in fragment shape, showing that these groups might present sets of species with more intrinsic preferences for edge/interior environments. This is an important finding for urban planning because many parks within the city are crossed by large streets and avenues, thus producing more irregular perimeters and reducing the size of more conserved interior forest areas. Since the decline of interior environment species of butterflies happens at multiple spatial scales (Brown and Hutchings 1997, Leidner et al. 2010), the more complex the fragment is the less is the probability to find these butterfly species across the urban landscape.

Finally, the ecological literature shows how geographic scale can alter the way we detect correlations between landscape variables and organism diversity (Chave 2013). Although the differences on scale size used in this study seems narrow, relevant results have demonstrated that very restrict scales (80-200 m) are more effective in showing how but-

terfly assemblages are correlated to local landscape (Hogsden and Hutchinson 2004, Ribeiro et al. 2012). In our case, both scales (250 m and 750 m) yielded a very similar number of noteworthy correlations. According to Clark et al. (2007), correlations of assemblages and landscape measurements are dependent on which measurements of assemblages are taken, as well as on which landscape variable is being correlated. Generally, species' host-plant associations within the immediate vicinity of the fragment are reported as the mechanism responsible for the findings that shows that butterflies respond better to landscapes at smaller scales. Because of that, adults and larvae would usually present similar geographical distribution (Blair and Launer 1997, Ribeiro et al. 2012). On the other hand, when larger scales give more robust results, the high dispersal ability of butterflies and the use of larger areas to forage are suggested as the most likely explanation (Clark et al. 2007, Ribeiro et al. 2012). The present results agree with both mechanisms, supporting that distinct butterfly families may regard one or other of these ecological traits in most of their species. Therefore, such ecological traits of butterflies are of great value not only to estimate their influence on the distribution patterns of assemblages, but also to select a more appropriate spatial scale to be used in experiments.

Conclusion

Compared to other South American cities (Olivares and Tapias 2010, Lazzeri et al. 2011, Marín et al. 2014, Pérez et al. 2017b), all forest fragments sampled in Curitiba showed high species richness, showing that landscapes under extreme impact can still harbor a substantial fraction of the original diversity. However, preserving the quality of urban fragments should be extended beyond the mere conservation of the fragment itself, to include modifications that promote connectivity between fragments. For instance, a simple exchange of paved sidewalks to tree lines or lawns would itself favor a fraction of butterfly species to disperse among isolated fragments and thus increases the number of organisms that occupy large metropolises. More importantly, the preservation of interior environments inside natural fragments is fundamental to assure the population dynamics of butterfly species dependent of this kind of habitat.

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Supplementary material

Table S1. List of butterfly species found in eight forest fragments of Curitiba, Paraná, Brazil, between September 2015 and April 2016.

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