Importance of urban green areas connectivity for the conservation of pollinators

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Abstract

Urbanization is one of the main processes generating most of changes on the earth's surface. The remaining green spaces within cities can be of utmost importance for pollinator conservation. Through a meta-analytical study, we evaluate how the position, connectivity and abundance of urban green areas (parks, gardens, squares, among others) in different cities can affect the richness and abundance of pollinators. We developed a connectivity metric using satellite images corresponding to 241 urban green areas obtained from 20 published works. The green areas were classified in Urban, Peri-urban and Non-urban according to their percentage of impervious surface estimated in each image. The metric relates the connectivity of green areas contained within images with a radius of 500 meters immersed within a city. Our study show the richness and abundance of pollinators is positively related to the connectivity of green areas in sites with different degrees of urbanization. Our results emphasize the importance of green spaces to maintain the ecosystem service of pollination in cities.

Introduction

The earth's surface is undergoing a critical transition from natural to man-made areas (Ellis et al., 2010; Potts et al., 2010). While natural ecosystems are reduced, cities and urban settlements are growing and getting more industrialized over years (United Nations, 2018). It is expected that by 2030 urban land increase 1.2 million km^2 (Seto et al. 2012). Furthermore, in the last decades the urban expansion rate has been considerably higher than the population grow rate (Liu et al. 2020). Pondering this scenario, it is possible to consider cities as potential reservoirs of biodiversity and ecosystem services (Lowenstein et al. 2015; Hall et al. 2017; Derby-Lewis et al. 2019).

Urban landscapes are a mosaic of impervious and pervious surface, which holds (semi) natural habitats with different degrees of disturbance (Sattler et al. 2010). The remnants of natural habitats (Urban Green Areas, hereafter UGA) that persist immersed in the urban matrix are considered biodiversity reservoirs (Seto et al., 2012; Gardiner et al., 2013; Baldock et al., 2015; Hall et al., 2017). Public parks and residential gardens can be considered UGAs as well, since they provide food, shelter and/or nesting sites to different animals, and allow the establishment and survival of wild plant populations as well (Threlfall et al., 2015). The structural connectivity of UGAs is a physical attribute of the landscape that can be measured through metrics of configuration, distribution, and patch size, among others (LaPoint et al. 2015). This is a property that can greatly influence the movement of animals and dispersion of plant fruits/seeds/propagules. For this reason, cities are an important resource for the provision of ecosystem services (Turo and Gardiner, 2019). Particularly, pollination service is a vital process to hold plant communities (Ashman et al. 2004) and ensure food production (Klein et al. 2007; Ricketts et al. 2008). Communities of urban pollinators seem to provide sufficient pollination services for wild vegetation and crops (Wenzel et al. 2020; Da Rocha-Filho et al. 2020). Besides, food production on a small scale in urban sites makes a significant contribution to food production worldwide, in addition to presenting environmental and social advantages over large-scale industrial agriculture (Nicholls et al. 2020; Yacamán-Ochoa et al. 2020).

Several studies have approached the conservation of pollinators (mainly bees) and the maintenance of the urban pollination ecosystem services (revised in Turo and Gardiner 2019). It has been suggested that the size of the UGA is positively related to the abundance and richness of wild bees it harbors (Quistberg et al. 2016). Despite this, richness, abundance, and/or composition of the different groups of pollinators are variable. Some studies have found a negative relationship between pollinator richness and degree of urbanization (Hernandez et al. 2009; Bates et al. 2011), in others a maximum richness of certain groups has been observed at medium levels of urbanization (Fortel et al. 2014; Banaszak-Cibicka et al. 2018), while another study suggest there is no significant relationship between both variables (Amado De Santis and Chacoff 2020). These parameters could vary due to the irregular distribution of green areas within urbanized areas (Hülsmann et al., 2015; Kaluza et al., 2016; Theodorou et al., 2017; Yang et al. 2020). Likewise, the degree of isolation or connectivity of the UGAs present within a city could influence the variability of these results.

In agroecosystems, Steffan-Dewenter (2003) found a positive relationship between the richness of solitary bees and size of the semi-natural habitats immersed in the agricultural matrix. In addition, the author observed that the connectivity among these habitats positively influenced the number of solitary bee brood cells built per nest, showing the importance of the proximity among the semi-natural habitats for the flow of animals in agroecosystems (Potts et al. 2016; Theodorou et al. 2020). Urban landscapes could present similar responses to agricultural ones (Potts et al. 2016; Yang et al. 2020) and, therefore, the configuration of UGAs (size and connectivity among UGAs) within the urban matrix could be decisive for the establishment, maintenance and dispersion of pollinator communities (Baldock et al. 2019). However, the composition of pollinator and plant communities in natural, agricultural and urban systems are usually different (Banaszak-Cibicka et al. 2018; Nakamura and Kudo 2019; Persson et al. 2020), and for that reason, ecological processes can differ too.

We performed a meta-analysis to estimate how the connectivity and abundance of UGAs in different cities around of the world can affect pollinator richness and abundance. Our hypothesis is that the relative position of the UGAs within the urban landscape affects the richness and abundance of pollinators. We predict that (i) richness and abundance will decline as the urbanization increases; and (ii) the richness and abundance of pollinators will increase as connectivity and the percentage of occupied area for UGAs in urban landscapes increases.

Materials And Methods

Bibliographic search

We performed a comprehensive literature search in the Scopus web database, using the string: "wild bee" OR "wild bees" OR “pollinator” OR “pollinators” AND "urban area" OR "urban garden" OR “urbanization” OR "community garden". Initially our search query returned 2393 potential papers (last accessed 14th July 2020). Considering that the great majority of the publications were recent, we narrowed the search to the last 6 years, keeping the publications between 2014 and July 14, 2020, with which we obtained 1896 potential papers. The papers were filtered by reading the summary, materials and methods, results and supplementary material if necessary. For a work to be considered valid for our meta-analysis, it had to contain data (richness and/or abundance) of pollinators from at least three UGAs (hereinafter: target area (TA)) and present geographic coordinates or the name of each TA used (for example, Munich Botanical Garden), to be able to be geolocated by Google Earth (Google Earth 7.1.5.1557, 2015). Further, we collected information of pollinator guild studied (bees, butterflies, flies, etc.) and data collection method (pan-traps, trap nests, direct observation, etc.) to include them in the analysis as variables. Finally, we indicated the continent where the study was carried out (Table S1, S2).

Landscape classification and connectivity

For each of the papers selected, all TAs were geolocated and marked using Google Earth Pro (Google Earth 7.1.5.1557, 2015). For each analyzed TA, a circular portion of the image with a radius of 500 m was delimited, containing the focal TA in the center (Fig. 1). Next, all the observed UGAs from each image were marked (TA and associates UGAs), delimited with polygons, and their areas were calculated using the tools of Google Earth Pro (only those with an area ≥ 0.2 ha were considered).

With these values, the degree of urbanization was calculated (estimated as the percentage of impervious surface [100-(percentage occupied by UGAs)]), which allowed classifying each circular portion of the image containing TA in one of the following three categories of anthropic landscape: a) Urban (> 70% of impervious surface); b) Peri-urban (30–70% of impervious surface); y c) Non-urban (< 30% of impervious surface; this category includes cultivated areas and natural or semi-natural areas) (modified from Fortel et al. 2014). These three categories can be assumed as representing different degrees of urbanization, being urban, sites with high urbanization; peri-urban, sites with intermediate levels of urbanization; and non-urban sites, with low urbanization.

To estimate the connectivity among the analyzed green areas in each image with a radius of 500 m were measured minimum distances between focal TA and its associated UGAs (Fig. 1). With these data, a connectivity measure was calculated for each TA. This estimation informs about the TA connectivity with the associated UGAs within the image of 500 m radius (for example, TAs with closer UGAs will have greater connectivity than those with remote UGAs). We used the estimation considered by Steffan-Dewenter (2003), and modified from Hanski & Thomas (1994):

$$C = \Sigma e^{-dij} A_{j,}$$

where A_j is the area of UGA*i* (in ha) and *d* represents the distance (in km) between the TA and the UGA*j*. Connectivity could take values between zero and infinity. The increase in C correspond to more connected (or less isolated) sites respectively.

Figure 1 Representative diagram of data considered for connectivity calculation. Grey forms of each circle indicates the focal TA. The external circles represent the radius of 500-meters around each TA i. Black patches represents UGAs (j1 a j5) associated. Dotted lines represent the minimum distance between TA i and UGA j, which were considered to calculate connectivity within the images. A larger permeable surface (occupied area by grey and black patches) indicates less urbanization.

Data analyses

Two General Linear Mixed Models (GLMM) were built to assess how connectivity and the summation of occupied area for UGAs in each image with a radius of 500 m (explanatory variables) affect pollinator richness and abundance (response variables) in each TA. The glmer function of the lme4 package was used for this analysis, with a Negative Binomial distribution for both response variables due to the over-dispersion of our data. In the models, the connectivity (C), the percentage of occupied area for UGAs associated to each TA ([summation of green area found in each image/total area]*100) and the classification of the anthropic landscape (urban, peri-urban and non-urban) were used as fixed factors, while the study identity and the data collection method (pan-trap, net, direct observations, nest traps, emergency traps, bait traps) were considered as nested random factors (Table 1). The models included the interaction between the C and the anthropic landscapes. Variables C and percentage of occupied area for UGAs were rescaled using the function $\log_{10}$. The goodness of fit of each model was evaluated using the plotQQunif and plotResiduals functions of the DHARMa package (Hartig & Hartig, 2017, Fig. S1 and Fig. S2). In addition, multiple comparison contrast tests were performed, one for richness and one for abundance of pollinators, in order to observe the differences between arithmetic means of each anthropic landscape (urban, peri-urban, non-urban). For this, the glht function of multcomp package was used (R Development Core Team, 2013), using the GLMMs constructed above (Table 1) and degree of urbanization as fixed factor in both cases.

Table 1

Models used for the analysis. Response variables: richness and abundance of pollinators. Random variables: study identity (author) and data collection method (capture). These last two variables were nested. Fixed factors: connectivity (C), anthropic landscape or degree of urbanization (classification) and percentage of occupied area for UGAs within each circle of 500 m radius (green).

Model	Formula	Distribution
M1	*richness ~ (1 |author/capture) + C:classification + classification + green*	*Negative Binomial*
M2	*abundance ~ (1 |author/capture) + C:classification + classification + green*	*Negative Binomial*

Results

As a result of applying our inclusion criteria 20 publications that contained a total of 241 TAs in the three anthropic landscapes (94 urban, 91 peri-urban and 56 non-urban) were obtained. Of them, 214 TAs presented data on pollinator richness, and 207 on pollinator abundance (Table S2). Of the 20 studies evaluated, 12 (60%) were performed in Europe, five (25%) in America and three (15%) in Asia.

GLMM for pollinator richness

The pollinator richness and the connectivity (C) showed a positive and highly significant relationship in urban and peri-urban landscapes, while there was no relationship in non-urban landscapes (Table 2: Model 1, Fig. 2). On the other hand, no relationship was found between the pollinator richness and percentage of occupied area for UGAs. The results obtained from the multiple comparisons among the three different anthropic landscapes analyzed regarding pollinator richness were significant between non-urban and peri-urban sites ($Z=-2.7840$; p value = 0.0144) and between non-urban and urban sites ($Z=-4.156$; p value = 0.001), while there were no significant differences between urban and peri-urban landscapes (Fig. 3a, Table S3).

Table 2

GLMMs outputs. Models used to compare A) richness (M1) and B) abundance (M2) of pollinators with the anthropic landscapes or degree of urbanization (Urban, Peri-urban and Non-urban): connectivity (C) and percentage of occupied area for UGAs (green). Statistically significant values are in bold.

A) M1	Estimate	Standar error	Z value	Probability (>|z|)
Intercept	1.08163	0.39031	2.771	**0.00558**
Non-urban	1.02193	0.36711	2.784	**0.00537**
Urban	-0.19061	0.35414	-0.538	0.59042
Green	0.12106	0.15739	0.769	0.44178
C:peri-urban	0.43126	0.16839	2.561	**0.01043**
C:non-urban	0.08371	0.15130	0.553	0.58008
C:urban	0.48892	0.16225	3.013	**0.00258**

B) M2	Estimate	Standar error	Z value	Probability (>|z|)
Intercept	3.230816	0.665038	4.858	**1.19e-06**
Non-urban	1.964717	0.707109	2.779	**0.00546**
Urban	-0.398585	0.644235	-0.619	0.53612
Green	-0.004359	0.310911	-0.014	0.98881
C:peri-urban	0.637093	0.337744	1.886	0.05925
C:non-urban	-0.035952	0.311041	-0.116	0.90798
C:urban	0.722434	0.282025	2.562	**0.01042**

Figure 2 Relationship between a) pollinator richness and b) pollinator abundance with the connectivity of TAs (C) with its associated UGAs in the different anthropic landscapes (Non-urban, Peri-urban and Urban).

Figure 3 Results of multiple comparisons between the different categories of anthropic landscapes for: a) richness and b) abundance of pollinators, with 95% confidence intervals.

GLMM for pollinator abundance

Pollinator abundance showed a positive and significant association with the connectivity in urban sites, while it was not significant in peri-urban and non-urban sites (Table 2: Model 2, Fig. 2b). On the other hand, no relationship was found between pollinator abundance and percentage of occupied area for UGAs. Urban and non-urban sites showed significant differences in pollinator abundance ($Z = 2.451$; p-value = 0.0142), with urban sites being more abundant that non-urban ones (Fig. 3b). The results obtained from the multiple comparisons among the different anthropic landscapes regarding abundance were significantly between non-urban and peri-urban sites ($Z=-2.811$; p value = 0.0135) and between non-urban and urban sites ($Z=-3.958$; p value < 0.001), while there were no significant differences between urban and peri-urban landscapes (Fig. 3b, Table S4). Urban and peri-urban landscapes had lesser pollinator abundance than the non-urban sites (Fig. 3b).

Discussion

Importance of UGAs connectivity

Using data available in the literature combined with landscape analysis we found that, as we predicted, the connectivity among UGAs, measured through relative position and size, within the urban landscape is positively related to the richness and abundance of pollinators. Our results show urban green areas host a greater diversity and abundance of pollinators when they are closer to each other (i.e., more connected), although this connectivity has no effect on non-urban sites (< 30% of impervious surface). Works such as the one by Fenoglio et al. (2020) reported negative effects of urbanization for arthropods in cities and attribute it, among other things, to the loss of habitable area and low habitat connectivity. Regardless of connectivity, non-urban sites presented more pollinator richness than urban and peri-urban sites. These results are partially opposite to those found by Baldock et al. (2015), who did not register differences in the diversity of pollinators in urban, agricultural and natural sites. However, such differences may be due to the use of different methodologies and criteria to classify the sampling sites. On the other hand, these authors found different responses for several taxonomic groups (bees, flies, hoverflies), with bees being more abundant in urban sites than in the rest (Baldock et al. 2015). In our study, most of the analyzed papers included bees as one of the main taxa and we found a greater richness of these in non-urban sites (Geslin et al. 2016; Kratschmer et al. 2018; Sobreiro et al. 2019; Birdshire et al. 2020, among others). Despite this, bees and other insects can be declared “winners and losers” of the urbanization, because the effects that this has on insects will depend on various factors like sociability, nesting substrate and breadth of diet (Banaszak-Cibicka and Zmihorski 2012).

Higher or lower connectivity of UGAs among anthropic landscapes could differentially affect the different taxonomic groups of pollinators. Most bees and some wasps are central place foragers and their foraging ranges depend largely on their body size (Greenleaf et al. 2007). It is known that the wild bees are smaller in urban than in rural sites (Buchholz and Egerer 2020), inclusive Eggenberger et al. (2019) reported urban bumblebees are smaller compared with their rural co-generic. However, Theodorou et al. (2021) showed the inverse pattern in *Bombus terrestris* (foragers larger in cities than rural habitats) and found no significant differences in size in forager of *B. lapidarius* and *B. pascorum* between both ecosystems. Therefore, it would be reasonable to think that sites with more connected UGAs would be beneficial for small-, medium-, and large-sized bees, while those sites with more distant UGAs would be disadvantageous for smaller bees and bumblebees.

On the other hand, the dispersal ability of other taxa seems be variable. Syrphid species are considered highly mobile groups and generalist floral visitors (Schweiger et al. 2007). These biological traits could demonstrate that these flies are little affected by the degree of connectivity of UGAs in the cities; however, the enormous behavioral and morphological diversity of syrphid (Vockeroth and Thompson 1987) could make our statement speculative. Butterflies have relatively short lifespan as adults and moderate dispersal abilities (Soga and Koike 2013). Then, less mobile organisms could be more influenced to local scale (e.g., host plants for larvae butterflies) and more mobile organisms (bees, bumblebees, syrphid) more impacted to landscape scale (e.g., UGAs connectivity) (Braaker et al. 2014).

Pollinator richness

Our results showed that landscapes with more connected UGAs (i.e., less isolated), are harboring a greater richness of pollinators in urban and peri-urban sites, but not in non-urban sites. This relationship was even more pronounced in urban landscapes than peri-urban ones, which could indicate that landscape connectivity as a maintainer of pollinator richness becomes more useful in environments with a high degree of urbanization. On the other hand, Steffan-Dewenter (2003) found in rural landscapes (agroecosystems) results similar to those that we showed for urban landscapes, but we did not find relationships in our non-urban landscapes. Nevertheless, “non- urban” classification covers either rural and natural areas, or a mixture of both, and this could be conditioning our results. The limiting resources (e.g., availability of nesting sites for bees, plant hosts for butterflies, floral diversity and richness for all pollinators) in each type of landscape could differ and influence pollinator richness. Generally, cities offer flower resources for a longer period throughout the year (Twerd & Banaszak-Cibicka, 2019) and nesting sites, while in rural environments flower resources are more limiting than nesting sites (Rosanigo et al. 2020, but see Fortel et al. 2014).

It is important to highlight that, there are more factors that influence the presence of pollinators within the cities such as the surrounding landscape, temperature, and humidity, among others (Ayers and Rehan, 2021). For example, impervious surface could be generating physical barriers within the landscape and mainly among the vegetation patches, thus limiting the diversity of pollinators capable of living in such sites, such as those with greater flight ranges or greater body size. Thus, the connectivity of green areas, as well as other landscape variables such as environmental heterogeneity, fragmentation, etc. (Ayers and Rehan 2021), are important estimators for the evaluation of the quality of habitat of different anthropic landscapes. In our study we did not analyze the different taxa separately, and the community present in each environment may vary according to their functional traits and life histories (flight ranges, body size, time of emergence, among others) (Luder et al. 2018; Wenzel et al. 2020). Although the general trend of the pollinator community is to enhance as the connectivity increases, some taxonomic groups could respond with different magnitude to these variables, or to the urbanization gradient (Baldock et al. 2015). However, proper urban planning that ensures proximity between UGAs would become a key factor to take into account to mitigate the decline of pollinators.

Pollinator abundance

The abundance of pollinators increases with the connectivity of UGAs in urban sites (Plascencia & Philpott 2017, but see Cohen et al. 2020), but no relationship was found in peri-urban and non-urban sites. In the same way as for pollinator richness, the abundance of pollinators is higher in non-urban sites compared to urban ones. This contrasts with the results of Zaninotto et al. (2021), who studied the overall species assemblage composition between the urban and rural communities visiting two focal plant species; these authors observed a great abundance of pollinators in urban environments compared to rural ones. They attribute such results to the greater dominance of social species (*Apis mellifera* and *Bombus pascorum*) in urban sites. In our study we included other taxonomic groups of pollinators in addition to bees (as syrphids, other flies, butterflies), but we did not make any evaluation regarding their behavior or functional traits.

Within the cities, exist a most homogenized fauna mainly composed by a small subset of cosmopolitan species adapted to urban conditions (Patitucci et al 2011). These synanthropic species (generally, exotic and dominant) are associated with human settlements (Nuorteva 1963) and can reach high population densities (e.g., *Musca domestica* [Muscidae], *Eristalis tenax* [Syrphidae], among others). Also, urbanization positively correlated with increased prevalence of exotic bees (social [e.g., *Apis mellifera* and *Bombus* spp.] and solitary species [e.g., *Anthidium manicatum* [Megachilidae]) on native bees (Fitch et al. 2019). In an urban context, these synanthropic species could be responsible for the increase in the abundance of pollinators.

Resources for pollinators

Although urban settlements are disturbed and heterogeneous landscapes, they offer nesting sites and flower resources (principally, ornamental and exotic species, but also native species are present) for pollinators (Matteson et al. 2008; Fortel et al. 2014; Hülsmann et al. 2015). In our study we did not include floral diversity as a variable because less than 10% of the studied work reported these data (Table S2) that this variable could influence our results.

We are also aware that the pollinator diversity in a city can always be underestimated, because many of the private gardens cloud contain a large number of species that cannot be recorded. Baldock et al. (2019) and McCune et al. (2020) show that there is a positive relationship between abundance of flower resources and pollinator abundance (but see Cohen et al. 2020 and Persson et al. 2020). In addition, the distribution of floral resources could be driving the distribution of pollinators throughout the cities (Krahner and Greil, 2020), since they represent an abundant and constant resource over time due to the presence of ornamental plants in private gardens and squares (Garbuzov et al. 2017; Corcos et al. 2019).

Although urban landscapes may have a higher flower density than agricultural or natural landscapes (Lynch et al. 2021), some authors claim that increasing floral abundance may not mitigate the negative effects of urbanization (Wilson and Jamieson 2019), such as the increase of impervious surface and surface warming, among others. Plan management is imperative for the urban green areas, taking into account the identity, quantity and spatial arrangement of the floral resources present (Plascencia and Philpott 2017). However, the increased connectivity of the UGAs at urban landscapes, combined with the increase in floral resources and availability of nesting sites could collaborate to minimize the effects of urbanization. Krahner and Greil (2020) suggested the configuration of landscape and the degree of connectivity of the UGAs as very effective measures to estimate the vulnerability of populations or communities of pollinators. The connectivity of UGAs within different anthropic landscapes could increase the rate of colonization of new individuals among them, which is vital to maintain the genetic flow among populations (Braaker et al. 2014; Lanner et al. 2020).The measures of connectivity developed in our study are a novel, accessible and simple tool to estimate the degree of urbanization of UGAs and it could be considered as a key factor for urban planning. Giving the rapid expansion of cities, it is important to note that the precision of this method will depend on the use of updated satellite images.

Finally, most of analyzed studies were carried out USA and Europe, and only a handful in South America and Asia (continents with high rate of urbanization and large cities). We believe that it is necessary deepen the study of this important world problematic to detect general patterns that may be applicable to most urban centers. In this way, it will be possible to alleviate the human impact and develop policies for an environment that support pollination as well as other ecosystem services (Hall et al. 2017; Potts et al. 2016). Our study summarizes and analyzes central aspects of urban ecology considered lately, and it hints the aspects on which we must focus on and those places where information is still lacking.

Declarations

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Contributions

SG and HJM were responsible for the conception and design of the study. RGV and JPT carried out the bibliographic search and selection. SG carried out the georeferencing and measurements of the work. SG and HJM performed the statistical analyses. SG and HJM made the first draft of the work and all the authors commented on the previous versions and approved the final manuscript.

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Ethics approval

Not Applicable.

Consent to participate

Not Applicable.

Consent for publication

All authors have contributed to and approved the manuscript's content. The materials within this manuscript are neither published nor being considered for publication elsewhere.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

The data can be found in the Dryad open source repository.

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Figures

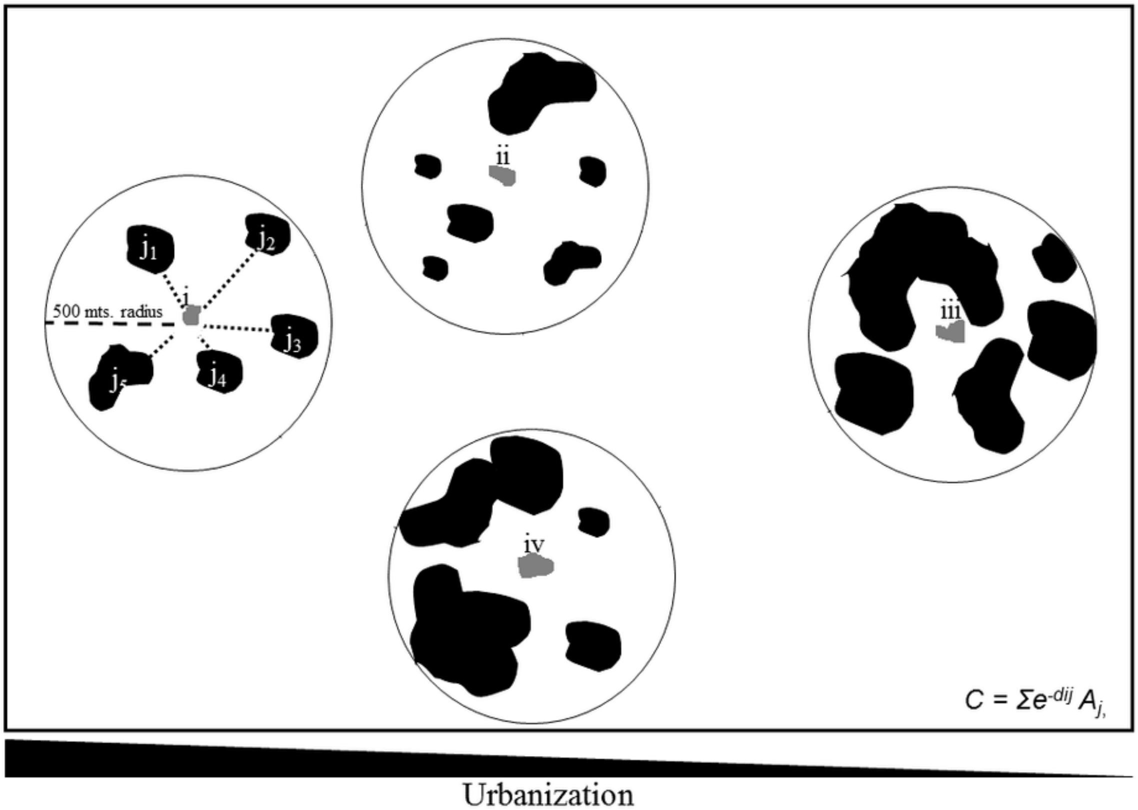

Figure 1

Representative diagram of data considered for connectivity calculation. Grey forms of each circle indicates the focal TA. The external circles represent the radius of 500-meters around each TA i. Black patches represents UGAs (j1 a j5) associated. Dotted lines represent the minimum distance between TA i and UGA j, which were considered to calculate connectivity within the images. A larger permeable surface (occupied area by grey and black patches) indicates less urbanization.

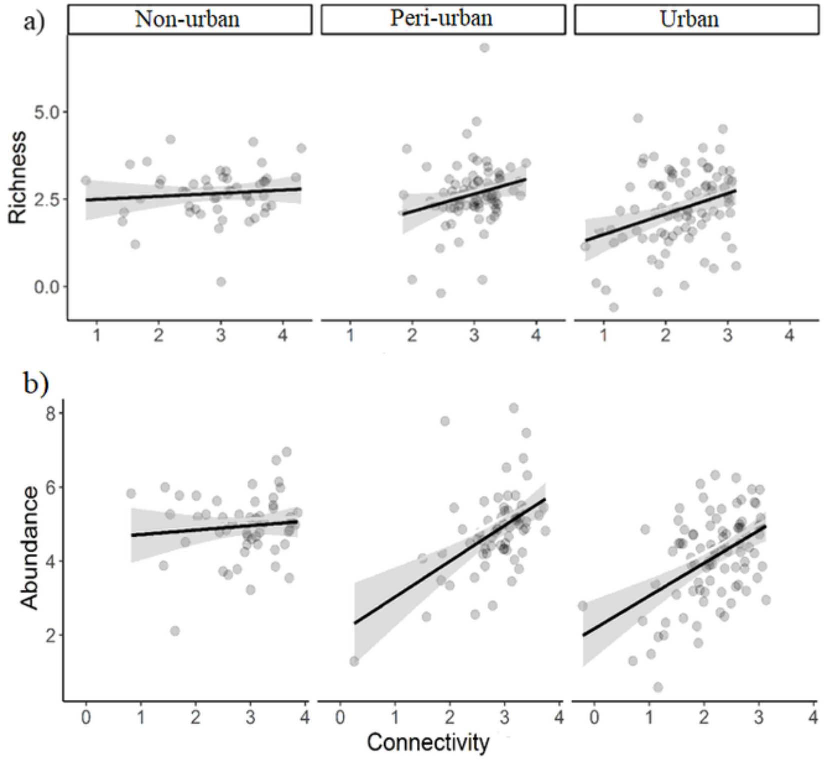

Figure 2

Relationship between a) pollinator richness and b) pollinator abundance with the connectivity of TAs (C) with its associated UGAs in the different anthropic landscapes (Non-urban, Peri-urban and Urban).

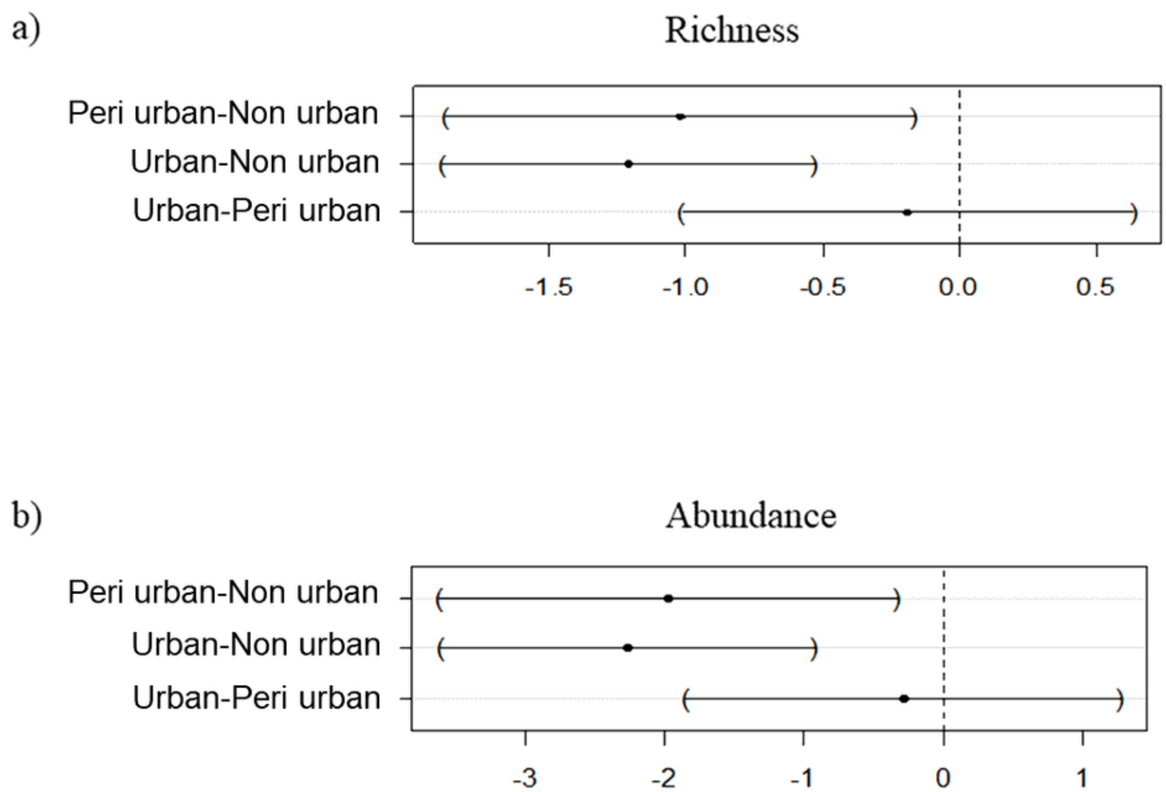

Figure 3

Results of multiple comparisons between the different categories of anthropic landscapes for: a) richness and b) abundance of pollinators, with 95% confidence intervals.

Supplementary Files

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