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Multiple-scale approach for evaluating the occupation of stingless bees in Atlantic forest patches

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ABSTRACT

Studies at multiple scales are essential to obtaining a holistic view of bee conservation. We aimed to detect the main factors that should be considered in a multiple-scale approach for small forest patches in order to contribute to the conservation plans for stingless bees. The study was conducted in small forest patches of the Atlantic Forest, in the municipality of Salto de Pirapora (SP, Brazil). The spatial analysis was developed based on forest patch size, forest patch core size, distance from the nearest forest patch, and distance from the nearest body of water. Based on these criteria, we selected three hotspot forest patches (including all criteria that favor the presence of stingless bees with arboreal nesting habits) and three control forest patches (which does not fulfill all these criteria), and we evaluated the presence of stingless bees based on the occupation of artificial shelters installed in the patches. From the 72 installed artificial shelters, we observed 27 shelters (37.5%) carrying some association with stingless bees presence. Bees showed a preference for occupying artificial shelters that were located in the patches' cores (66.7%). The structure and composition of the vegetation showed great importance to the occupation of the artificial shelters, as there was a strong correlation between the occupied shelters and the diameter and the height of the trees. There was also a correlation between the presence of grasses and shrubs ($p < 0.05$), which were the main providers of floral resources. The data of the land cover was an essential factor for the development of spatial analysis, and we found a strong negative correlation with pastures and a positive correlation with forestry ($p < 0.05$). To elaborate multiscale approaches, it is essential to evaluate the quality of foraging (amount of flowers) and nesting (diameter and height of trees) resources, as well as the surroundings of the patches. The study provided data so that the information can be extrapolated to other scenarios and encourage the conservation of small forest patches as a strategy for the conservation of stingless bees.

1. Introduction

Bees represent the most important group among pollinating insects of tropical forests (Bawa, 1990) and are among the main pollinators of economically important agricultural crops around the world (Winfree, 2010, Giannini et al., 2015). Worryingly, many bee populations are declining (Potts et al., 2010, Goulson et al., 2015) due to the intensification of agriculture, which has caused fragmentation and habitat loss, the negative effects of agrochemicals on bee health, climate change, and the introduction and diffusion of exotic bee species (Steffan-Dewenter and Westphal, 2008, Freitas et al., 2009, Winfree, 2010, Meléndez-Ramirez et al., 2013, Goulson et al., 2015).

Landscape composition plays a key role in determining the richness and abundance of bee species in a habitat spot (Fabian et al., 2013), contemplating the structural aspects as much as the functional approaches, such as connectivity (Boscolo et al., 2017). The reduction of landscape connectivity affects the dynamics of bee colonies since pollination and gene flow decrease with nest distance and the fragmentation of natural environments (Kreyer et al., 2004, Hatfield and Lebuhn, 2007, Krewenka et al., 2011). For bee communities, changes in the landscape (fragmentation, loss, isolation, and modification of the habitat) cause a decrease in native plant diversity, which decreases

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floral resources for foraging and adequate nesting sites (Roulston and Goodell, 2011, Montero-Castaño and Vila, 2012).

Landscape changes, such as land use, can have different consequences on wild bees depending on the functional traits of bee species such as nesting habits (Hopfenmüller et al., 2014). In this way, bees with more specific nesting habits, such as the ones that nest only in tree cavities, might not withstand these changes in habitat (Ferreira et al., 2015). Forest patches present a great importance to the supply of resources (floral and nesting sites), and this distribution is essential for the reproduction of bees in heterogeneous landscapes (Williams and Kremen, 2007).

In order to carry out complete studies with bee communities, it is highly important to take a multiple-scale analysis, which evaluates both the composition of the landscape and the variables of the habitat (Hatfield and Lebuhn, 2007). Multiple-scale approaches such as the interaction between local scale factors (e.g. flower cover) and landscape scale factors (e.g. forest distance) are fundamental not only in contributing to the conservation of pollinators, but also in sustaining the bee communities that favor crop yields (Motzke et al., 2016). In the context of developing approaches for pollinator conservation, the lack of integrated monitoring programs results in fragmented data, so that the major challenge to conservation is not only identifying the different threats, but also assessing how these threats interact and together affect these organisms (Potts et al., 2010). Thus, multiple-scale studies are essential to obtain a holistic view of bee conservation.

This study deals with the possible factors that influence the presence of native stingless bees in fragmented landscapes, from a regional scale (forest patches' surroundings) to a local scale (habitat). We aimed to detect the main factors that should be considered in a multiple-scale approach to small forest patches of the Atlantic Forest, in order to contribute to strategic planning of conservation for stingless bees. Therefore, we aimed to answer four questions: (1) Is the presence of stingless bees in small forest patches influenced by the structure of the vegetation?; (2) Is the presence of stingless bees in small forest patches influenced by microclimatic parameters?; (3) Is the presence of stingless bees in small forest patches influenced by the surrounding landscape?; and (4) Can small forest patches be considered as a conservation strategy for stingless bees?

2. Materials and methods

2.1. Study area

The study was carried out in patches of the Atlantic Forest located in the municipality of Salto de Pirapora, State of São Paulo, Brazil (supplementary material, Appendix A, Fig. 1). According to the classification of Köeppen, the climate is characterized as "Cwa," warm subtropical climate (CEPAGRI, 2017). During the study period from August 2016 to April 2017, the average monthly temperature was 21.4 °C and the total precipitation recorded was 1,148.4 mm. The minimum monthly temperature recorded was 17.1 °C (in August) and the maximum monthly temperature was 24.9 °C (in February). The lowest rainfall recorded was 23.2 mm in September and the maximum was 291.8 mm in January (Appendix A, Table 1) (INMET, 2017). Salto de Pirapora has a total area of 28126.98 ha, with a predominance of pastures (29.49% of the total area) and forestry (21.88%), and has a total area of 5996 ha (21.32%) of vegetation cover (Pires et al., 2016a). The municipality contains 700 forest patches, mostly small, with only 27 (3.8%) being greater than 50 ha (Pires et al., 2016b).

2.2. Spatial analysis

In order to select forest patches of greater conservational integrity and to support the elaboration of the spatial analysis, we used information on the hydrography (supplementary material, Appendix B, Fig. 1) and information on the Atlantic Forest patches (Appendix B, Fig. 2), which is a component of the Geography Database of Laboratory for Landscape Ecology and Conservation Studies (http://www2.sorocaba.ufscar.br/neepc/) from the Federal University of São Carlos - Sorocaba (Pires, 2016). We defined four variables as priority for the detection of stingless bees susceptible to fragmentation (Appendix B, Chart 1): (a) forest patch size (Eltz et al., 2003, Samejima et al., 2004, Meneses-Calvillo et al., 2010, Ferreira et al., 2015); (b) forest patch core area (Murcia, 1995, Stangler et al., 2016); (c) the shortest distance to the nearest forest patch (Kreyer et al., 2004, Brosi et al., 2007, Hatfield and Lebuhn, 2007, Krewenka et al., 2011); and (d) the shortest distance to a body of water (Hatfield and Lebuhn, 2007, Sárospataki et al., 2009). As the forest patches had small areas, we adopted a distance of 35 m as the demarcation of what constitutes a forest patch's core (Rodrigues, 1998, Bourlegat, 2003, Degen et al., 2010). We chose this distance because the externalities of the forest patches are mostly attenuated after the first 35 m from the edge (Rodrigues 1998).

We generated four maps: two for calculating distances (one for the distance of forest patches and one based on forest patch hydrography), and two for calculating areas (one for the area of the forest patches and one for the area of the forest patches' cores). For the distance calculations, we generated buffers (coverage regions) with distances of 50 m between the rings (Appendix B, Figs. 3 and 4), and we classified sizes according to the area (Appendix B, Figs. 5 and 6). To standardize the metric values and make them comparable to each other, we normalized the four layers with values from 0 to 1, following the formula (1) (Martines et al., 2017). The calculation corresponds to a linear transformation between 0 and 1, where K is the attribute to be normalized. In the formula, we used the value of the attributes (Z_i^k), its maximum value (Z_{max}^k) and its minimum value (Z_{min}^k).

$$(Z_i^k)_N = \frac{Z_i^k - Z_{min}^k}{Z_{max}^k - Z_{min}^k} \quad (1)$$

For the calculation of distances, the highest value was attributed to the lowest distance (0 – farther, 1 – closer), and for the calculation of the areas, the highest value was attributed to the larger area (0 – smaller area, 1 – greater area), considering that larger values favor the presence of stingless bees. We converted the maps from vector to raster format (pixel size = 5 m), so that map algebra could be performed, and obtained four new maps in which each pixel was assigned to a value between 0 (less favorable to the occurrence of stingless bees) and 1 (more favorable). Finally, we created a synthesis map containing the sum of the previous ones by map algebra (Tomlinson, 1990) in which each pixel assumes a value from 0 (less favorable to the occurrence of stingless bees) to 4 (more favorable to their occurrence) (Appendix B, Fig. 7).

We reclassified the synthesis map into five categories from the manual classification of the histogram (Appendix B, Fig. 8), with values indicated from the lowest (dark green, with values closer to 0) to the highest (red, with values closer to 4), and the higher the value, the greater the potential of occupation of the artificial shelters by stingless bees (Fig. 1). Based on this classification, we selected six forest patches where the artificial shelter installation would take place: three forest patches denominated as "hotspot", serving as sampling sites where we expected a higher potential to the presence of stingless bees, and three forest patches denominated as control, where we expected the lower potential to the presence of stingless bees (Appendix B, Fig. 9). We labeled the hotspot patches HA, HB and HC, and the control patches CA, CB and CC.

2.3. Artificial shelter installation

In order to verify the presence of bees in the forest patches, we made artificial shelters for their nesting (Appendix A, Fig. 2) based on methodologies carried out by beekeepers and by the methodology proposed by Oliveira et al. (2013). We used 3 L plastic bottles and