Biota Neotropica 20(suppl.1): e20190906, 2020
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

Future scenarios of land-use-cover effects on pollination supply and demand in São Paulo State, Brazil

Marcela de Matos Barbosa[1]*, *Liedson Tavares Carneiro*[2], *Manuela Franco de Carvalho da Silva Pereira*[3,4], *Catalina Zuluaga Rodriguez*[5], *Tássia Rayane Ferreira Chagas*[6], *Wladimir Moya*[7], *Leonardo Lima Bergamini*[8], *Matheus Camargo Silva Mancini*[6], *Natalia Dantas Paes*[9] & *Laura Camila Perez Giraldo*[10]

[1]*Universidade de São Paulo, Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto, 65080-140, Ribeirão Preto, SP, Brasil.*
[2]*Universidade Federal de Pernambuco, Centro de Biociências, Departamento de Botânica, 50372-970, Recife, PE, Brasil.*
[3]*Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Centro de Energia Nuclear na Agricultura, Programa Interunidades de Pós-Graduação em Ecologia Aplicada, 13418-900, Piracicaba, SP, Brasil.*
[4]*Universidade Federal da Fronteira Sul, 85301-270, Laranjeiras do Sul, PR, Brasil.*
[5]*Universidade de São Paulo, Instituto de Biociências, Departamento de Ecologia, Programa de Pós-graduação em Ecologia, 05508-090, São Paulo, SP, Brasil.*
[6]*Universidade Federal de Lavras, Departamento de Ecologia, Programa de Pós-graduação em Ecologia Aplicada, 37200-000, Lavras, MG, Brasil.*
[7]*Universidad de Los Lagos, Programa de Doctorado en Manejo y Conservación de Recursos Naturales, Campus Osorno, 5290000, Osorno, Chile.*
[8]*Instituto Brasileiro de Geografia e Estatística - IBGE, Reserva Ecológica, 70312-970, Brasília, DF, Brasil.*
[9]*Universidade Estadual de Campinas, Departamento de Ecologia, Programa de Pós-graduação em Ecologia, 13083-862, Campinas, SP, Brasil.*
[10]*Fraunhofer Chile Research, 8580704, Santiago, Chile.*
**Corresponding author: Marcela de Matos Barbosa, e-mail: barbosamarcela@usp.br*

BARBOSA, M.M., CARNEIRO, L.T., PEREIRA, M.F.C.S., RODRIGUEZ, C.Z., CHAGAS, T.R.F., MOYA, W., BERGAMINI, L.L., MANCINI, M.C.S., PAES, N.D., PÉREZ-GIRALDO, L.C. **Future scenarios of land-use-cover effects on pollination supply and demand in São Paulo State, Brazil**. Biota Neotropica 20(suppl. 1): e20190906. https://doi.org/10.1590/1676-0611-BN-2019-0906

Abstract: Rapid land-use/land cover changes (LULCC) have led to habitat loss and fragmentation in the natural forest areas, which are mainly due to the intense and rapid expansion of urban areas and intense agricultural management. These processes are strongly threatening biodiversity maintenance and the ecosystem services provided by them. Among the ecosystem services under threat, pollination has been widely studied since this service is essential to promote food production and, therefore, human well-being. In a scenario of increasing LULCC it is crucial to understand the interplay between these changes, pollination demand by insect-dependent crops and pollinator availability to ensure these ecosystem services meet the increased demand for food production. In this study, we developed a conceptual model to disentangle the relationships between human-nature, especially LULCC, and its consequences, to the delivery of pollination service. We also presented a case study in the Brazilian São Paulo state, where we modeled the effects of predicted LULCC associated to agriculture expansion between the years 2012 and 2030 on pollinator demand by crops and pollinator supply, for fourteen economically important crops. Additionally, we systematized an expert-based Ecosystem Service matrix to estimate the influences of LULCC on the provision of pollination. Our results showed that by 2030, the demand for pollination will increase by 40% on average, while pollinator supply, estimated using suitability values for the different land-use/cover classes, will show, on average, a 3% decrease. Our results highlight the importance of considering the dialogue among stakeholders, governments, institutions, and scientists to find alternatives and strategies to promote pollinator-friendly practices and safeguard the provision of pollination services in a future under LULCC.
Keywords: *bees; crop-dependence; Ecosystem services; human-nature interface; Tropical Forest.*

Cenários futuros de mudanças de uso e cobertura do solo e seus efeitos sobre oferta e demanda de polinização no estado de São Paulo, Brasil

Resumo: As aceleradas mudanças de uso e cobertura do solo levaram à perda e fragmentação de habitat das florestas naturais, principalmente devido a uma intensa e rápida expansão de áreas urbanas e ao intensivo manejo agrícola. Esses processos ameaçam fortemente a manutenção da biodiversidade e os serviços ecossistêmicos associados. Entre os serviços ecossistêmicos ameaçados, a polinização tem sido amplamente estudada, pois se trata de um serviço essencial para a produção de alimentos e, consequentemente, para o bem-estar humano. Em um cenário de crescentes mudanças no uso e cobertura do solo, é crucial entender a interação entre essas mudanças, a demanda de polinização por culturas dependentes de insetos e a disponibilidade de polinizadores para garantir que esse serviço ecossistêmico atenda o aumento da demanda produtiva de alimentos. Neste estudo, desenvolvemos um modelo conceitual para evidenciar as relações homem-natureza, especialmente as consequências das mudanças de uso e cobertura do solo sobre a prestação do serviço de polinização. Nós também apresentamos um estudo de caso no estado brasileiro de São Paulo, onde modelamos os efeitos de mudanças de uso e cobertura do solo associados à expansão de agricultura entre os anos de 2012 e 2030 e as demandas e oferta de polinizadores por cultura, para quatorze culturas economicamente importantes. Além disso, sistematizamos uma matriz de serviços ecossistêmicos baseada em conhecimento de especialistas para estimar as influências das mudanças de uso e cobertura do solo na provisão do serviço de polinização. Nossos resultados mostraram que até 2030, a demanda por polinização aumentará em média 40%, enquanto a oferta de polinizadores estimada, usando valores de adequação para as diferentes classes de uso e cobertura do solo, terá uma redução média de 3%. Nossos resultados destacam a importância do diálogo entre agricultores e outros importantes agentes impulsionando as mudanças de uso do solo, governos, instituições e cientistas para encontrar alternativas e estratégias para promover práticas favoráveis aos polinizadores e salvaguardar a prestação de serviços de polinização em cenários futuros de mudanças de uso e cobertura do solo.
Palavras-chave: *abelhas; dependência de culturas agrícolas; serviços ecossistêmicos; interface homem-natureza; floresta tropical.*

Introduction

Habitat loss and fragmentation are caused mainly by land-use/land cover changes (LULCC) resulting from the expansion of agricultural and urban areas demanded by human population growth and economic development (Kremen et al. 2004, Foley et al. 2005, Roberts 2011, Aizen et al. 2019). By LULCC we refer to human activities that alter land surface processes including biogeochemistry, hydrology and biodiversity and changes on the physical and biological cover over the surface of land (Mustard et al. 2004, Ellis & Pontius 2007). These changes occur at alarming rates in the Tropics which harbors the highest terrestrial biodiversity (Gaston 2000). Tropical regions are expected to face a dramatic agricultural expansion during the next decades (Laurance et al. 2014). Regarding to the negative impacts that LULCC can generate upon biodiversity (IPBES 2019), pollinator communities decline is one of the most widely studied (e.g. Klein et al. 2007, Vanbergen et al. 2013), mainly due to the importance of pollinators in maintaining biodiversity and world crop productivity (Bauer &Wing 2016).

In Brazil, pollination services mainly rely on wild pollinators since there is an incipient development of practices to increase crop production with managed bees (Imperatriz-Fonseca et al. 2006). The services of wild pollinators in natural habitats tend to decrease in scenarios of intensive LULCC resulting from increased human demands (Aizen et al. 2008, Garibaldi et al. 2014). Since wild pollinators require specific resources for nesting, feeding and reproducing as well as certain habitat conditions to ensure their survival, intensive LULCC can negatively affect the density of pollinators at different scales (Fahrig et al. 2011, Motzkea et al. 2016, Senapathi et al. 2017). For example, Ferreira (2015) found that above-ground nesting bees are more sensitive to forest loss induced by anthropogenic factors than ground-nesting bees. For social bees, the effect of changes in forest cover at local scale depends on the regional forest cover, with negative effects being detected when landscapes had at least 35% of forest (Ferreira et al. 2015). In addition, the usual agricultural practices, which still rely on the intensive use of pesticides and extensive monoculture, threaten pollination services (Park et al. 2015). These practices also affect stability and resilience of farming systems, which present lower capacity to adopt alternative strategies under stresses like climate change (Nelson et al. 2010). Therefore, to preserve the pollination services in Brazil, it is necessary to review environmental policies, socioeconomic system and crop management practices (Cunha et al. 2012).

Tropical forests, such as the Atlantic Rainforest, are examples of natural ecosystems threatened by high levels of degradation and reduction of forested areas as a result of urban development and crop expansion. This biodiversity hotspot (Tabarelli et al. 2005) originally comprised one of the largest rainforests in the Americas, covering around 150 million hectares under highly heterogeneous environmental conditions (Ribeiro et al. 2009). The agricultural and urban expansion throughout the Atlantic Rainforest over the past 500 years resulted in 80% of forest loss and a fragmented landscape composed of isolated patches of forest (Ribeiro et al. 2009, Rezende et al. 2018). Furthermore, these natural fragments are embedded into different matrices of pasture, agriculture, forestry and urban areas (Perfecto & Vandermeer 2010, Joly et al. 2014).

Studies have emphasized the importance of forest fragments in maintaining bee pollinators and consequently the pollination services provided by them (Carvalheiro et al. 2010, Saturni et al. 2016, Buchori et al. 2019). Thus, alternative conservation strategies are urgently needed in the Atlantic Rainforests, especially where insect-dependent crops are expected to increase. Such strategies should promote the reconciliation of the current restoration policies and pollinator-friendly practices (Dicks et al. 2016) leading to a socially equitable conservation scenario.

In this study, we developed a conceptual model based on the general framework elaborated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to assess key components and its relationships to guarantee the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (Díaz et al. 2015; IPBES 2016). Here, we described connections among drivers related to nature and social key elements supporting or constraining the provision of pollination services taking LULCC as one of the major direct drivers. We also presented a case study using the state of São Paulo as a model of large-scale landscape for which we projected a future scenario of pollination demand and supply and applied the general conceptual model. The modeling procedure included 14 economically important crops and LULCC scenarios from OTIMIZAGRO model (Soares-Filho et al. 2013, 2016). We asked the following questions: (1) Which land-use/cover classes favor the provision of pollination services? (2) How do LULCC influence the pollination demand of pollinator-dependent crops and (3) How do LULCC influence the pollination supply, considering differences in estimated availability of food and nest resources between land-use classes? By answering these questions, it is possible to understand how projected LULCC can potentially affect the flow of pollination services provided by wild pollinators.

Material and Methods

1. General conceptual model

Our conceptual model is based on the Assessment Report on Pollinators, Pollination and Food Production (IPBES 2016) in accordance with the IPBES conceptual framework (Díaz et al. 2015). This model illustrates the relationships between direct and indirect drivers influencing pollination services as well as the contributions of these services to people generating human well-being. The model also presents the role of institutions and governments in promoting conservation strategies at a national scale. Since bee pollinators are associated with more than 90% of economically important crops (Klein et al. 2007), we applied the IPBES conceptual model considering ecological requirements and conservation strategies related to this functional group of pollinators.

According to our conceptual model direct drivers, represented here by an anthropogenic factor (e.g., land-use changes), directly influence nature at local site (Arrow number 1 and Boxes A and B; Figure 1). For example, LULCC and the fragmentation process affect how landscapes support pollinator biodiversity and pollination services by constraining bee dispersal, occurrence and gene flow (Jha et al. 2015, Jaffé et al. 2019, Barbosa et al. 2019). Due to bee dispersal constraints, pollen flow should also be limited by the fragmentation process, resulting in low rates of cross pollination and endogamy (Hadley et al. 2012).

The mutual-effect relationship between nest availability, natural and semi-natural habitats, and diversity of floral resources directly affect the diversity of bees by reducing bee's ability to face diseases (Jones et al. 2018) and to persist in environments due to the lack of floral resources (Ricotta & Moretti, 2011). Therefore, the relationships with nature elements at local scale determine the habitat capacity to maintain biodiversity and deliver of pollination services (Arrow 2 leading to Box C).

Finally, the interactions and practices among farmers, land-use policies and environmental laws (Box D) can influence the maintenance of pollination services. At the same time, the pollination service can stimulate specific farming practices and guide the development of land use policies (bidirectional Arrow 3). LULCC is also influenced by the indirect drivers from Box D (Arrow 4). New market trends dictate farmers' decisions about investing in certain types of crops, especially because most of them are commodities and follow international trends. Land-use policies and environmental laws (such as the Forest Code and Atlantic Forest Pact) establish limits to deforestation and, in this way, limits to new cultivated areas.

At the end of the model, the pollination service delivers the nature's contributions to people (NCPs) (Arrow 5; Box E). The increment of crop productivity or even the assurance of crop production is resulted not only by biodiversity, but also from quantification of the relationships of stakeholders and anthropogenic assets, such as development of new agricultural systems based on local technologies.

2. Ecosystem Service matrix

In order to complement the conceptual model interpretation and evaluate pollination-related ecosystem services (ES) under different LULCC scenarios, we proposed a matrix from which the scores were determined according to expert knowledge for estimating capacity, supply, use and demand (Campagne & Roche 2018). This matrix relates ES categories to influences of promoting pollination services associated with broad land-use/cover classes (forest, urban area, pasture, crops, waterbodies, silviculture and savannah). Matrix scores indicate the supporting capacity of each land-use/cover class in the provision of ES (Campagne & Roche 2018). According to this approach, matrix scores range from 0 to 5, where "0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = moderate relevant capacity, 4 = high relevant capacity, and 5 = very high relevant capacity" (Burkhard et al. 2009). To create the matrix, we searched for other studies that provide matrix scores describing the association between land-use/cover categories and ES. The studies were surveyed via the Web of Science repository (http://www.webofknowledge.com). Eleven studies developed in Tropical regions were selected. To obtain the final scores of our matrix, we calculated the mean scores considering the values representing the associations between each land-use/cover classes and ecosystems services, provided by these studies. We only considered land-use/cover classes relevant to our case study and ecosystem services related to pollination provision (habitat creation and maintenance, dispersion of pollen and other propagules, food security, medicinal and genetic resources, cultural heritage).

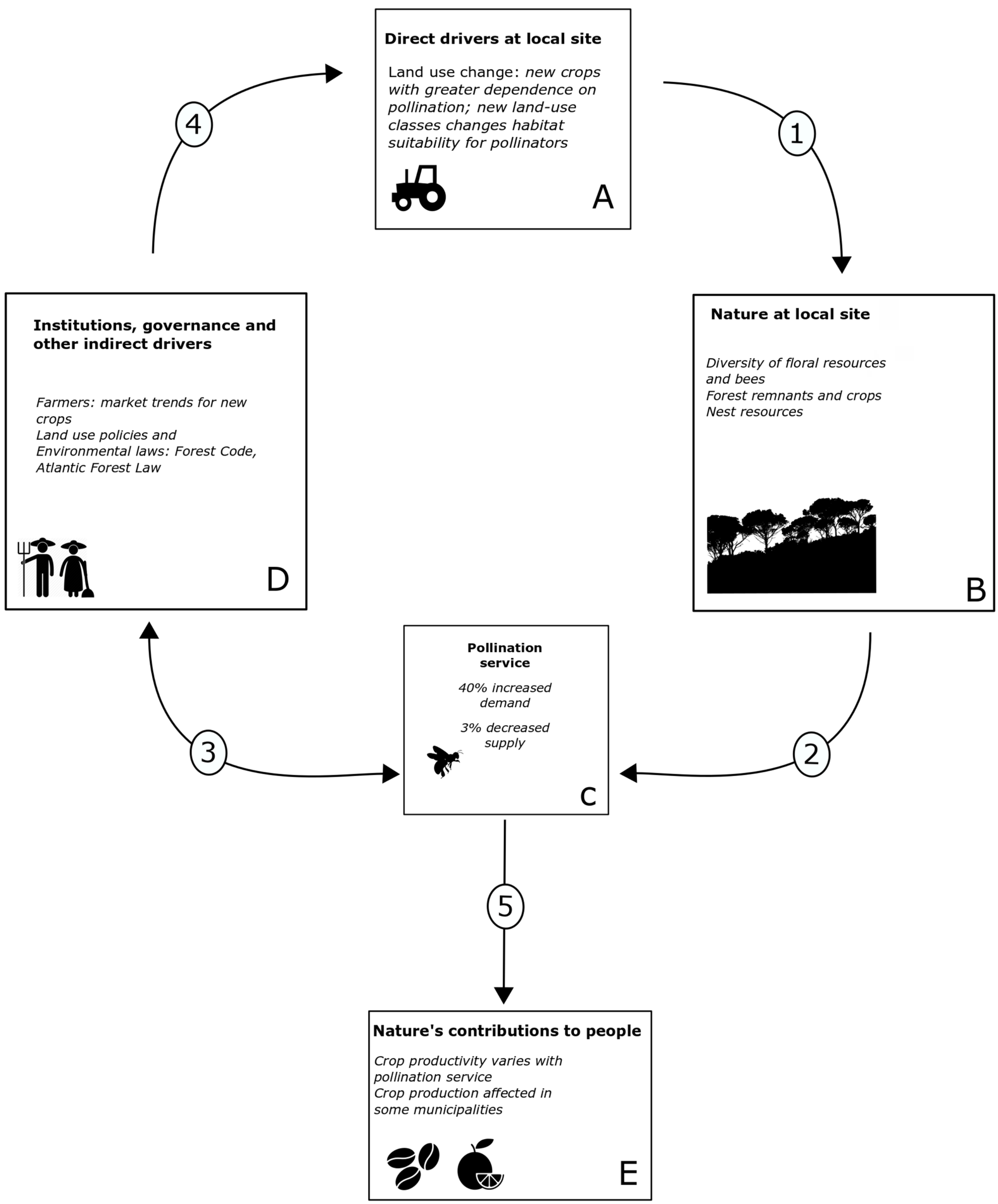

Figure 1. Study case conceptual model for achieving the increasing demand on pollination services in São Paulo State.

3. LULCC model

To predict future changes in land, we used outputs from the spatially explicit land-use/cover model provided by OTIMIZAGRO (Figure 2) (Soares-Filho et al. 2013, 2016). The model simulates future agricultural expansion for 14 economically important crops, considering the effects of transportation costs, climatic suitability and profitability: nine annual crops (soy, sugarcane, corn, cotton, wheat, beans, rice, manioc and tobacco), including single and double cropping systems; and five perennial crops (arabica coffee, robusta coffee, orange, banana and cocoa). The model also includes pastures, plantation forests, water surface, urban areas and native vegetation (Table S1). The future land-use/cover map of agricultural expansion is based on projections for 2024 (MAPA 2013) extrapolated to 2030 by using historical trends of agricultural production between 1994 and 2013 (IBGE 2013) and the modeled land cover changes considered deforestation within the limits established by the Brazilian Forest Code for Atlantic Forest and Cerrado Biomes.

To create a pollinator-dependence matrix comprising the 14 crops, we considered the pollination dependence rates estimated by the Brazilian pollination assessment (see Wolowski et al. 2019). The calculation of pollinator dependence rates provided by the assessment followed the methodology proposed by Gallai et al. (2009). The pollination dependence rates attributed to the crops included in the model were 0 (no dependence; e.g., rice and sugarcane), 0.25 (modest; e.g., soy and coffee) or 0.95 (essential; e.g., cocoa) (Table S1). The pollinator dependence matrix was spatialized using the OTIMIZAGRO Model maps of agricultural expansion for the years 2012 and 2030.

Mean dependence values were computed for each of the 645 municipalities São Paulo state considering the area covered by each category (crops, pasture, plantation forests, water, and urban area) and their respective pollinator dependence rate. Natural vegetation, urban area and water surface classes were not considered in the calculation. We used expert-based data on habitat suitability for bees synthesized by Kennedy et al. (2013) as a proxy for pollination supply in each land use/cover class (Table S1). Percentual changes in mean pollination demand and suitability values per municipality were computed for the period by subtracting the predicted value for 2030 and the value for 2012 and dividing the result by the 2012 value. Municipalities with null values for pollination demand in the year 2012 were not included in the calculations of percentage changes.

Associations between trends in pollination demand and supply were mapped by classifying each municipality in nine categories, representing all possible combinations of trends for both pollination supply and demand at the following three categorical levels: increases of more than 5% between 2012 and 2030, decreases of more than 5% between 2012 and 2030 and changes between +5% and -5% (see table S2 for the complete dataset).

The analyses were carried out in R version 3.6.1 (R Core Development Team 2019), using the packages *raster* (Hijmans 2019) and *rgdal* (Bivand et al. 2019). Maps were produced using the software QGIS (QGIS version 2.18).

Results

1. Conceptual model case study

We adapted the IPBES conceptual framework to our case study focusing on the effects of LULCC and the estimated demand for pollination services (Figure 1). We considered how land use changes affect pollination services and human well-being that were the focal components of our scenario modeling.

Land use change was the anthropogenic direct driver considered at local sites (Box A). Changes in land use and cover are known to impact significantly biodiversity and the delivery of ecosystem services.

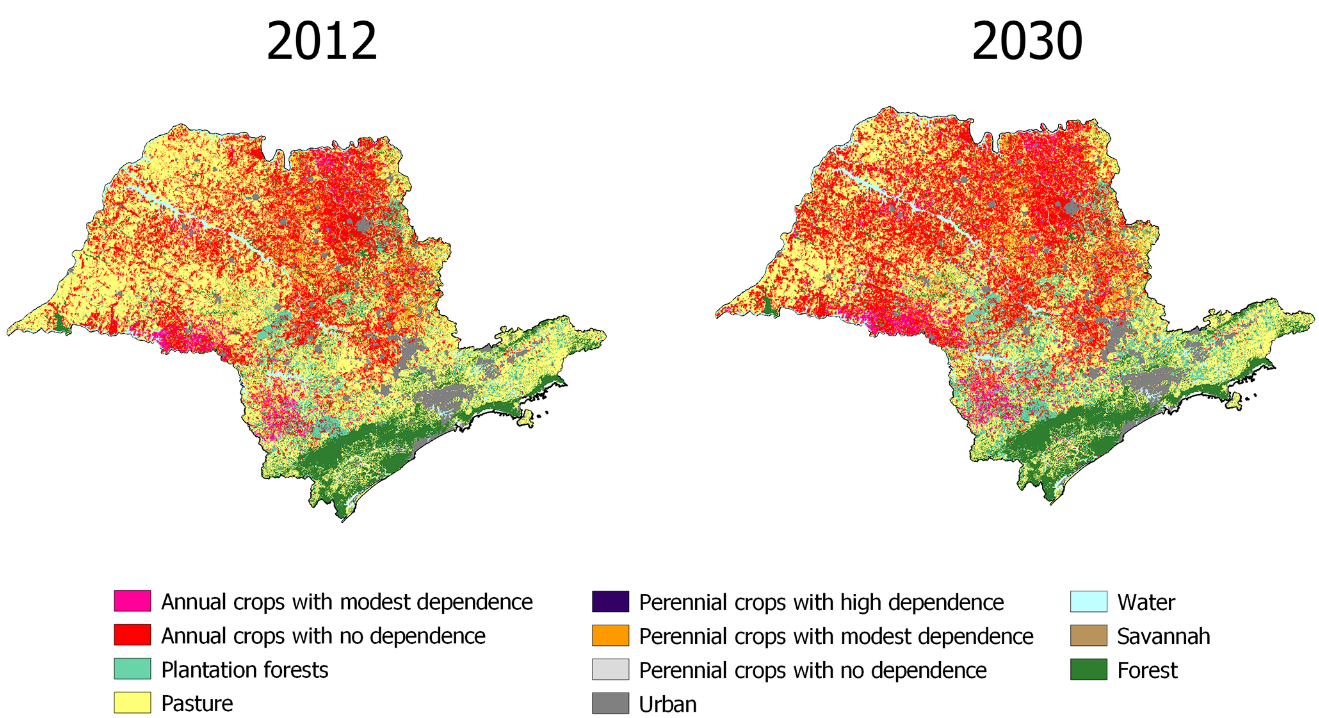

Figure 2. Land use changes scenarios for the state of São Paulo according to OTIMIZAGRO model.

The LULCC scenario modeling for São Paulo State projects a shift on the main dependence rate for pollination of croplands. It indicates a replacement of crops with low dependence rates on pollination by crops with higher dependence on pollinators. This change affects nature at a local site (Box B), since an increase of pollination dependent crops in semi natural habitats increases the demand for other floral resources used by bees in between crop season, which affects natural habitats, such as forest remnants that provide food resources for pollinators. These changes can also affect other factors, such as bee nesting resources, for example.

As a result of new cultivated crops and their specific dependence rates on pollination, we predict a 40% of increased demand for pollination service (see LULCC model effects on pollination section). This means that agricultural products will rely more on pollination service than they already do. Since the current scenario of bee conservation is not optimistic (see LULCC model effects on pollination section), productivity might be at risk in some municipalities.

Therefore, in order to ensure adequate pollination of these crops and safeguard productivity in these regions, strategic planning is needed. Involved actors, such as farmers and decision makers, should focus on spatial arrangements to improve bee's access to crops and to maintain resources and conditions for their survival.

This increased demand will directly affect nature's contribution to people (Arrow 5, Box E), as crops will provide different resources from those obtained in the past. It is expected that new products are more valuable than previous ones if farmers follow international market tendencies. Moreover, pollinator dependent crops also provide high quality and quantity products when pollinated, which add even more value to these products, both in intrinsic and extrinsic aspects (e.g. healthy foods and market prices, respectively).

2. *Ecosystem service matrix*

We evaluated eleven papers related to land use and different managements of landscape providing benefits to pollinator biodiversity and provision of pollination services. The resulting matrix showed that the land use types that contributed most with ES supply by pollinators were annual crops, native forest and forest plantations (Figure 3). On the other hand, pastures, constructed areas and water bodies contributed to a lesser extent.

3. *LULCC model effects on pollination*

The OTIMIZAGRO land use model predicts an increase trend for the demand on pollination services in São Paulo state considering the expansion of the modeled crops up to 2030 (Figure 4, Table S2). Comparing the present (2012) with the future scenarios, the mean demand for pollination services increases by 40%, considering predictions for future LULCC. The municipalities from the south of São Paulo state (such as Itapetininga, Itararã, Itapeva and Buri) show the highest mean crop dependence. This region and the northern region of the state comprise important agricultural areas and the crops under study, will expand on these regions in the future. Thus, these regions are more vulnerable and more likely to suffer from the implications of a decline in threatened pollinators.

The municipalities that currently do not have any pollinator-dependent crop will face the establishment and expansion of pollinator-dependent crops. As soybean expansion is predicted for the southwestern region, comprising Rosana and Presidente Prudente municipalities (Figure 4, Table S2), the demand for pollinators agents will rise. Most municipalities that do not have any crops dependent on pollinators will tend to remain so into the next decade.

Land Use Types/Average	Habitat creation and maintainance	Dispersion of pollen and other propagules	Food security	Medicinal, biochemical and genetic resources	Cultural heritage (Intrinsic value of biodiversity)	Pollination
Forest	2.4	2.76	1.02	2.22	2.66	4.36
Urban areas	0.6	0.36	0.26	0.22	0.68	0.76
Pasture	1.6	0.8	1	1	0.2	0
Crops	1.4	1.3	3.8	1	0.7	1.64
Water bodies	2.4	0.42	0.14	0.82	2.18	0.64
Forestry	2.6	2.9	1.4	2.82	2.66	0.6

Figure 3. ES assessment matrix illustrating the land use types capacities to provide pollination ecosystem service and other ecosystem service favoring wild pollinators.

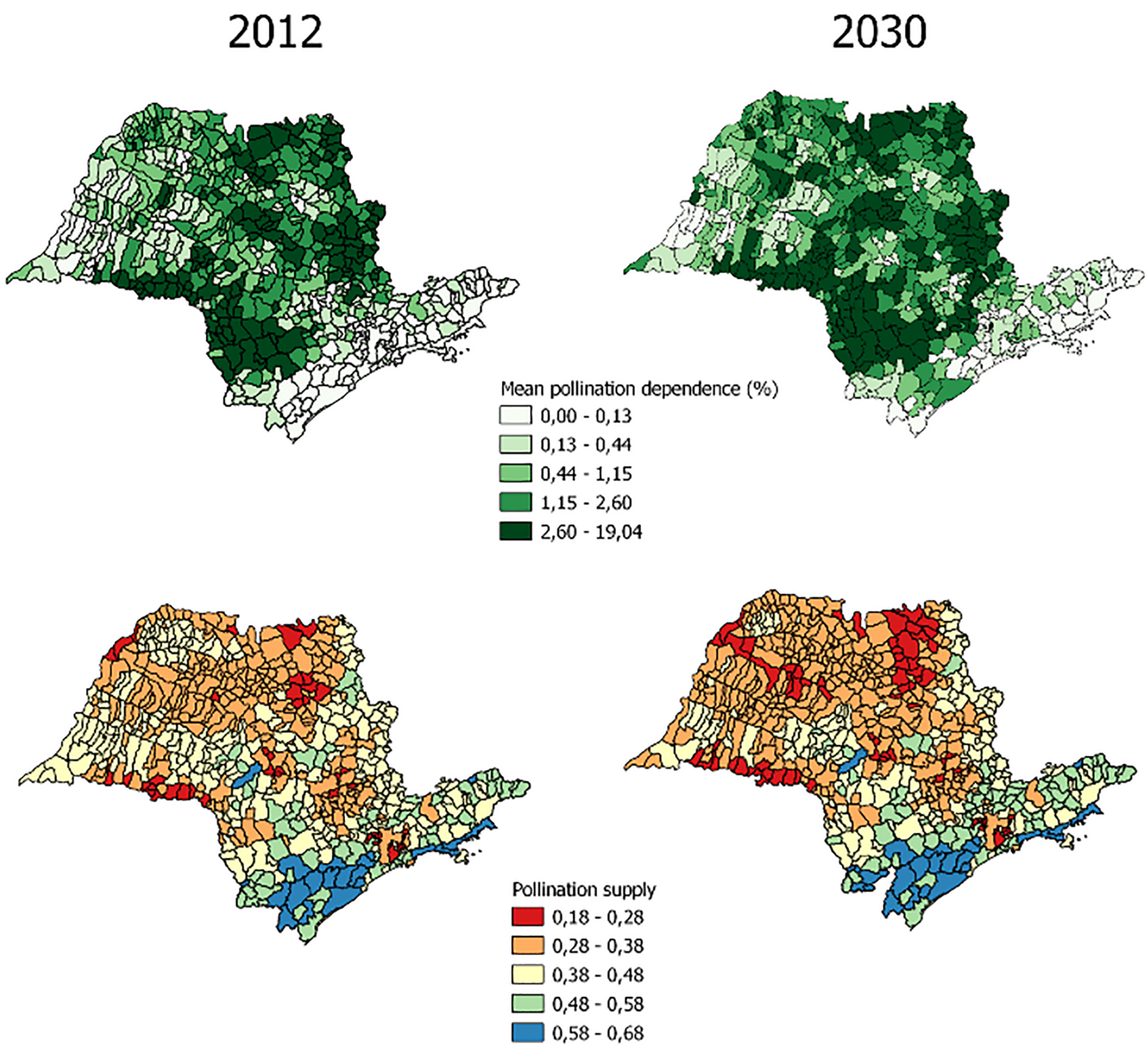

Figure 4. Present (2012) and future (2030) scenarios for the effects of land use change on pollination supply and demand of demands for pollination services in the state of São Paulo, Brazil. Top: Mean crop dependence on pollinators. Bottom: Mean pollinator supply.

Pollination supply is predicted to decline on average by 3% due to LULCC, represented mainly by expansion of annual row crops over areas that provide more suitable habitats to bees (such as native vegetation and pastures). These change will be more pronounced on the western municipalities (Figure 4, Table S2), with the higher percentage of changes expected to occur in Ipiguá, Bastos and São João do Pau d'alho, all with projected supply declines of over 20% (Table S2). The most common combined trend between pollination supply and demand was the increase in demand accompanied by a decrease in supply, observed in 195 municipalities, most of them located in the western portion of São Paulo State (Figure 5, Table S2). Only six municipalities showed the opposite trend (decrease in dependence and increase in suitability, Figure 5, Table S2) and the main pattern observed in this case was the replacement of crops by plantation forests (as observed, for example, in Pinhalzinho, SE São Paulo). Another 144 municipalities, also concentrated in the western region of the State, are expected to show an increase in dependence rate alongside a relatively stable pollination supply (changes between +5% and -5%; Figure 5, Table S2).

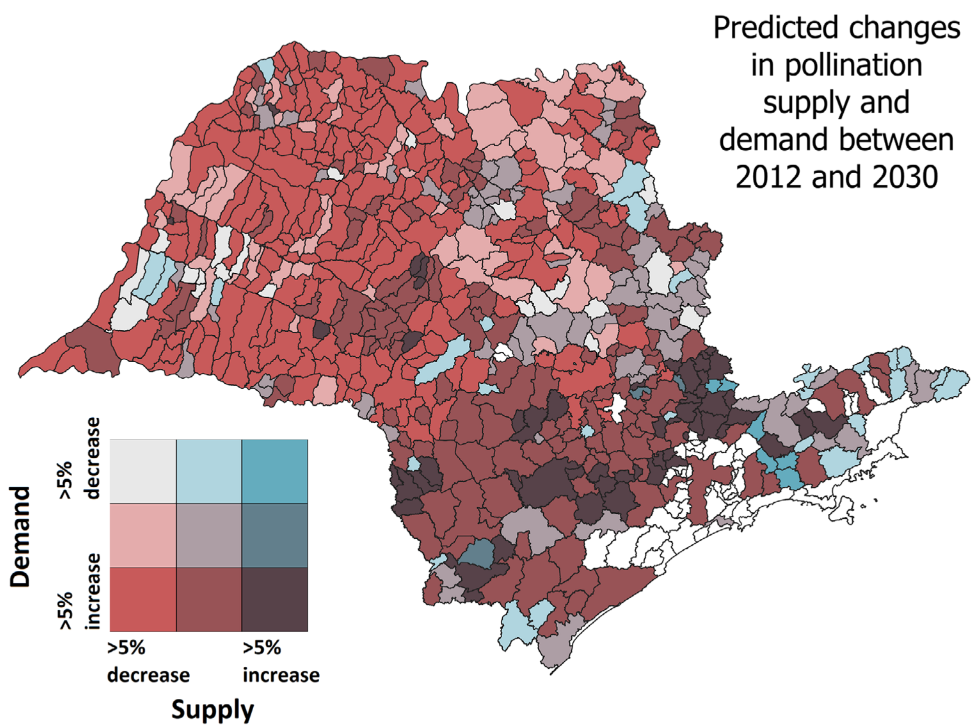

Figure 5. Changes in pollination supply and demand between 2012 and 2030. Municipalities in white had mean pollination dependence rate of 0 in 2012, and were not included in the percentage change calculations.

Discussion

In this study, we projected a future scenario that showed an increased demand coupled with a slightly reduced supply for pollination services in the state of São Paulo due to LULCC over the next twenty years. Population growth and the availability of suitable land for agriculture are major factors explaining present and historical LULCC in the state of São Paulo. These same factors can be considered as the major drivers of LULCC in a few years, suggesting an urgent need to reconcile environmental and economic policies.

The predicted increase in pollination demand up to 40% for São Paulo State was due to the expansion of areas with more pollinator-dependent crops, such as coffee, orange and cotton, replacing those that do not need pollination – mainly sugarcane, plantation forests and pastures. It is important to note that these results are probably an underestimation, since many of the crops not considered in the OTIMIZAGRO scenario have modest to high dependencies on pollinators (fruits and vegetables such as watermelon, tomatoes, strawberries, peppers etc.). Although the mean reduction in estimated pollination supply was not high, some municipalities are expected to show higher supply decreases simultaneously with increases in dependence. Thus, if this increasing demand is to be met, especially in those more affected municipalities, effective measures to conserve and promote the sustainable use of native and wild bees are needed, such as better allocation of areas for conservation units, pollinator-friendly management practices to improve the condition of the existing habitat and the adoption of better practices regarding agrochemical use (especially insecticides).

As indicated in the conceptual model, LULCC promotes loss of natural habitats and threaten pollinators, by affecting the quality and quantity of food resources and number of nesting sites. It is important to remark that our scenario approach only considers broad patterns in LULCC at the municipality level. At finer spatial scales, other effects have been demonstrated, such as the effects of fragmentation on biodiversity and gene flow of bees (Ferreira et al. 2015, Boscolo et al. 2017, Montagnana et al. 2018, Nery et al. 2018, Barbosa et al. 2019). The spatial configuration of crop fields and habitat patches can also be important, as exemplified by observed effects of the distance to the nearest native vegetation (Garibaldi et al. 2011). Nevertheless, the results shown here serve as a first step in describing the expected effects of LULCC in the considered scenario and are useful in defining research priorities and point directions for better management.

In order to reach the demand for pollination service in the future scenario, practices to maintain forest cover should be addressed, since this is the most important land-use class that supplies pollination ES. It has been widely reported that forest fragments can increase the diversity and abundance of pollinators with substantial gains in crop production (Campbell et al. 2017, Hipólito et al. 2019).This has been highlighted for orange (unpublished data) and coffee (Saturni et al. 2016) across the Atlantic Rainforest domain within the state of São Paulo. The role played by forest fragments in providing biodiversity of bees results in both an increase of crop productivity and improvement of nutritional composition of fruits (Brittain et al., 2014; Klatt et al., 2014). Therefore, maintaining, increasing and managing appropriate habitats for wild pollinators are profitable opportunities for species conservation and continuous crop production (Lautenbach et al. 2012).

Simulations have predicted that, depending on the magnitude and location of ongoing forest conversion, pollination services are expected to decline continuously and thus directly reduce coffee yields by up to 18% and net revenues per hectare up to 14% in other tropical forests (Priess et al. 2007). However, this scenario can be avoided if patches of forests (or other natural vegetation) are maintained in agricultural landscape, which could be a viable near future option for local local farmers and regional land-use planners (Priess et al. 2007). This same approach may be applied for Brazilian tropical forests in order to prevent the reduction of crop pollination and attend the increased demand for future scenario in São Paulo state.

We observed a gap in Brazilian studies linking pollination services and different restoration contexts to promote crop yields. Filling this gap is urgent to inform and support land-use planners and decision makers to choose priority areas for restauration. This reflects not only on the delivery of the service in itself, but also to human well-being, since it may improve net revenues to small farmers. Among strategies that may contribute to the maintenance of natural habitat, the expansion of protected areas can act as reservoirs of pollinators and, therefore, provide pollination services for crops nearby. This gap might be fulfilled in order to provide information to land managers and obtain efficient provision of pollination considering future scenarios.

It is important to make a reservation about the results obtained by our model for the capacity of forest plantations on maintaining pollinators' communities. Even though in Kennedy et al. (2013) this land-use category was considered as suitable habitat as native broadleaf forest, we believe that there are some important differences between both habitat types in our study area. Plantation forests, typically consist of one or a few tree species, are grown as even-aged monocultures, intensively managed and harvested on relatively short rotations (Taki et al. 2011). These characteristics raise concerns that plantation forests may negatively impact forest biodiversity (Brockerhoff et al. 2008). However, moderate disturbances in native forests, including forest plantations, may help maintain pollinator abundance and diversity by expanding the cover of herbaceous plant species, thereby increasing nectar and pollen availability (Winfree et al. 2007). Nevertheless, for the sake of consistency, we opted to maintain the suitability value for plantation forests provided in Kennedy et al. (2013). In this way, the results driven by predicted changes in plantation forest should be interpreted with care in our case study and more specific information about the differences in floral resource and nesting site availability between native forests and plantation forests are needed for a better understanding of those trends.

From the perspective of crop management, Brazil has been adopting decisions in opposite directions that jeopardize biodiversity of pollinators and threaten pollination services. The consumption of insecticides in Brazil more than doubled (152%) in the last 15 years, from 2003 to 2018 (Santos et al. 2018). Besides increasing pesticide use, control policies by competent agencies are insufficient (SABESP 2019), which hamper monitoring for correct use of agrochemicals as required by the Brazilian Ministry of the Environment (Cham et al. 2017). Thus, to overcome this barrier and guarantee the delivery of pollination up to 2030 in São Paulo state, alternative strategies to regulate or diminish the use of chemicals products, should be adopted, such as agroecological systems, organic agriculture practices and integrated pest management (IPM). These strategies should be discussed with all parties involved including farmers, beekeepers, scientists, governments and decision-makers (Díaz et al. 2015, Wolowski et al. 2019).

Although we could not include in our case study the effects of urban expansion, since this process is beyond the OTIMIZAGRO land-use scenarios' scope (Soares-Filho et al. 2019), we consider that urban expansion may have important impacts on pollinators, especially in our study area. Even in a scenario of expansion of land use change, some degree of habitat and food resources for pollinators can be provided by urban areas. This supply may be enhanced by urban green environments that can help to maintain pollination service, particularly by habitat creation and dispersion of pollen and other propagules (Henning & Ghazoul 2011). These areas may be important to promote gene flow in native bee species, such as *Tetragonisca angustula* and those species with generalist habit that can nest inside urban pre-existing cavities, such as some solitary bees. Threlfall et al. (2015) suggest that established urban green areas that contain native flowering plants with lower surrounding impervious surface cover, support greater bee abundance and greater richness of bee species, especially ground-nesting and floral specialist bees. Future work considering these effects would be particularly useful for the better planning of urban development.

Practical application of ES knowledge enables integration of institutional organizations, governance, stakeholders and partnerships between them with small and large farmers, crucial to guide and elucidate the best directions and pollinator-friendly practices to crop management. Initiatives such as the pact to restore Atlantic Rainforest can compensate the loss of original habitats in agricultural areas located in the south region of the state. This can be observed by the prediction for the 2030, wherein planted forest and annual crops tends to increase. Following the ES approach, it is expected to achieve long-term results in the environmental, social, cultural, political and economic aspects of sustainable development in the respective area (Nedkov et al. 2018).

Guidelines and organizations promoting efforts to avoid pollinator crisis are increasing with a still incipient participation of the Brazilian government. For example, Brazilian Environmental Ministry published an assessment on the risks of insecticides to bees (MMA, 2018) and the Brazilian Network of Plant–Pollinator Interactions (REBIPP) brought up a National Report on Pollination, Pollinators and Food Production. This asset followed the IPBES conceptual assessment (IPBES 2016). Future studies that explore the relationships between the aforementioned drivers and the potential of pollination by native animals, taken together with spatially-explicit scenario analysis of future demand of these services, may better inform which are priority areas to focus on management actions in order to successfully reach future demand and ensure a higher productivity and sustainability of the agriculture. Mitigating indirect and direct drivers that impact pollinator communities is a general step for the conservation of pollination services under scenarios of increased demands. Indirect drivers represented mainly by governance and institutions, play an important role in guiding anthropogenic direct drivers, particularly in relation to management crop and land use.

Supplementary material

The following online material is available for this article:

Table S1 - Description, dependence rates (BPBES report) and suitability values (obtained from table S4_2 of Kennedy et al. 2013) for OTIMIZAGRO class

Table S2 - Mean dependence and suitability values for the years 2012 and 2030 and percentage change in dependence and suitability along the period, for each São Paulo State municipality.

Acknowledgments

We would like to thank the organization team and institutions that made the realization of the São Paulo School of Advanced Science on Scenarios and Modelling on Biodiversity and Ecosystem Services to Support Human Well-Being possible: FAPESP, UNICAMP, USP, INPE, IAI, BPBES and Biota FAPESP. LLB received funding from IBGE to participate in the school. We also thank Jennifer Mckay Myers for the English Review.

Authors Contributions

Marcela de Matos Barbosa: Contribution in concept the study; data interpretation; manuscript preparation; contribution to critical revision, adding intellectual content.

Liedson Tavares Carneiro: Contribution in concept the study; data collection; manuscript preparation; contribution to critical revision, adding intellectual content.

Manuela Franco de Carvalho Silva Pereira: Contribution in concept the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Catalina Zuluaga Rodriguez: Contribution in concept the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Tássia Rayane Ferreira Chagas: Contribution in concept the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Wladimir Moya: Contribution in the concept of the study; manuscript preparation; data collection; contribution to critical revision, adding intellectual content.

Matheus Camargo Silva Mancini: Contribution in the concept of the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Leonardo Lima Bergamini: Contribution in concept the study; data analysis and interpretation; contribution to critical revision, adding intellectual contente.

Natalia Dantas Paes: Contribution in the concept of the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Laura Camilo Perez Giraldo: Contribution in the concept of the study; manuscript preparation; contribution to critical revision, adding intellectual content.

Conflicts of Interest

The authors declare no conflicts of interest related to this publication.

References

AIZEN, M.A., AGUIAR, S., BIESMEIJER, J.C., GARIBALDI, L.A., INOUYE, D.W., JUNG, C., MARTINS, D.J., MEDEL, R., MORALES, C.L., NGO, H., PAUW, A., PAXTON, R.J., SÁEZ, A. & SEYMOUR, C.L. 2019. Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Glob. Chang. Biol. 25(10):3516–3527.

AIZEN, M.A., GARIBALDI, L.A., CUNNINGHAM, S.A. & KLEIN, A.M. 2008. Long-Term Global Trends in Crop Yield and Production Reveal No Current Pollination Shortage but Increasing Pollinator Dependency. Curr. Biol. 18(20):1572–1575.

BARBOSA, M. 2019. Influência da quantidade de habitat e heterogeneidade espacial sobre comunidade e estrutura genética de abelhas sem ferrão no continuum Cantareira-Mantiqueira na Mata Atlântica. Tese de Doutorado. Universidade de São Paulo. Faculdade de Filosofia Ciência e Letra de Ribeirão Preto.

BAUER, D.M. & SUE WING, I. 2016. The macroeconomic cost of catastrophic pollinator declines. Ecol. Econ. 1261–13.

BIVAND, R., KEIT, T. & ROWLINGSON, B. 2019. rgdal: Bindings for the 'Geospatial' Data Abstraction Library. R package version 1.4-6. https://CRAN.R-project.org/package=rgdal.

BRITTAIN, C., KREMEN, C., GARBER, A., KLEIN, A-M. (2014). Pollination and Plant Resources Change the Nutritional Quality of Almonds for Human Health. PLoS ONE 9(2): e90082.

BROCKERHOFF, E.G., JACTEL, H., PARROTTA, J.A., QUINE, C.P. & SAYER, J. 2008. Plantation forests and biodiversity: Oxymoron or opportunity? Biodivers. Conserv. 17(5):925–951.

BOSCOLO, D., TOKUMOTO, P.M., FERREIRA, P.A., RIBEIRO, J.M., SILVEIRA DOS SANTOS, J. 2017. Positive responses of flower visiting bees to landscape heterogeinity dependo on functional connectivity levels. Perspect. Ecol. Conser. 15(1): 18-24.

BUCHORI, D., RIZALI, A., LARASATI, A., HIDAYAT, P., NGO, H. & GEMMIL-HERREN, B. 2019. Natural habitat fragments obscured the distance effect on maintaining the diversity of insect pollinators and crop productivity in tropical agricultural landscapes. Heliyon 5(3):01425.

BURKHARD, B., KROLL, F., MÜLLER, F. & WINDHORST, W. 2009. Landscapes' capacities to provide ecosystem services - A concept for land-cover based assessments. Landsc. Online 15(1):1–22.

CAMPAGNE, C.S. & ROCHE, P. 2018. May the matrix be with you! Guidelines for the application of expert-based matrix approach for ecosystem services assessment and mapping. One Ecosyst. 3e24134.

CAMPBELL, B.M., BEARE, D.J., BENNETT, E.M., HALL-SPENCER, J.M., INGRAM, J.S.I., JARAMILLO, F., ORTIZ, R., RAMANKUTTY, N., SAYER, J.A. & SHINDELL, D. 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecol. Soc. 22(4).

CARVALHEIRO, L.G., SEYMOUR, C.L., VELDTMAN, R. & NICOLSON, S.W. 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. J. Appl. Ecol. 47(4):810–820.

CHAM, K.O., REBELO, R.M., OLIVEIRA, R.P., FERRO, A.A., VIANA-SILVA, E.C. V., BORGES LO, et al. 2017. Manual de avaliação de risco ambiental de agrotóxicos para abelhas. Brasília/ Brazil: Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Ibama/Diquahttps://doi.org/10.1590/S0100-67622004000400014

DÍAZ, S. et al. 2015. The IPBES Conceptual Framework — connecting nature and people. Curr. Opin. Environ. Sustain. 141–16.

DICKS, L. V., VIANA, B., BOMMARCO, R., BROSI, B., ARIZMENDI, M.D.C., CUNNINGHAM, S.A., GALETTO, L., HILL, R., LOPES, A. V., PIRES, C., TAKI, H. & POTTS, S.G. 2016. Ten policies for pollinators. Science (80). 354(6315):975–976.

ELLIS, E., PONTIUS, R. 2007. "Landuse and landcover change." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published July 17, 2006; Last revised January 31, 2007; Retrieved April 30, 2020]. <http://www.eoearth.org/article/Landuse_and_landcover_change>

FAHRIG, L., BAUDRY, J., BROTONS, L., BUREL, F.G., CRIST, T.O., FULLER, R.J., SIRAMI, C., SIRIWARDENA, G.M. & MARTIN, J.L. 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol. Lett. 14(2):101–112.

FERREIRA, P.A., BOSCOLO, D., CARVALHEIRO, L.G., BIESMEIJER, J.C., ROCHA, P.L.B. & VIANA, B.F. 2015. Responses of bees to habitat loss in fragmented landscapes of Brazilian Atlantic Rainforest. Landsc. Ecol. 30(10):2067–2078.

FOLEY, J.A., DEFRIES, R., ASNER, G.P., BARFORD, C., BONAN, G., CARPENTER, S.R., CHAPIN, F.S., COE, M.T., DAILY, G.C., GIBBS, H.K., HELKOWSKI, J.H., HOLLOWAY, T., HOWARD, E.A., KUCHARIK, C.J., MONFREDA, C., PATZ, J.A., PRENTICE, I.C., RAMANKUTTY, N. & SNYDER, P.K. 2005. Global consequences of land use. Science (80). 309(5734):570–574.

GARIBALDI, L.A., STEFFAN-DEWENTER, I., KREMEN, C., MOREALES, J.M., BOMMARCO, R., CUNNINGHAM, S. ET AL. 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. Ecol. Lett. 14(10):1062-1072.

GALLAI, N., SALLES, J.-M., SETTELE, J. & VAISSIÈRE, B.E. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol. Econ. 68(3):810–821.

GARIBALDI, L.A., STEFFAN-DEWENTER, I., WINFREE, R., AIZEN, M.A., BOMMARCO, R., CUNNINGHAM, S.A., KREMEN, C. & CARVALHEIRO, L.G. 2014. Honeybee Abundance. Science (80). 339(May):1608–1611.

GASTON K.J. 2000. Global patterns in biodiversity. Nature 405220–227.

HADLEY, A.S. & BETTS, M.G. 2012. The effects of landscape fragmentation on pollination dynamics: Absence of evidence not evidence of absence. Biol. Rev. 87(3):526–544.

HENNIG, E.I. & GHAZOUL, J. 2011. Plant–pollinator interactions within the urban environment. Perspect. Plant Ecol. Evol. Syst. 13(2):137–150.

HIJMANS, R.J. 2019. raster: Geographic Data Analysis and Modeling. R package version 3.0-7. https://CRAN.R-project.org/package=raster

HIPÓLITO, J., SOUSA, B. dos S.B., BORGES, R.C., BRITO, R.M. de, JAFFÉ, R., DIAS, S., IMPERATRIZ FONSECA, V.L. & GIANNINI, T.C. 2019. Valuing nature's contribution to people: The pollination services provided by two protected areas in Brazil. Glob. Ecol. Conserv. 20e00782.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2013. Produção Agrícola Municipal: Culturas Temporárias e Permanentes. Brasília (DF): Instituto Brasileiro de Geografia e Estatística. Available: http://www.ibge.gov.br/home/estatistica/economia/pam/2013.

IMPERATRIZ-FONSECA, V. L., SARAIVA, A. M., & JONG, D. D. (2006). Bees as pollinators in Brazil: assessing the status and suggesting best practices. In Proceedings of the Workshop on São Paulo Declaration on Pollinators plus 5 Forum, São Paulo, Brazil, 27-31 October 2003. Holos Editora, Ribeirão Preto.

IPBES. 2016. Assessment Report on Pollinators, Pollination and Food Production.

IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

JAFFÉ, R. et al. 2019. Landscape genomics to the rescue of a tropical bee threatened by habitat loss and climate change. Evol. Appl. 12(6):1164–1177.

JHA, S. 2015. Contemporary human-altered landscapes and oceanic barriers reduce bumble bee gene flow. Mol. Ecol. 24(5):993–1006.

JHA, S. & DICK, C.W. 2010. Native bees mediate long-distance pollen dispersal in a shade coffee landscape mosaic. Proc. Natl. Acad. Sci. U. S. A. 107(31):13760–4.

JOLY, C.A., METZGER, J.P. & TABARELLI, M. 2014. Experiences from the Brazilian Atlantic Forest: Ecological findings and conservation initiatives. New Phytol. 204(3):459–473.

JONES, J.C., FRUCIANO, C., HILDEBRAND, F., AL TOUFALILIA, H., BALFOUR, N.J., BORK, P., ENGEL, P., RATNIEKS, F.L.W. & HUGHES, W.O.H. 2018. Gut microbiota composition is associated with environmental landscape in honeybees. Ecol. Evol. 8(1):441–451.

KLATT, B.K., HOLZSCHUH, A., WESTPHAL, C., CLOUGH, Y., SMIT, I., PAWELZIK, E., ET AL. 2014. Bee pollination improves crop quality, shelf life and commercial value. P. Roy. Soc. B-Biol. Sci. 281: 2013-2440.

KENNEDY, C.M., LONSDORF, E., NEEL, M.C., WILLIAMS, N.M., RICKETTS, T.H., WINFREE, R., BOMMARCO, R., BRITTAIN, C., BURLEY, A.L., CARIVEAU, D., CARVALHEIRO, L.G., CHACOFF, N.P., CUNNINGHAM, S.A., DANFORTH, B.N., DUDENHOFFER, J.H., ELLE, E., GAINES, H.R., GARIBALDI, L.A., GRATTON, C., HOLZSCHUH, A., ISAACS, R., JAVOREK, S.K., JHA, S., KLEIN, A.M., KREWENKA, K., MANDELIK, Y., MAYFIELD, M.M., MORANDIN, L., NEAME, L.A., OTIENO, M., PARK, M., POTTS, S.G., RUNDLOF, M., SAEZ, A., STEFFAN-DEWENTER, I., TAKI, H., VIANA, B.F., WESTPHAL, C., WILSON, J.K., GREENLEAF, S.S. & KREMEN, C. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecol. Let. 16:584-599.

KLEIN, A.M., VAISSIÈRE, B.E., CANE, J.H., STEFFAN-DEWENTER, I., CUNNINGHAM, S.A., KREMEN, C. & TSCHARNTKE, T. 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B Biol. Sci. 274(1608):303–313.

KREMEN, C., WILLIAMS, N.M., AIZEN, M.A., GEMMILL-HERREN, B., LEBUHN, G., MINCKLEY, R., PACKER, L., POTTS, S.G., ROULSTON, T., STEFFAN-DEWENTER, I., VÁZQUEZ, D.P., WINFREE, R., ADAMS, L., CRONE, E.E., GREENLEAF, S.S., KEITT, T.H., KLEIN, A.M., REGETZ, J. & RICKETTS, T.H. 2007. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. Ecol. Lett. 10(4):299–314.

KREMEN, C., WILLIAMS, N.M., BUGG, R.L., FAY, J.P. & THORP, R.W. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. Ecol. Lett. 7(11):1109–1119.

LAURANCE, W.F., SAYER, J. & CASSMAN, K.G. 2014. Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol. 29(2):107–116.

LAUTENBACH, S., SEPPELT, R., LIEBSCHER, J. & DORMANN, C.F. 2012. Spatial and Temporal Trends of Global Pollination Benefit J. Ollerton, ed. PLoS One 7(4):35954.

MINISTÉRIO DA AGRICULTURA PECUÁRIA E ABASTECIMENTO. 2013. Projeções do Agronegócio: Brasil 2013/2014 a 2023/2024—Projeções de Longo Prazo. 5nd ed. Brasília: Ministério da Agricultura, Pecuária e Abastecimento. Assessoria de Gestão Estratégica; 100 p.

MOTZKE, I., KLEIN, A.-M., SALEH, S., WANGER, T.C. & TSCHARNTKE, T. 2016. Habitat management on multiple spatial scales can enhance bee pollination and crop yield in tropical homegardens. Agric. Ecosyst. Environ. 223144–151.

MONTAGNANA, P. C. 2018. Efeitos multi-escala da quantidade de habitat e heterogeneidade da paisagem sobre comunidade de abelhas. Tese de Doutorado. Universidade de São Paulo. Faculdade de Filosofia Ciência e Letra de Ribeirão Preto.

MUSTARD, J., DEFRIES, R., FISHER, T., MORAN, E.F. 2004. Land use and land cover change pathways and impacts M.A. Cochrane (Ed.), Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface, Springer-Verlag, Dordrecht, the Netherlands.

NEDKOV, S., ZHIYANSKI, M., BORISOVA, B., BRATANOVA-DONCHEVA, S. (2018). Mapping and assessment of ecosystem condition and ecosystem services across different scales and domains in Europe. One Ecosystem. 3: e29288.

NELSON, R., KOKIC, P., CRIMP, S., MARTIN, P., MEINKE, H., HOWDEN, S.M., DE VOIL, P. & NIDUMOLU, U. 2010. The vulnerability of Australian rural communities to climate variability and change: Part II-Integrating impacts with adaptive capacity. Environ. Sci. Policy 13(1):18–27.

NERY, L.S., TAKATA, J.T., CAMARGO, B.B., CHAVES, A., FERREIRA, P.A., BOSCOLO, D. ET AL.2018. Bee diversity responses to forest and open areas in heterogeneous Atlantic Forest. Sociobiol. 65: 686–695

PARK, M.G., BLITZER, E.J., GIBBS, J., LOSEY, J.E. & DANFORTH, B.N. 2015. Negative effects of pesticides on wild bee communities can be buffered by landscape context. Proc. R. Soc. B Biol. Sci. 282(1809).

PERFECTO, I., & VANDERMEER, J. (2010). The agroecological matrix as alternative to the land-sparing/agriculture intensification model. Proceedings of the National Academy of Sciences, 107(13), 5786-5791.

PRIESS, J.A., MIMLER, M., KLEIN, A.-M., SCHWARZE, S., TSCHARNTKE, T., STEFFAN-DEWENTER, I. 2007. Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems. Ecol. Appl. 17(2): 407-417.

QGIS DEVELOPMENT TEAM. 2019. QGIS Geographic information system. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

R CORE TEAM. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

REZENDE, C.L., SCARANO, F.R., ASSAD, E.D., JOLY, C.A., METZGER, J.P., STRASSBURG, B.B.N., TABARELLI, M., FONSECA, G.A. & MITTERMEIER, R.A. 2018. From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. Perspect. Ecol. Conserv. 16(4):208–214.

RIBEIRO, M.C., METZGER, J.P., MARTENSEN, A.C., PONZONI, F.J. & HIROTA, M.M. 2009. The Brazilian Atlantic Forest: How much is left and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142(6):1141–1153.

RICOTTA, C. & MORETTI, M. 2011. CWM and Rao's quadratic diversity: a unified framework for functional ecology. Oecologia, 167: 181-188.

ROBERTS, L. 2011. Population is growing - fast... 9 billion? Science (80). 333(July):540–3.

SABESP Saneamento Básico do Estado de São Paulo. 2019. Disponível em: http://site.sabesp.com.br/site/interna/subHome.aspx?secaoId=3

SANTOS CF, OTESBELGUE A, BLOCHTEIN B. 2018. The dilemma of agricultural pollination in Brazil: Beekeeping growth and insecticide use. PLoS ONE 13(7): e0200286. https://doi.org/10.1371/journal.pone.0200286

SATURNI, F.T., JAFFÉ, R. & METZGER, J.P. 2016a. Landscape structure influences bee community and coffee pollination at different spatial scales. Agric. Ecosyst. Environ. 2351–12.

SENAPATHI, D., GODDARD, M.A., KUNIN, W.E. & BALDOCK, K.C.R. 2017. Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps. Funct. Ecol. 31(1):26–37.

SOARES-FILHO, B.S. 2013. "OTIMIZAGRO: Uma Plataforma Integrada de Modelagem de Uso e Mudanças no Uso da Terra para o Brasil." Final report.

SOARES-FILHO, B.S., RAJÃO, R., MERRY, F., RODRIGUES, H., DAVIS, J., LIMA, L., MACEDO, M., COE, M., CARNEIRO, A. & SANTIAGO, L. 2016. Brazil's Market for trading forest certificates. Plos One 11(4):e0152311. Disponível em: http://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0152311

TABARELLI, M., PINTO, L.P., SILVA, J.M.C., HIROTA, M. & BEDE, L. 2005. Challenges and Opportunities for Biodiversity Conservation in the Brazilian Atlantic Forest. Conserv. Biol. 19(3):695–700.

TAKI, H., YAMAURA, Y., OKABE, K. & MAETO, K. 2011. Plantation vs. natural forest: Matrix quality determines pollinator abundance in crop fields. Sci. Rep. 11–4.

VANBERGEN, A.J. et al. 2013. Threats to an ecosystem service: Pressures on pollinators. Front. Ecol. Environ. 11(5):251–259.

WINFREE, R., WILLIAMS, N.M., DUSHOFF, J. & KREMEN, C. 2007. Native bees provide insurance against ongoing honeybee losses. Ecol. Lett. 10(11):1105–1113.

WOLOWSKI, M., AGOSTINI, K., RECH, A., VARASSIN, I., MAUÉS, M., FREITAS, L., CARNEIRO, L., BUENO, R., CONSOLARO, H., CARVALHEIRO, L., SARAIVA, A. & SILVA, C. 2019. Relatório Temático Sobre Polinização, Polinizadores E Produção De Alimentos No Brasil E. Cubo, ed. 2019. The impact of four widely used neonicotinoid insecticides on Tetragonisca angustula (Latreille) (Hymenoptera: Apidae). Chemosphere 22465–70.

Received: 21/10/2019
Revised: 08/05/2020
Accepted: 25/05/2020
Published online: 10/07/2020