Urban pollination services and movement corridors for wild bees

都市野生蜂授粉服務與移動廊道之研究

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Abstract

The global bee population and diversity have declined sharply in recent years, and urbanization has been identified as one of the major factors. Consequences from the phenomenon include reduced crop pollination services and inability for plants to propagate, further leading to destruction in our economy and living environment. By designating Taichung City as our experimental area and using spatial modeling, we estimated the supply of pollination services by wild bees in the city and identified movement corridors through circuit theory. This study discovered that the hotspots for pollination services within Taichung City were among the hills on the eastern side of the city, where large areas were planted with fruit trees of high economic value. Contrarily, the western side of the city receives less pollination services due to urbanization and the simplification of crop areas. We also found that the southeastern side of the city has an obvious potential corridor for wild bees. However, bee movement in the entire region has not been smooth. We suggest that areas with pollination shortages should increase habitats with improved flower resources around potential corridors and expand outward gradually. In summary, our analysis yielded a comprehensive understanding of the advantages and disadvantages of pollination services by wild bees and their possible range of movement. This information can serve as a reference for habitat management and to facilitate sustainable development for biodiversity and urban agriculture.

Key words: urbanization, spatial modeling, circuit theory, flower resources, habitat management

摘要

近代全球蜂類數量大幅減少，都市化現象被認定是重大因素之一，因都市擴張會明顯衝擊野生蜂的物種多樣性，對人類的影響即是作物授粉服務短缺，經濟嚴重受損，相對植物無法有效繁衍，生活環境也會產生負面影響。本研究以台中市做為試驗區，使用空間建模方法，推估市野生蜂的授粉服務供給，並透過電路理論辨別移動廊道。研究結果發現，台中市境內的授粉服務熱點位於東半側的淺山帶，該區有種植大面積的高經濟價值果樹，西半側因都市化與作物區趨於單一化的因素，授粉服務相對稀少；此外，東南側有一條明顯的野生蜂潛在廊道，但全區來說，流動情形並不通暢。本研究建議，授粉短缺的地區應增加花卉資源改善棲地，可先從潛在廊道周邊進行，再逐步向外延伸。總結來說，通盤瞭解野生蜂授粉服

務供給的優劣和它們可能的移動範圍，可做為棲地經營管理之重要依據，將有助生物多樣性與都市農業的永續發展。

關鍵詞：都市化、空間建模、電路理論、花卉資源、棲地經營管理

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Introduction

Urban agriculture refers to agriculture that urban and periurban areas are closely reliant on. This form of agriculture is vital; it provides food and economic income, indirectly maintains living environment quality, and serves as recreational activity venues. Approximately 15%–20% of global food production originates from urban and periurban areas (Armar-Klemesu 2000), and approximately 10% of the population engage in urban agriculture (Smith *et al*. 2006). Currently, urban expansion progresses at an astonishing speed across the globe. Due to radical changes in land use, large areas of natural and seminatural ecosystems have been transformed into urban landscapes. This has caused a severe decline in biodiversity and ecosystem services (Cumming *et al*. 2014; Newbold *et al*. 2015; Delphin *et al*. 2016), particularly among pollinators closely tied to urban agriculture and the pollination services they provide (Tylianakis *et al*. 2013; Vanbergen and Initiative 2013).

Bees are critical pollinators. Currently, approximately 25,000 species worldwide aid in the pollination of flowering plants (Michener 2007) and participate in the pollination of 75% of major cultivated crops (Klein *et al*. 2007). Bees also effectively improve the quality, shelf life, and commercial value of agricultural products (Bommarco *et al*. 2012; Klatt *et al*. 2014). Therefore, bees are unequivocally the primary pollinator in the natural world. In recent years, urbanization has been recognized as a major contributing factor to the drastic decline in bee species across the world. Studies have argued that urban expansion has significant impact on the biodiversity of wild bees (Matteson *et al*. 2013; Leong *et al*. 2016; Hung *et al*. 2017; DePalma *et al*. 2017). The effects on humans include declining pollination rates, lower crop production and quality, and serious economic damage (Gallai *et al*. 2009; Lautenbach *et al*. 2012). In addition, plants will be unable to effectively propagate, leading to negative effects on the environment.

To ensure high pollination quality in the environment, Londsdorf *et al*. (2009) developed a pollination services spatial model based on expert knowledge. Using the habits of different species of bees in regards to landscape elements, chiefly nesting, foraging distances, and access to flower resources as its parameters, the model predicts the spatial distribution of pollination services. This model has been applied to urban areas in recent years (Davis *et al*. 2017; Stange *et al*. 2017; Zhao *et al*. 2019), but no such cases have been studied in Taiwan. Therefore, we designated the second most populous city in Taiwan, Taichung City, as our experimental area and referenced Lonsdorf *et al*. in our spatial modeling to predict pollination services by urban wild bees. Furthermore, ecological corridors can fill in blank spaces between habitats and facilitate the effective exchange of organisms and genes, as well as promote the movement of pollinators to provide ideal pollination services (Van Geert *et al*. 2010; Cranmer *et al*. 2012; Kormann *et al*. 2016). Therefore, we also analyzed potential movement corridors for wild bees to provide clearer guidance in habitat management for pollinators while maintaining urban agriculture sustainability.

Materials and methods

Study Area

Taichung City, situated in Central Taiwan and facing the Taiwan Strait to the west (Fig. 1a), is one of six special municipalities of the Republic of China. At present, the city has 38 administrative districts and one mountain indigenous district. The scope of this study focused on urban areas with relatively higher population density, therefore the indigenous district, which primarily consisted of natural mountains, was eliminated (Fig. 1b). The surface area of the study's range was approximately 1,177 km^2, with a population of approximately 2.8 million people. The terrain consists primarily of basins and hills, and the three main rivers from north to south are the Da'an River, Dajia River, and Dadu River. Data from Taiwan's Central Weather Bureau indicated that the mean daily temperature, mean relative humidity, and mean rainfall are approximately 23 °C, 76%, and 1,770 mm, respectively. The 2015 Land Use Investigation by the National Land Surveying and Mapping Center (NLSC)

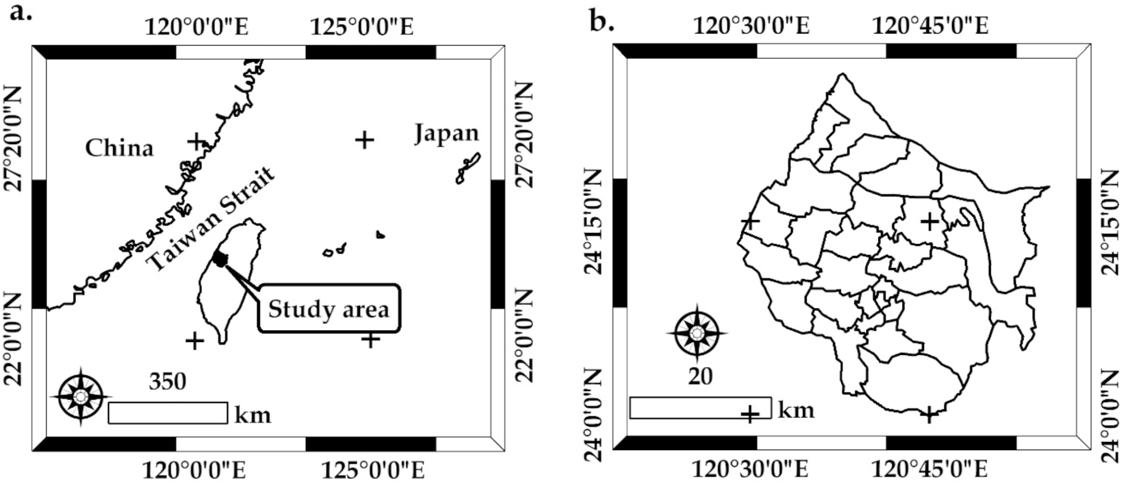

Fig. 1. (a) Geographical position of the study area; (b) Study range and administrative districts.
圖1. (a) 研究區地理位置圖；(b) 研究範圍與行政區劃。

revealed that the land use/land cover (LULC) in the area is predominantly human development and farmland (rice, dry farming, and fruit trees), accounting for nearly 63% of total land (Table 1).

InVEST model

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a suite of freeware, open-source software models that mainly analyzes LULC to evaluate multiple counts of ecosystem corridor data (Talls *et al*. 2013). This software also includes the model developed by Lonsdorf *et al*. to predict pollination by wild bees and can be viewed as an indicator for pollination service supply. The mathematical formula is as follows (Lonsdorf *et al*. 2009; Tallis *et al*. 2013):

$$P_{x\beta} = N_j \frac{\sum_{m=1}^{M} F_{jm}\, e^{\frac{-D_{mx}}{\alpha\beta}}}{\sum_{m=1}^{M} e^{\frac{-D_{mx}}{\alpha\beta}}}$$

In the formula, $P_{x\beta}$ represents the index of relative pollination richness for bee colony β on x pixel and falls between 0 and 1. A higher value indicates higher levels of pollination supply, and vice versa. N_j is the nesting suitability on LULC type j, and F_j is the flower resource that LULC type j can produce. D_{mx} represents the Euclidean distance between pixel m (1, 2,..., M) and pixel x, and $\alpha\beta$ is the mean foraging distance for bee colony β.

Among the variables required by this model, based on land use investigations conducted by the NLSC for 2015, the study area was redrawn into 13 LULC types and converted to a spatial resolution of 10 m per pixel (Fig. 2). Regarding target species, we considered the groups with high pollination contribution and wide distribution. We designated commonly found species groups: honeybees, bumblebees, and solitary bees, and all ecological parameters were configured based on published literature; mean foraging distances were set at 1 km for honey bees, based on studies by Beekman and Ratnieks (2000) and Barbuzov *et al*. (2015); 1.5 km for bumblebees, based on Chapman *et al*. (2003) and Charman *et al*. (2010); and 0.3 km for solitary bees, based on Gathmann and Tscharntke (2002). Table 1 presents the parameters for nesting

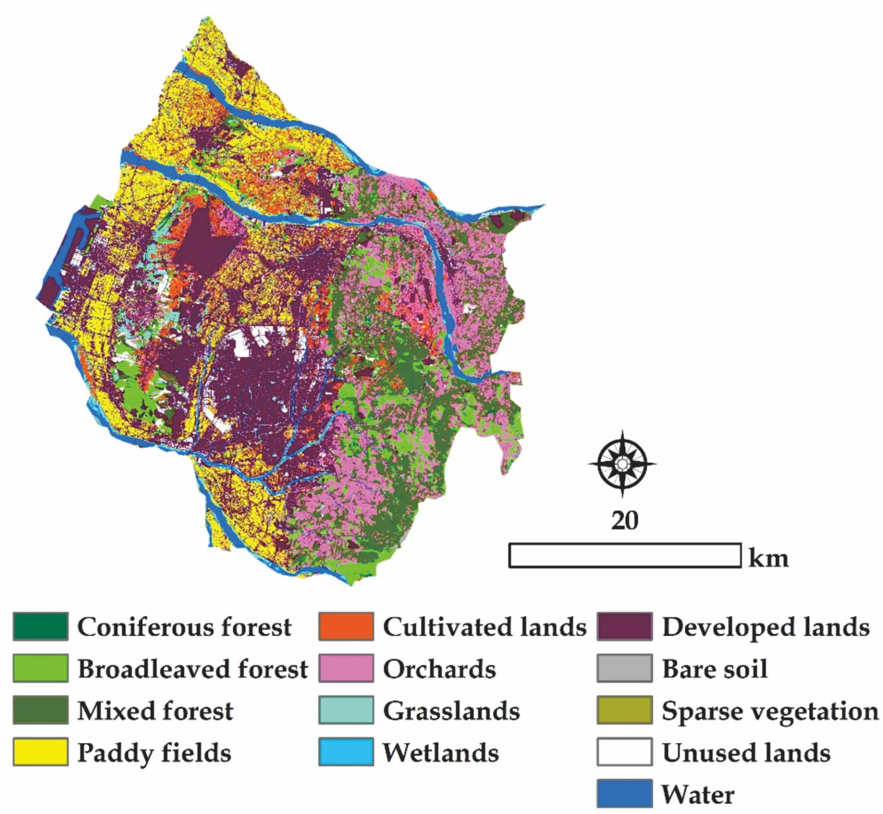

Fig. 2. Land use/land cover in the study area.
圖2. 研究區土地利用/覆蓋圖。

suitability and flower resources corresponding to each LULC type, referencing Lonsdorf *et al*. (2009) and Kennedy *et al*. (2013). Finally, the mean of the estimations for the three bee groups were used to derive the spatial distribution of pollination services, which were divided into five grades, from high to low using the Jenks natural break method. Areas in the highest grade are viewed as hotspots (O'Farrell *et al*. 2010; Onaindia *et al*. 2013).

Landscape connectivity

A method of analyzing landscape connectivity, circuit theory is the random and multidirectional integration of circuits with movement ecology. A landscape is viewed as a conductive panel, where each spatial unit has resistance; units with lower resistance have a higher current density, indicating frequent species movement or gene exchange (McRae *et al*. 2008). We used the software Circuitscape 4.0 (McRae *et al*. 2008) for

Table 1. Land use/land cover (LULC) ratios and parameters for predicting pollination services.
表1. 本研究區土地利用/覆蓋類型所占比例與授粉服務推估所需參數

LULC	Area (%)	Nesting suitability	Flower resources
Coniferous forest	0.20	0.46	0.06
Broad-leaved forest	7.05	0.76	0.53
Mixed forest	13.12	0.64	0.25
Rice paddies	12.31	0	0
Dry farming	7.15	0.25	0.48
Orchards	13.64	0.28	0.67
Grassland	3.57	0.46	0.23
Wetland	0	0.33	0.36
Development	29.80	0.28	0.15
Bare land	0.38	0.25	0
Sparse vegetation	0.06	0.25	0.12
Vacant land	5.35	0.1	0.05
Water body	7.37	0	0

analysis, which requires two types of data for basic calculations: current nodes and either resistance or conductance (the resistance reciprocal). The calculation results will yield the number of connection paths between any two nodes; that is, the current density distribution. Pollination hotspots are directly proportional to the species richness of wild bees (Davis *et al*. 2017), thereby representing highly suitable habitats for wild bees. Therefore, we entered the hotspots discovered in the previous section as nodes. For the resistance or conductance input, the pollination richness index was used as the conductance, and the connection paths for node combinations were accumulated using pair operation. Pixels with higher current density represent higher chances of being corridors that wild bees must pass through.

Results

Figure 3 presents the results of the InVEST pollination prediction model. The range in which wild bees can provide superior pollination services are demonstrably in the east, which is dominated by broad-leaved forest, mixed forest, and orchards; conversely, the western half consists of extensive development land, with only scatterings of broad-leaved forest,

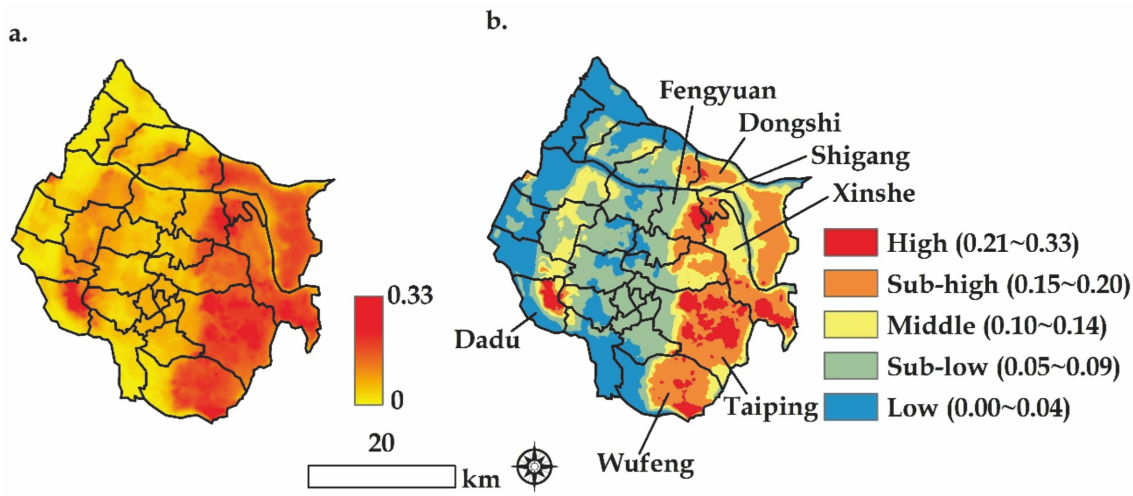

Fig. 3. (a) Supply of pollination services by wild bees; (b) Jenks natural break classification and administrative districts with pollination hotspots.

圖3. (a) 野生蜂授粉服務供給圖；(b) 將推估結果使用Jenks 自然間斷法分級，圖中文字為含有熱點的行政區。

orchards, dry farming, and wetlands (Fig. 2). The available services in this area are not as visible (Fig. 3a). Results from using the Jenks natural break method demonstrated that pixels from the pollination hotspots account for approximately 5% of the total area and are mainly distributed in seven districts—Dongshi, Shigang, Fengyuan, Xinshe, Dadu, Taiping, and Wufeng (Fig. 3b). Furthermore, the areas with the lowest grades are mostly distributed among the outer edges of the western half because the numerous rice paddies there result in shortages of pollination services (Fig. 2).

Figure 4 presents the results from Circuitscape (Fig. 4), depicting high and concentrated current densities to the southeastern side. Most of the surface areas fall among the Taiping and Wufeng districts and indicate what should be areas with the most foraging activities by wild bees, which may be a potential corridor. Conversely, the western side and central area, because of the many effects of manmade LULC, have a sparse current density, and the isolated hotspots cannot be effectively connected. For instance, the Dadu District in the west has a visibly isolated patch.

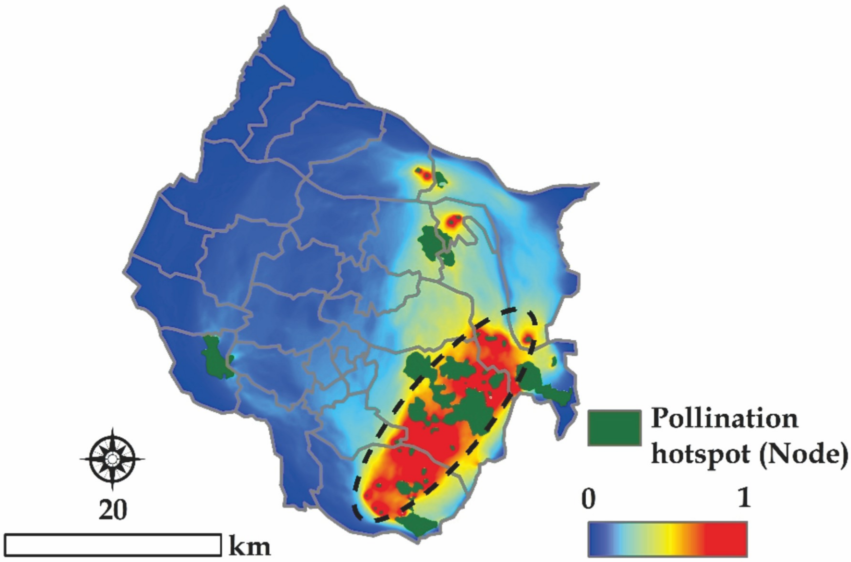

Fig. 4. Connectivity of pollination hotspots. The dotted black line indicates a potential movement corridor for wild bees.

圖4. 授粉服務熱點連接度，黑色虛線為野生蜂潛在的移動廊道。

Conclusion and suggestions

The wild bee pollination model constructed using InVEST can quickly provide insights into spatial distributions for the supply of urban pollination services. Our results (Fig. 3) indicated that areas within Taichung City with high pollination services are mostly in the eastern hills. Large swathes of this region are planted with fruit trees of high economic value—top grafted pear, loquat, longan, and lychee—which effectively support local economic development and provide valuable sources of nectar for wild bees. Of note, because of urbanization in the western part of the study area, the landscapes with pollination potential are fragmented, which often results in an insufficient supply of pollination services (Kremen *et al*. 2008; Steffan-Dewenter and Westphal 2008). Therefore, further improvements are required.

Relevant studies have substantiated that habitat management can promote biodiversity among wild bees and is a feasible and practical approach to improving pollination services (Blackmore and Goulson 2014; Davis *et al*. 2017). Even in highly urbanized areas, the timely introduction of shrubs, ornamental plants, and grass can increase flower resources in cities, which can effectively mitigate the negative effects of urbanization on wild bees (Matteson and Langellotto 2010; Lowenstein *et al*. 2014). Based on current LULC allocations in the study area, the western side primarily consists of developed land and rice paddies (Fig. 2). These two LULC types can only supply small amounts of pollination potential. Therefore, we suggest either planning more green spaces within the developed areas or planting more flowering plants or creating gardens in existing parks, sports fields, town squares, and playgrounds. In terms of public acceptance, a survey in the United Kingdom found that most visitors supported designating some green space in parks as insect habitats (Garbuzov *et al*. 2015). Most flat surface farmlands in Taichung City are rice paddies, and the landscape patterns tend to be homogeneous. We posit that the building of flower strips between the paddies has become a widely-accepted method in recent years to directly increase the density of wild bees and other pollinating insects (Jönsson *et al*. 2015; Buhk *et al*. 2018) and also indirectly encourage biological control (Tschumi *et al*. 2016), landscape beautification, and leisure and entertainment (Stallman 2011).

Based on the analysis results for landscape connectivity (Fig. 4), a potential bee corridor is apparent in the southeastern part of the study area. This range should be a key area to support the urban agricultural economy. Based on the entire region, the spatial limitations of the pollination services also reflect the obstructed movement of wild bees, resulting in the fragile state of biodiversity and urban agriculture development. This signifies that the current LULC allotment in Taichung City still has room for improvement. Linear landscape elements that are built to emphasize flower resources will function as biological corridors or stepping stones, which can effectively promote the movement of pollinating insects and the spread of plant pollen (Cranmer *et al*. 2012; Van Rossum and Triest 2012; Van Geert *et al*. 2014). Therefore, we suggest that with administrative districts bordering potential corridors as the primary targets, the aforementioned habitat management approaches should be used to reinforce flower resources when necessary. Then, node or linear extensions should be gradually extended toward the center of the city based on areas with relatively higher current density. This will improve the movement of wild bees and stabilize their provision of pollination services, which will surely aid in improving biodiversity and sustainable urban agriculture development in the future.

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Literature Cited

Armar-Klemesu, M. 2000. Urban agriculture and food security, nutrition and health. Growing cities, growing food. Urban agriculture on the policy agenda 99-118.

Beekman, M. and F. L. W. Ratnieks. 2000. Long-range foraging by the honey-bee, *Apis mellifera* L. Functional Ecology 14: 490-496.

Blackmore, L. M. and D. Goulson. 2014. Evaluating the effectiveness of wildflower seed mixes for boosting floral diversity and bumblebee and hoverfly abundance in urban areas. Insect Conservation and Diversity 7: 480-484.

Bommarco, R., L. Marini and B. E. Vaissière. 2012. Insect pollination enhances seed yield, quality, and market value in oilseed rape. Oecologia 169: 1025-1032.

Buhk, C., Oppermann, R., Schanowski, A., Bleil, R., Lüdemann, J., & Maus, C. (2018). Flower strip networks offer promising long term effects on pollinator species richness in intensively cultivated agricultural areas.

BMC ecology, 18(1), 1-13.

Chapman, R. E., J. Wang and A. F. G. Bourke. 2003. Genetic analysis of spatial foraging patterns and resource sharing in bumble bee pollinators. Molecular ecology 12: 2801-2808.

Charman, T. G., J. Sears, R. E. Green and A. F. Bourke. 2010. Conservation genetics, foraging distance and nest density of the scarce Great Yellow Bumblebee (*Bombus distinguendus*). Molecular Ecology 19: 2661-2674.

Cranmer, L., D. McCollin and J. Ollerton. 2012. Landscape structure influences pollinator movements and directly affects plant reproductive success. Oikos 121: 562-568.

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Cumming, G. S., A. Buerkert, E. M. Hoffmann, E. Schlecht, S. von Cramon-Taubadel *et al*. 2014. Implications of agricultural transitions and urbanization for ecosystem services. Nature 515: 50-57.

Cunningham, C., P. Tyedmers and K. Sherren. 2018. Primary data in pollination services mapping: potential service provision by honey bees (*Apis mellifera*) in Cumberland and Colchester, Nova Scotia. International Journal of Biodiversity Science, Ecosystem Services and Management 14: 60-69.

Davis, A. Y., E. V. Lonsdorf, C. R. Shierk, K. C. Matteson, J. R. Taylor *et al* 2017. Enhancing pollination supply in an urban ecosystem through landscape modifications. Landscape and Urban Planning 162: 157-166.

De Palma, A., M. Kuhlmann, R. Bugter, S. Ferrier, A. J. Hoskins, *et al*. 2017. Dimensions of biodiversity loss: Spatial mismatch in land-use impacts on species, functional and phylogenetic diversity of European bees. Diversity and Distributions 23: 1435-1446.

Delphin, S., F. J. Escobedo, A. Abd-Elrahman and W. P. Cropper. 2016. Urbanization as a land use change driver of forest ecosystem services. Land Use Policy 54: 188-199.

Gallai, N., J. M. Salles, J. Settele and B. E. Vaissière. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological economics 68: 810-821.

Garbuzov, M., K. A. Fensome and F. L. Ratnieks. 2015. Public approval plus more wildlife: twin benefits of reduced mowing of amenity grass in a suburban public park in Saltdean, UK. Insect Conservation and Diversity 8: 107-119.

Garbuzov, M., Schürch, R. and F. L. Ratnieks. 2015. Eating locally: dance decoding demonstrates that urban honey bees in Brighton, UK, forage mainly in the surrounding urban area. Urban Ecosystems 18: 411-418.

Gathmann, A. and T. Tscharntke. 2002. Foraging ranges of solitary bees. Journal of animal ecology 71: 757-764.

Haaland, C., R. E. Naisbit and L. F. BERSIER. 2011. Sown wildflower strips for insect conservation: a review. Insect Conservation and Diversity 4: 60-80.

Hung, K. L. J., J. S. Ascher and D. A. Holway. 2017. Urbanization-induced habitat fragmentation erodes multiple components of temporal diversity in a Southern California native bee assemblage. PloS one 12: e0184136.

Jönsson, A. M., J. Ekroos, J. Dänhardt, G. K. Andersson, O. Olsson *et al*. 2015. Sown flower strips in southern Sweden increase abundances of wild bees and hoverflies in the wider landscape. Biological Conservation 184: 51-58.

Kennedy, C. M., E. Lonsdorf, M. C. Neel, N. M. Williams, T. H. Ricketts, R. Winfree *et al*. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecology letters 16: 584-599.

Klatt, B. K., A. Holzschuh, C. Westphal, Y. Clough, I. Smit, *et al*. 2014. Bee pollination improves crop quality, shelf life and commercial value. Proceedings of the Royal Society B 281: 0132440.

Klein, A. M., B. E. Vaissiere, J. H. Cane, I. Steffan-Dewenter, S. A. Cunningham, *et al*. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences 274: 303-313.

Kormann, U., C. Scherber, T. Tscharntke, N. Klein, M. Larbig *et al*. 2016. Corridors restore animal-mediated pollination in fragmented tropical forest landscapes. Proceedings of the Royal Society B: Biological Sciences 283: 20152347.

Kremen, C., N. M. Williams, M. A. Aizen, B. Gemmill-Herren, G. LeBuhn *et al*. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology Letters 10: 299-314.

Lautenbach, S., R. Seppelt, J. Liebscher and C. F. Dormann. 2012. Spatial and temporal trends of global pollination benefit. PLoS One 7: e35954.

Leong, M., L. C. Ponisio, C. Kremen, R. W.

Thorp and G. K. Roderick. 2016. Temporal dynamics influenced by global change: bee community phenology in urban, agricultural, and natural landscapes. Global change biology 22: 1046-1053.

Lonsdorf, E., C. Kremen, T. Ricketts, R. Winfree, N. Williams and S. Greenleaf. 2009. Modelling pollination services across agricultural landscapes. Annals of botany 103: 1589-1600.

Lowenstein, D. M., K. C. Matteson, I. Xiao, A. M. Silva and E. S. Minor. 2014. Humans, bees, and pollination services in the city: the case of Chicago, IL (USA). Biodiversity and conservation 23: 2857-2874.

Matteson, K. C. and G. A. Langellotto. 2010. Determinates of inner city butterfly and bee species richness. Urban Ecosystems 13: 333-347.

Matteson, K. C., J. B. Grace and E. S. Minor. 2013. Direct and indirect effects of land use on floral resources and flower-visiting insects across an urban landscape. Oikos 122: 682-694.

McRae, B. H, B. G. Dickson, T. H. Keitt and V. B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89: 2712-2724.

Michener, C. D. 2007. The bees of the world, 2nd ed. Baltimore, MD: Johns Hopkins University Press.

Newbold, T., L. N. Hudson, S. L. Hill, S. Contu, I. Lysenko *et al*. 2015. Global effects of land use on local terrestrial biodiversity. Nature 520: 45-50.

O'Farrell, P. J., B. Reyers, D. C. Le Maitre, S. J. Milton, B. Egoh, A. Maherry *et al*. 2010. Multi-functional landscapes in semi arid environments: implications for biodiversity and ecosystem services. Landscape Ecology 25: 1231-1246.

Onaindia, M., B. F. de Manuel, I. Madariaga and G. Rodríguez-Loinaz. 2013. Co-benefits and trade-offs between biodiversity, carbon storage and water flow regulation. Forest Ecology and Management 289: 1-9.

Smith, R. M., P. H. Warren, K., Thompson and K. J. Gaston. 2006. Urban domestic gardens (VI): environmental correlates of invertebrate species richness. Biodiversity and Conservation 15: 2415-2438.

Stallman, H. R. 2011. Ecosystem services in agriculture: determining suitability for provision by collective management. Ecological Economics 71: 131-139.

Stange, E., Zulian, G., Rusch, G., Barton, D., & Nowell, M. (2017). Ecosystem services mapping for municipal policy: ESTIMAP and zoning for urban beekeeping. One Ecosystem, 2, e14014.

Steffan-Dewenter, I. and C. Westphal. 2008. The interplay of pollinator diversity, pollination services and landscape change. Journal of Applied Ecology 45: 737-741.

Tallis, H. T., T. Ricketts, A. D. Guerry, S. A. Wood, R. Sharp, E. Nelson *et al*. 2013. Integrated valuation of environmental services and tradeoffs (InVEST) 2.6.0 user's guide. Natural Capital Project, Stanford.

Tschumi, M., M. Albrecht, C. Bärtschi, J. Collatz, M. H. Entling *et al*. 2016. Perennial, species-rich wildflower strips enhance pest control and crop yield. Agriculture, Ecosystems and Environment 220: 97-103.

Tylianakis, J. M. 2013. The global plight of pollinators. Science 339: 1532-1533.

Van Geert, A., F. Van Rossum and L. Triest. 2010. Do linear landscape elements in farmland act as biological corridors for pollen dispersal? Journal of Ecology 98: 178-187.

Van Geert, A., L. Triest and F. Van Rossum. 2014. Does the surrounding matrix influence corridor effectiveness for pollen dispersal in farmland? Perspectives in plant ecology, evolution and systematics 16: 180-189.

Van Rossum, F. and L. Triest. 2012. Stepping-stone populations in linear landscape elements increase pollen dispersal between urban forest fragments. Plant Ecology and Evolution 145: 332-340.

Vanbergen, A. J. and T. I. P. Initiative. 2013. Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecology and the Environment 11: 251-259.

Zhao, C., H. A. Sander and S. D. Hendrix. 2019. Wild bees and urban agriculture: assessing pollinator supply and demand across urban landscapes. Urban Ecosystems 22: 455-470.