Opportunities and threats for pollinator conservation in global towns and cities

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Urban expansion is considered to be one of the main threats to global biodiversity yet some pollinator groups, particularly bees, can do well in urban areas. Recent studies indicate that both local and landscape-level drivers can influence urban pollinator communities, with local floral resources and the amount of impervious cover in the landscape affecting pollinator abundance, richness and community composition. Urban intensification, chemicals, climate change and increased honey bee colony densities all negatively affect urban pollinators. Maintaining good areas of habitat for pollinators, such as those found in allotments (community gardens) and domestic gardens, and improving management approaches in urban greenspace and highly urbanised areas (e.g. by increasing floral resources and nesting sites) will benefit pollinator conservation. Opportunities for pollinator conservation exist via multiple stakeholders including policymakers, urban residents, urban planners and landscape architects.

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Introduction

Animal pollination is essential for the reproduction of many plant species [1,2] and its global value for agriculture has been estimated at $235–577 billion US dollars (in 2015; [3]). However declines have been reported for many pollinator groups, including bees, hoverflies and butterflies [3–5]. Land use change has been identified as one of the key drivers of pollinator decline [6], and urbanisation is a major driver of land cover change worldwide [7].

Urban expansion is considered to be one of the main threats to global biodiversity [8]. Over half the world's population now lives in urban areas and this trend is expected to continue, with nearly 70% of the world's population living in urban areas by 2050 [9]. Urbanisation has been shown to negatively affect many taxa, including birds and plants [10]. Negative effects of urbanisation on pollinators include lower visitation rates to flowers, lower species richness, loss of rare species and homogenisation of species pools [11–13,14•,15•]. However, several recent studies have found that some pollinator groups, particularly bees, seem to do well in urban areas [16] with higher bee species richness [17,18] and higher bumblebee colony reproductive success [19] recorded in urban areas compared to nearby farmland. Guenat *et al.* [20••] also found no effect of urbanisation on bee abundance or richness in West African cities, although wasps and beetles were negatively impacted by urbanisation, and other studies have shown negative effects for hoverflies [17,21].

Urban areas are comprised of a complex mosaic of different land uses and ecological habitats. Broadly, urban greenspace falls into two main categories: (i) publicly accessible greenspace managed by local authorities (public parks and other amenity grassland including playing fields) and (2) privately owned greenspace (domestic or other private gardens). Other urban land uses include allotments (community gardens), cemeteries and churchyards, school grounds and university campuses, planters in built up areas, industrial estates and green roofs. Towns and cities also contain transport infrastructure that could provide habitat for pollinators, including road and railway verges and green space at airports. This means that the management of urban spaces relies on multiple stakeholders with different responsibilities and motivations, which can present challenges for wildlife conservation.

In this article, I consider potential threats to animal pollinators in urban areas including the impacts of pesticides and pollution, the effects of climate change and concerns over competition for resources between managed honey bees and wild pollinators. I also outline conservation opportunities for pollinators in urban areas that could be achieved through adapting urban land management approaches (see Figure 1 for a summary of threats and opportunities) and by ensuring that policymakers, practitioners, planning agencies, landscape architects and the urban residents have the evidence-based information they need to implement effective pollinator conservation policies and actions.

Figure 1
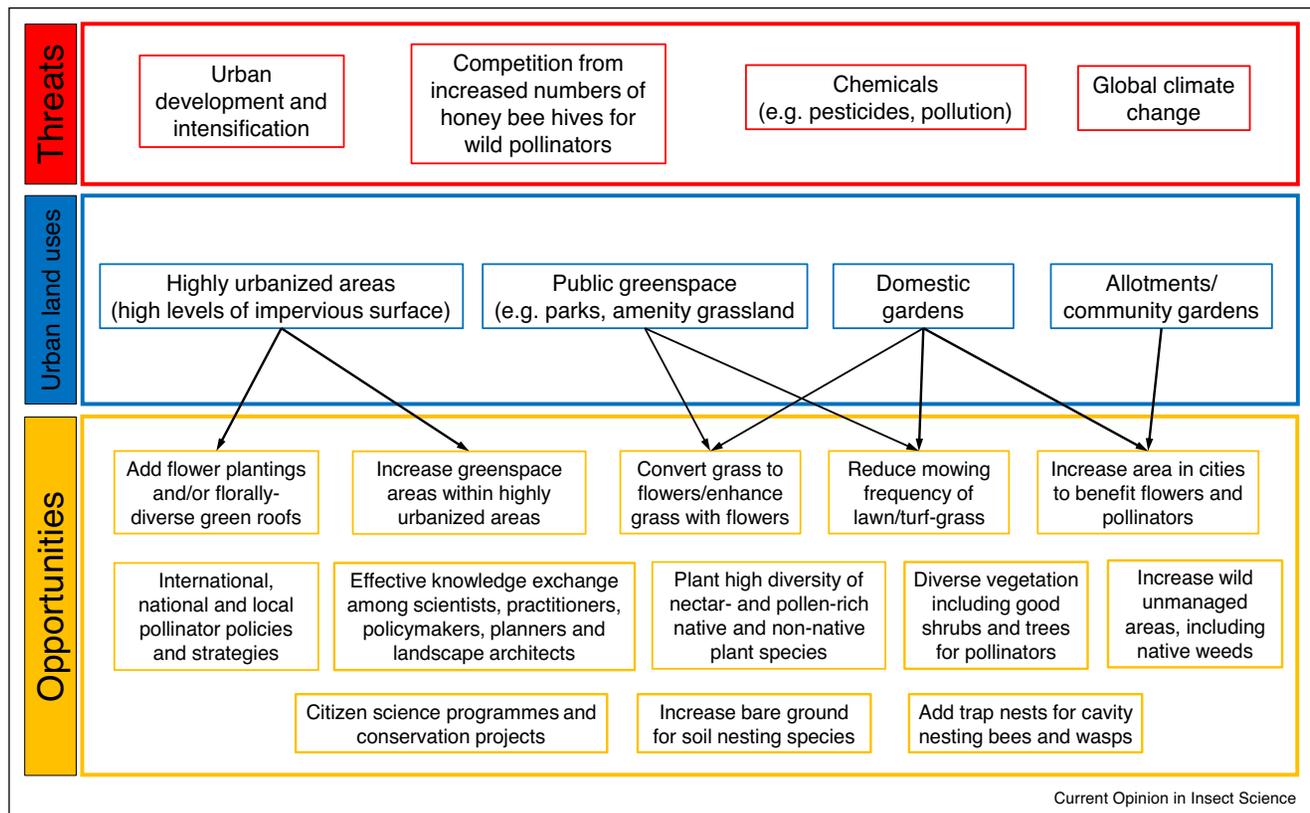
Threats to pollinators in urban areas (red boxes) and opportunities to improve urban landscapes for pollinators (yellow boxes). Arrows indicate which opportunities apply to which urban land uses, opportunities with no connecting arrows apply to all urban land uses.

Positive impacts of allotments and domestic gardens

Different urban land uses vary in their suitability for pollinators; therefore, identifying which are better for pollinators and promoting their inclusion in urban developments is a key priority. A study comparing plant-pollinator communities across nine urban land uses in four UK cities identified domestic gardens and allotment gardens (also known as 'community gardens' in some countries, hereafter both terms are collectively referred to as 'allotments') as important urban land uses for pollinators [22••]. More bee and hoverfly flower visits were recorded in allotments and domestic gardens compared to most other land uses. A modelling approach predicted that despite their relatively small area (<1% of city area), increasing the total area of allotments in cities has a beneficial effect on the robustness of plant-pollinator communities. Evidence from other studies supports these findings. Bumble bee nest densities can be higher in UK domestic gardens compared to rural habitats [23]) and the foraging activity of stingless bees was higher in Australian suburban gardens compared to natural forests and plantations [24]. Proximity to domestic gardens was important

for pollinators in residential areas in central France [25] and bee communities in allotments in two Canadian cities had higher functional trait diversity than in nearby cemeteries, although lower functional diversity than for parks in the same cities [26•].

These findings suggest that areas of towns and cities managed for cultivation include good habitat for pollinators. Ensuring that allotments and domestic gardens are protected in existing urban areas and included in future urban developments will therefore benefit pollinators and is likely to bring benefits for humans as well. Domestic gardens can form large areas of cities (25–35% [22••] and 22–28% [27] of UK cities) and are a significant component of urban green infrastructure. Gardening as an activity can benefit human health [28,29] and both allotments and domestic gardens can contribute to local temperature regulation, water and carbon storage as well as bring cultural and societal benefits [30–33]. Furthermore, increasing the areas of allotments and domestic gardens in urban areas is likely to lead to an increase in urban agriculture and therefore contribute to local food sustainability.

Identifying the particular features of allotments and domestic gardens which make them good for pollinators will help develop management practices to recommend to gardeners. Increased plant diversity and numbers of flowers are likely to be key drivers for pollinators. Baldock et al. [22••] found more plant species and flowers in allotments and domestic gardens compared to other urban land uses, a pattern driven by non-native plants as native plant floral abundance and species richness did not differ among land uses. Other studies support the idea that increased plant diversity and floral abundance in urban areas benefit pollinating insects and birds [34–39], with several noting that increases in native plantings had a positive effect [36,40]. Mach and Potter [41•] found no differences in bee visitation or diversity between native and non-native woody species.

Vegetation structure may have an impact on pollinators. Large vegetated areas in domestic gardens in Cape Town, South Africa can benefit nectar-feeding birds [42], and increases in tall herbaceous vegetation and woody plant cover in domestic gardens in Ohio had a positive effect on bee abundance [36]. Garden management is also likely to affect pollinators. Increased garden management (e.g. increased weeding or pruning, chemical use) had a negative effect on bumble bee species richness in UK domestic gardens [34] and the presence of wild/unmanaged areas in allotments in New York had a positive effect on bee species richness [35].

Negative impacts of impervious surface at a landscape level

The proportion of impervious surface is often used as a measure of the degree of urbanisation. In a study of allotments and city parks in Toledo, Ohio, increases in impervious surface in the surrounding landscape had a negative effect on bee abundance [43••]. However, negative impacts on bee species richness were minimised when floral resource availability was high which suggests that increasing floral resources in locations with high concentrations of impervious surface may counteract the negative effects. Similarly, two studies in France found that wild bee abundance in Lyon [44] and abundance and species richness in Paris [45] were negatively related to increases in the area of impervious surface. In Lyon, bee community composition changed along the urbanisation gradient with more cavity-nesting species and long-tongued species in sites with higher proportions of impervious surface. In Paris, ground-nesting bees were particularly sensitive to the urbanisation gradient [45]. In the Chicago metropolitan area, a study in allotments and city farms found that while overall bee species richness declined with increasing levels of impervious cover, bee abundances differentially responded to landscape variables depending on body size and nesting habit. Large-bodied bees (bumble bees and honey bees) were positively associated with increasing amounts of

impervious cover while small-bodied soil-nesting *Halictus* were negatively correlated with increasing impervious cover [46]. Larger bees are able to fly further [47] which could mean they are able to persist in increasingly urbanised areas by exploiting more dispersed floral resources than smaller bodied bees.

Green roofs are one way to introduce potential pollinator habitat to areas of cities with limited greenspace. A high diversity of bee species has been recorded foraging on green roofs (236 species recorded in 35 studies from Europe, Asia and North America; [48]) and other pollinator taxa, including wasps and beetles, have also been recorded on green roofs [49,50]. The proportion of cavity-nesting bees on green roofs is higher than that on nearby ground, while the percentage of pollen specialists is lower [48]. In a study of green roofs in Switzerland, although bee species richness was lower than for ground sites, the roof communities maintained high functional diversity [50]. However, little is known about the reproductive success of bees on green roofs or how non-bee pollinators use green roofs.

Improving nesting sites is more challenging than increasing floral resources. Artificial trap nests (also known as 'bee hotels') are one way to add potential nesting sites for cavity-nesting bees and wasps. A study in Toronto, Canada found 36 bee species (representing >50% of bee species known from the area) reared from nests in domestic gardens, allotments, city parks and rooftops, with more native bees reared from nests in domestic gardens and more native wasps from trap nests in parks compared to other land uses [51]. Another study in Toronto found 27 species of cavity-nesting bees and wasps in trap nests on buildings, and that nests located on taller buildings were less successful than those on lower buildings [49]. A decline in green space area within a 600 m radius was linked to decreasing abundance and species richness of trap nesting species. Fortel et al. [52] tested two types of human-made nests in Lyon, finding 37 ground-nesting bee species in soil squares (0.5 m deep holes filled with soil) and 21 above-ground nesting species in trap nests, which combined represent 23% of the wild bee species recorded in the area. Other studies have found positive effects of increasing the area of bare soil on ground-nesting bee abundance and richness [38,39].

Improving greenspace management for pollinators

Public greenspace, including parks, playing fields, and other amenity grassland (e.g. within housing developments) can comprise large proportions of urban areas (approximately a third of UK cities studied by [22••]). However these areas are often managed by regular grass cutting, leading to the loss of the majority of flowers. The potential impact of increasing the floral abundance of public greenspaces was investigated for four UK cities

using models which simulated the effect of increasing the floral abundances of three common native plant species. The model predicted that adding flowers increases the robustness of city-scale plant-pollinator communities [22••].

Increasing the floral resources in public greenspace could be achieved by reducing mowing frequency or adding flowers through planting. Recent studies have shown that more frequent mowing is associated with lower abundance and richness of bees in Tubingen, Germany [53], lower butterfly diversity in Malmö, Sweden [54], a decrease in native plant species in Xi'an, China [55] and a decrease in flowers and pollinator visits in UK road verges [56]. More frequent lawn mowing in domestic gardens is also associated with lower floral and bee abundances [57•]. Since many domestic gardens contain large proportions of lawns (>60% in UK gardens [58]) and lawns in public and private urban greenspaces can collectively comprise more than 50% of urban areas [22••,59] reducing mowing intensity could have a huge beneficial effect on the amount of floral resources available for pollinators in cities.

An alternative approach to increase floral resources in greenspace is to plant more flowers. Simulating the partial conversion of lawn/turf-grass to floral resources in city parks, domestic gardens and available turf grass near to urban farms, allotments, and domestic gardens in Chicago found that this more florally rich land cover would support increased supply of pollinators and urban agriculture [60•]. Planting areas of urban flower 'meadows' has become an increasingly popular approach in the UK and other European cities. When added to amenity grassland, these plantings can markedly increase the available floral resources. Planting either a perennial native seed mix or a non-native annual mix in greenspace areas greatly increased the nectar and pollen resources, with the native perennial mix producing up to 20 times more nectar and 6 times more pollen than the non-native annual mix [61]. The study also showed that native weeds growing within the mixes contributed high quantities of pollen and nectar, with dandelions (*Taraxacum* agg.) being one of the most important nectar contributors among the species commonly considered as weeds [61]. Increased numbers of pollinator visits to flowers have been recorded in perennial native plantings compared to amenity grassland controls, with 50 times more bumble bee visits and 13 times more hoverfly visits [62]. Small-scale as well as large-scale plantings can also benefit pollinators [63].

Effects of urban beekeeping on wild pollinators

Keeping honey bees in urban areas is increasing in popularity. There is a general belief that increasing the numbers of honey bee hives will help pollinators;

however, this is unlikely to benefit wild pollinators and increasing honey bee numbers may even exacerbate problems for wild pollinators through competition for food resources [64–67]. Evidence for competition between honey bees and wild pollinators in urban areas has been found in Paris, with wild pollinator visitation rates negatively correlated with honey bee colony densities in the surrounding landscape [68••]. Large solitary bee and beetle visitation rates were affected by honey bee colony densities within a 500 m buffer and bumblebee visitation rates were affected by honey bee colony density within a 1000 m buffer. If beekeepers set up hives in urban areas they should ensure that they also enhance the local landscape by adding floral resources to minimise the effects of competition with wild pollinators.

Climate change and urban warming

City climates can differ from that of surrounding rural areas. The urban heat island (UHI) effect is a recognised phenomenon in which cities experience significantly warmer temperatures relative to the surrounding landscape due to higher energy use and impervious surface area. This can lead to positive effects for plants, and potentially pollinators as well, through longer and warmer growing seasons [69,70]. Urban warming may also alter plant–pollinator interactions by shifting the phenologies of plants and/or pollinators, selecting for thermophilic native plants and by facilitating the establishment of non-native plants from warmer regions [71,72]. Furthermore, management in urban areas, such as watering or additional nutrients, can lead to extended flowering seasons [73]. Seasonal patterns of abundance and species richness for 91 bee species in California varied less through the year in urban landscapes compared to natural habitats in which floral resources are relatively scarce in the dry summer months [73], demonstrating that anthropogenic environmental changes can alter the temporal dynamics of pollinators. Urban areas offered resources during the early and late parts of the season when there is little floral availability in natural habitats.

Global climate change is expected to affect the phenologies of plants and pollinators, potentially resulting in mismatches in timing, and is also likely to affect species ranges (reviewed in [71]). Spring emerging bees and those that occur in urban areas could be less vulnerable to extinction [74]. The potential effects of climate change were modelled for the Australian native bee species *Ceratina australensis*, suggesting that it would have an increasing area of suitable habitat as climate change progresses, and that its potential range will shift towards coastal areas with high human population densities and high urbanisation, meaning that it is predicted to increase in urban areas [75•]. Bee species can have different thermal tolerances which will affect how sensitive they are to urbanisation and global change [76]. In Toledo, Ohio, bumblebees were found to be less sensitive to

warming than sweat bees and honey bees, with bumble bees and sweat bees closer to their critical thermal maximum temperatures in more urbanised locations [76].

Chemicals and pollutants

There is increasing evidence of the negative effects of neonicotinoids and other pesticides on pollinators [77] and several recent studies have examined their effects in urban settings. Bumble bees in UK ornamental urban gardens had detectable levels of neonicotonoid insecticides and fungicides, although lower levels than for bees in farmland sites [78], and many ornamental plants on sale to the public contain pesticide residues [79••]. Neonicotinoid pesticide use in urban lawns can negatively affect bumble bee colony growth and new queen production when applied to blooming plants [80] and there was a negative correlation between butterfly and bumble bee abundance and use of insecticides and herbicides in French gardens [81]. Plant species diversity in lawns in China was negatively associated with frequency of chemical fertiliser use [55]. Petrol exhaust pollution has been shown to affect honey bee learning and memory [82•]. Other chemicals that could affect pollinators in urban settings include nitrogen deposition and soil pollution (reviewed in Ref. [69]).

Public, policy and planning opportunities

Over the last two decades both the public and policymakers have become increasingly concerned over pollinator declines and there has been a growing interest in taking action to help pollinator conservation. Urban areas are particularly well suited to engaging the public in conservation activities due to high densities of residential housing and community projects. Many local conservation projects aimed at improving pollinator habitat have been developed in North American and European countries. These include activities organised by conservation charities (e.g. the 'Urban Buzz' project organised by Buglife), independent projects by community groups, or habitat creation linked to national campaigns. For example, the Royal Horticultural Society's annual 'Britain in Bloom' competition in the UK now promotes wildlife friendly gardening initiatives and the 'Million Pollinator Garden Challenge' has recruited more than a million garden owners across the US to preserve and create a network of gardens and landscapes to benefit pollinators. As well as involving urban residents in habitat creation, engaging them in citizen science projects can simultaneously educate and collect scientific data (e.g. [16,83,84]).

Policymakers recognised concerns over pollinator decline in the late 1990s as part of the United Nations Convention on Biological Diversity (CBD) programme 'Conservation and Sustainable Use of Agricultural Biological Diversity'. This led to the development of regional pollinator initiatives (Food and Agriculture Organization of the United Nations:

URL: http://www.fao.org/pollination/major-initiatives/en) as well as national strategies including the Welsh Government's Action Plan for Pollinators [85], the National Pollinator Strategy for England [86], the All-Ireland Pollinator Plan [87] and the Pollinator Partnership Action Plan in the US [88]. In 2016 the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES) published a global report on 'Pollinators, pollination, and food production' [3]. Many of these strategies include specific recommendations related to pollinator conservation in urban areas including residential gardens and public greenspaces. In some countries new laws are being created to protect pollinators, for example Hall *et al.* [89] identified 110 new laws related to pollinator conservation that were passed by US state-level legislatures between 2000 and 2017. However they note that effective pollinator protection urgently requires national and international level policies that include monitoring programmes to assess changes over time. One key aspect of particular importance to urban landscapes is to ensure that planning policy and legislation includes the preservation and creation of pollinator habitat in new residential and commercial developments. Engaging landscape architects, landowners and land managers in these actions through effective knowledge exchange activities with scientific researchers is a vital part of this process to ensure that policy and practice recommendations are based on scientific evidence.

Examining the social and cultural drivers of pollinator distributions in urban areas presents an opportunity to direct conservation efforts to specific regions and communities. High bee abundances and species richness were associated with lower income neighbourhoods with low human population densities compared to more densely populated high-income neighbourhoods in Chicago in the US [90]. In contrast, higher pollinator abundances were associated with higher income neighbourhoods in the UK [22••], which is consistent with the 'luxury effect' [91]. Further research is clearly needed to understand the effects of these socio-economic drivers and how they interact with other drivers. Low-income, less-populated areas can contain more vacant lots (termed 'brownfield sites' in the UK) as well as abandoned and crumbling infrastructure and residential pesticide use is often lower in low-income neighbourhoods [92]; therefore, in areas undergoing urban regeneration it will be important to consider how the features that benefit pollinators can be incorporated into changes in the landscape.

Conclusions

Recent studies have increased our knowledge of how pollinators respond to urbanisation as well as which features of urban areas are better for pollinators. This information can be used to improve urban land management practices and develop recommendations for stakeholders including gardeners, urban land managers and practitioners. Ensuring that this information is communicated with key stakeholders and

integrated into national and local pollinator strategies, and conservation policies are key to improving urban areas for pollinators.

The majority of studies to date have been located in European or North American cities, so more research is needed to improve our understanding of urban pollinator communities in other regions where differences in the composition of urban areas may be important factors. Many studies have focussed on bees, however there are many non-bee pollinators with flies a large component of the pollinator communities in urban areas [22••] and an important pollinator group [93,94]. Thus future studies should broaden their remit beyond bees.

Urban landscapes represent a unique environment for biodiversity. Hall *et al.* [95] proposed the concept of the city as a 'refuge' for insect pollinators in comparison with intensively managed agricultural land. Factors such as the urban heat island (UHI) effect, increasing public interest in wildlife gardening practices and the high diversity of floral resources in gardens and other cultivated areas all have the potential to benefit pollinators. However urban areas also confer a range of associated challenges, the UHI could have negative effects for some plant and pollinator taxa and, whilst the high numbers of non-native plant species provide additional floral resources for pollinators, their presence could have negative impacts for the wider ecosystem, especially when the plant is an invasive species [96]. Furthermore, the fine-scale heterogeneity of land uses involves a complex network of stakeholders including policymakers, land managers and the public who need to find ways to work effectively together to ensure that urban areas fulfil their potential to be 'refuges' for pollinators. One of the top ten policies for pollinators recommended by the IPBES pollinators report is to conserve and restore green infrastructure in urban landscapes [97]. Therefore ensuring that planning policies for urban development and urban habitat management allow the provision of a continuous network of greenspace with suitable resources and nesting habitats for pollinators should be a priority.

Acknowledgements

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This study is the first to examine all pollinator groups across all major urban land uses, comparing pollinator communities and floral resources in 360 sites located in nine urban land uses in four UK cities using a plant-pollinator network approach. Allotments and domestic gardens had more bee and hoverfly flower visits, as well as higher flowering plant richness and floral abundance than most other land uses. A modelling approach suggested that increasing the area of allotments in cities has the most beneficial effect on plant-pollinator network robustness compared to other land uses and that increasing flowers in greenspace also has a positive impact on network robustness. The study also found more pollinator visits in domestic gardens with higher household income.

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