TYPE Perspective
PUBLISHED 14 August 2024
DOI 10.3389/fevo.2024.1401233

Current trends in bee conservation and habitat restoration in different types of anthropogenic habitats

Olivia Kline and Neelendra K. Joshi*

Department of Entomology and Plant Pathology, University of Arkansas, Fayetteville, AR, United States

Check for updates

OPEN ACCESS

EDITED BY
Michael D. Ulyshen,
United States Department of Agriculture,
United States

REVIEWED BY
Diane Lynn Larson,
United States Department of the Interior,
United States

*CORRESPONDENCE
Neelendra K. Joshi
nkjoshi@uark.edu

RECEIVED 14 March 2024
ACCEPTED 26 July 2024
PUBLISHED 14 August 2024

CITATION
Kline O and Joshi NK (2024) Current trends in bee conservation and habitat restoration in different types of anthropogenic habitats. *Front. Ecol. Evol.* 12:1401233.
doi: 10.3389/fevo.2024.1401233

Recent declines in bee populations and ranges have been cause for concern due to the valuable pollination service that they provide. Several factors have been proposed to contribute to these declines, including habitat loss, pathogen spread, and pesticide usage, so many pollinator conservation schemes have involved the addition of pollinator-friendly habitat through wildflower plantings and artificial nesting sites. Because of this, many efforts have been made to enhance bee populations across different landscape types, including natural, agricultural, urban, and industrial areas. Many of these schemes have focused on providing habitat for bees and other animal pollinators in agricultural landscapes, but other managed areas, such as cities, suburbs, and industrialized areas may have untapped potential for pollinator conservation. Available green space can be enhanced to provide healthy forage and safe nesting sites for pollinators. As these areas are also often frequented by human residents, the needs and perceptions of people, as well as the potential benefits for pollinators, must be considered to ensure the success of pollinator conservation on anthropogenic habitats.

KEYWORDS

wild bees, butterflies, wildlife, conservation, pollinator habitat, solar parks, roadside verges

1 Introduction

Bees, along with other flower-visiting insects and animals, provide the essential ecosystem service of pollination, which can benefit wild ecosystems, large-scale agricultural landscapes, and smaller residential gardens (Garibaldi et al., 2011; Ollerton et al., 2011; Lowenstein et al., 2015; Reilly et al., 2020; Allen-Perkins et al., 2022). Worldwide, around 85% of wild angiosperms are animal pollinated (Ollerton et al., 2011). In agriculture, over 75% of the leading food crops benefit from animal pollination, showing better yields and often larger, more appealing fruit when visited by pollinators (Foley et al., 2005; Klein et al., 2007; Sáez et al., 2020; Hünicken et al., 2021; Levenson et al., 2022). This pollination service improves the profits for growers, amounting to over $171 billion USD globally (Gallai et al., 2009). As well as providing pollination in natural and agricultural landscapes, bees and other animal pollinators can improve the fruit set of plants in residential gardens (Lowenstein et al., 2015; Reilly et al., 2020).

Despite their importance across these natural and anthropogenic landscapes, several native bee species of North America have had population and range declines in recent years, which can then lead to losses in the pollination services they provide. This has been best documented in the bumble bees (*Bombus* spp.) in North America (Colla and Packer, 2008; Grixti et al., 2009; Cameron et al., 2011; Jacobson et al., 2018), though in Europe, there is more documented evidence of similar declines in solitary bees (Rasmont et al., 2005; Fitzpatrick et al., 2006). In many regions, these declines have resulted in an overall loss in bee species richness and local pollinator populations (Turley et al., 2022; Nagamitsu et al., 2024), which are unable to meet the pollination requirements for dependent crops (Rucker et al., 2012; Degrandi-Hoffman et al., 2019). There have been several drivers implicated in these pollinator declines, including habitat loss, pesticide usage, parasites and pathogens, and climate change (Goulson et al., 2015; Belsky and Joshi, 2019; 2020).

The importance of bees and other pollinators, along with the concerns for their population declines, has led to an increasing need to mitigate risks and find ways to enhance pollinator populations across different landscapes (Alison et al., 2022; Glenny et al., 2022; Stout and Dicks, 2022; Duque-Trujillo et al., 2023). A growing trend in pollinator conservation has been the conversion and restoration of anthropogenic habitats, including cities, suburbs, and rights-of-way (ROWs) into pollinator habitat. Adding pollinator habitat to these managed areas, however, can increase human-pollinator interactions. Any pollinator habitat scheme on managed land cannot be for the benefit of the pollinators alone. Rather, for such schemes to be successful, they must rely on the support and enthusiasm of the human stakeholders who own or use the managed land. Here we discuss the potential benefits of developing pollinator habitat in these anthropogenic habitats, as well as the concerns for human health and safety that can arise from such schemes, in order to create more successful pollinator habitat schemes in human populated areas.

2 Enhancing managed landscapes in different habitats for floral resources

There are several managed lands with the potential to provide pollinator habitat and aid in pollinator conservation, including public parks, residential lawns, golf courses, solar parks, roadside verges, and powerline easements. Some of these areas already have semi-natural habitat that can be maintained and enhanced to provide pollinator forage, whereas others are degraded and would require more intensive conversion to provide adequate foraging and nesting sites for pollinators. These conversions could include seeding plots with native wildflowers, reducing pesticide spraying, or mowing less frequently at the sites (Muratet and Fontaine, 2015; Ramer et al., 2019). Any such conversions of developed areas would turn the land into multiple use sites and need to consider factors affecting the animal pollinators and human stakeholders in the area. These factors would include the original functionality of the site, the expense to implement and maintain pollinator habitat, the perception of the people who use it, and the benefit to local pollinator communities (Hopwood, 2008; Turo and Gardiner, 2019).

Currently, there is little national or international policy regarding habitat management for enhancing pollinator communities. In the United States, most policy implementation has occurred at the state or local level (Hall and Steiner, 2019; Bloom et al., 2022; DiDonato and Gareau, 2022; Pham et al., 2022; Campanelli et al., 2023). Increasing public awareness of pollination population declines and best management practices for improving habitat quality for these organisms, however, can increase local and regional scale improvements to pollinator habitat and populations in anthropogenic habitats.

2.1 Urban and suburban landscapes

Urban areas are often perceived as lacking in native wildlife populations, and many species decline in abundance as they move from natural to urban lands. Bees, however, have been shown to have fairly robust populations in many urban areas, especially when compared to intensive agricultural landscapes (Baldock et al., 2015; Samuelson et al., 2018; Guenat et al., 2019; Theodorou et al., 2020). With the proper management, urban and suburban landscapes are able to support a high diversity of bees and other pollinators (Baldock et al., 2015). Traditionally, most green spaces in cities and residential areas have mowed turfgrass lawns, herbicide applications for weed removal, and non-native ornamental plants (Aronson et al., 2017), which do not support as much pollinator richness and abundance as diverse floral plantings (Lowenstein et al., 2015). Additionally, most of the green spaces in urban areas are privately owned, leading to many individuals making management plans independently, rather than having a unified strategy (Aronson et al., 2017). Public perception of a habitat can also greatly influence the success of a conservation program, in both negative ways, including vandalism and protest, or positive ones, such as bringing in funding for the project (Turo and Gardiner, 2019). Any such programs, in order to be successful in urban and suburban areas, must consider the perceptions of the local residents, the expense and time to create and maintain the habitat, and the needs of the pollinators as well as opportunities for their conservation (Braman and Griffin, 2022).

Public parks are one type of urban green space with potential for creating bee habitat, either through planting low-growing flowers to replace turfgrass or through seeding areas of the park with wildflowers in order to create meadow patches. Surveys of park visitors in Minneapolis, MN reacted positively to the idea of enhancing turfgrass with low-growing forbs, such as lanceleaf coreopsis (*Coreopsis lanceolata*) and calico aster (*Symphyotrichum lateriflorum*), with over 95% of participants saying they would support the program (Ramer et al., 2019). Similarly, in a park in Saltdean, UK, 97% of park visitors supported management schemes to increase the abundance of wildflowers and insects

(Garbuzov et al., 2015). In spite of the support, several park visitors voiced concerns for schemes that would replace turfgrass with wildflowers. These included dislike of the "weedy" appearance of the wildflowers, fear of insects stings, and concerns that the flowers would take up usable park space (Garbuzov et al., 2015; Ramer et al., 2019). Insect stings can be medically relevant, with around 3% of adults that have systemic allergic reactions to them (Golden, 2017). These systemic reactions can result in anaphylaxis and even death in some cases, though occurrences tend to be low. In Europe, an average of 0.26 deaths per million people resulted from reactions to insect stings (Feás et al., 2022). Because of these concerns, any parks aiming to add pollinator habitat should keep areas well marked with signage and well maintained. Public outreach could also help inform people on the benefits of pollinators and keep them safer from stings (Ramer et al., 2019). Additionally, frequently mowed areas for recreation and sport should still be preserved in areas of the park.

In urban habitats, sections of residential lawns can also be converted from frequently mowed turfgrass into meadow patches to enhance pollinator populations, as frequent mowing can alter insect biodiversity (Proske et al., 2022). In an online national survey across the US, people in residential areas responded positively to the idea of adding wildflowers to their yards, though many cited concerns, such as "maintenance time" and "not knowing what to do" (Turley et al., 2020). In public outreach, then, conservation schemes should focus on residential programs that are simple, low maintenance, and relatively small scale (Turley et al., 2020). In addition to actively planting wildflowers, homeowners and renters can decrease mowing frequency to increase flower and pollinator abundance on their lawns (Lerman et al., 2018) and create pollinator friendly habitats in turfgrass systems (Billeisen et al., 2021).

Golf courses, which take up over 2 million acres of land in the US (Dobbs and Potter, 2015), offer another opportunity for pollinator habitat. By design, golf courses have mowed turfgrass fairways intermixed with woody areas and rough patches with taller grasses and other vegetation. These rough patches tend to have less intensive management than the fairways, with less mowing and reduced pesticide spraying, which makes them good candidates for bee habitats, as well as improving the aesthetics of the course (Dobbs and Potter, 2015). Enhanced golf courses with bee habitat can even host rare bee species, such as the three declining bumble bee species, *Bombus auricomus*, *Bombus pensylvanicus*, and *Bombus fervidus*, that were found on Kentucky golf courses after wildflower planting (Dobbs, 2013). Courses with wildflowers can also have greater bee abundance than those with turfgrass monocultures (Billeisen et al., 2021). As with the residential lawns, owners and managers of golf courses have voiced concerns over increased labor and maintenance for creating pollinator gardens (Bates et al., 2023). As such, any plantings should fit within the budget, labor, and time constraints of the golf course.

In cities, the proportion of impervious surfaces can impact pollinator abundance and species richness. Areas with high percentages of paved roads, parking lots, and buildings compared to green space provide smaller and more fragmented habitats for pollinators (Wenzel et al., 2020). Small-bodied pollinators, which fly shorter distances, in particular need more connected habitats to access resources (Zurbuchen et al., 2010). In city environments, green roofs have become more popular, and have several suggested benefits for the building and surrounding area, including reduced energy consumption, thermal regulation, improved air quality, and enhanced habitat in urban environments (Berardi et al., 2014). For bee pollinators, green roofs with flowering plants were able to support the same species richness and abundance as nearby fields (Colla et al., 2009). Building height, however, can limit the amount of pollinator species that are willing to fly up to the roof (Wu, 2019). Large- and medium-bodies bees were more commonly found on green roofs (MacIvor et al., 2015), so these roofs may not provide the same benefit to bees with shorter flight distances. The surrounding green space in the area can also impact the populations of bees on green roofs (Wu, 2019). Although cities can support numerous pollinator species, they often fail to provide suitable habitats for the rarest and most sensitive species with critical conservation status (Fauviau et al., 2024).

In the urban and suburban areas, where human residents are living and working in close proximity to these added pollinator habitats, the financial and cultural factors become especially important. For instance, pollinator habitats along footpaths and city roadsides, lacking signage, may appear overgrown and weedy to some residents, so improving public opinion of the sites can involve collaboration between ecologists, community leaders, landscape designers, and others, as well as adding "cues of care" to the habitats, signals to the residents that the areas are being maintained. As urbanization increases, finding successful ways to add pollinator habitat to urban and suburban areas can help maintain pollinator populations and pollination services (Derby Lewis et al., 2019). The interaction of bee habitats with the local human communities - not just the impact of humans on the habitat, but also the habitat on the community - is an important issue that is often overlooked in urban conservation schemes, but one that must be considered for their success (Turo and Gardiner, 2019).

2.2 Solar parks

As solar panels are becoming increasingly cost effective and solar photovoltaic energy one of the primary types of renewable energy, the land use dedicated to solar energy production is expected to increase (IEA, 2019; Blaydes et al., 2021). Though many people have installed solar panels on the roofs of buildings, widespread solar energy requires ground-mounted solar panels (Blaydes et al., 2021). Several solar energy companies have placed their ground-mounted panels in flat gravel-covered lots or fields of turfgrass, though some have put the land to agricultural use (Semeraro et al., 2022), by growing crops (Moore et al., 2022) or hosting livestock amongst the panels (McCall et al., 2023). Another proposed idea is to put in native prairie grasses and flowers, with low-growing, shade-tolerant plant species directly beneath the panels to provide habitat for pollinators (Davis, 2016) or to enhance population of certain bee species (Blaydes et al., 2022). Some solar parks have already established plantings of native perennial wildflowers and have had higher bee abundance compared to solar parks with only gravel or turfgrass (Randle-Boggis et al., 2020). Native prairie plants could have the additional benefit of improved erosion control and an even more environmentally conscious face for the solar companies (Briberg, 2016; Davis, 2016).

Some environmental and cost concerns have been raised for establishing native plantings in photovoltaic solar parks (Lafitte et al., 2022; McCall et al., 2023). The polarized light reflected off of solar panels can impact the movement and behavior of polarotactic insects, especially those that oviposit in aquatic environments. The solar panels may mimic the glare of sunlight on bodies of water (Horváth et al., 2010; Száz et al., 2016). Most studies have looked at insects with juvenile aquatic phases, such as Trichoptera, Ephemeroptera, and certain Diptera (Horváth et al., 2010; Száz et al., 2016). The area beneath the solar panels tends to be cooler and shadier than the surrounding environment, which can impact plant growth and pollination activity around the panels (Armstrong et al., 2016; Graham et al., 2021). While active pollination still occurred in the full shade regions below panels, the diversity and abundance of pollinators was lower in the full shade compared to partial shade and full sun areas (Graham et al., 2021). Pollinator gardens in solar parks would need to include shade-tolerant flowering plants in the areas under and directly around the panels. The addition of these gardens may provide the greatest benefit to more cold-tolerant pollinators, such as bumble bees (*Bombus* spp.) (Dehon et al., 2019). The implementation and first years management of native plantings can be more expensive and intensive than other solar park management options, such as sheep grazing, gravel lots, and turfgrass (McCall et al., 2023).

2.3 Rights-of-way: roadside vegetation

Roadside verges, the strips of land alongside roads, cover around 50,000 km^2 in the US, and provide a large area of land that could be used for wildlife habitat (Forman et al., 2003; Phillips et al., 2020). They tend to have more diverse plant species than many agricultural landscapes, including several early successional flowering plants (Hopwood et al., 2015; Phillips et al., 2020). Though roads themselves can cause habitats to become more fragmented, roadside verges can serve as corridors between habitats for insects (Hopwood et al., 2015), and these habitats have potential to support greater pollinator abundance (Dietzel et al., 2023).The conventional methods of maintenance of these sites include frequent mowing, use of non-native grasses, and herbicide spraying for weed control. Restored roadsides, those that have been seeded with native grasses and forbs can provide more flowering plants and support higher numbers and diversity of bees (Figure 1). There are concerns for the pollinators in providing habitat for them alongside roads (Meinzen et al., 2024). Management practices such as mowing of the roadside verges can impact pollinator community as well as their abundance. Similarly, proximity to roads can increase the incidents of vehicle collisions and the amount of automobile pollution, including heavy metals to which they are exposed (Phillips et al., 2020) and the contaminated roadside pollinator habitat (Shephard et al., 2022). Traffic intensity alongside road verges with pollinator habitat can also affect population of certain bee species such as bumblebee (Dániel-Ferreira et al., 2022). Verges alongside roads

FIGURE 1
Illustration showing establishment of pollinator habitats in roadside verges. These pollinator habitats can support diverse communities of pollinators as well as native plant species.

with less traffic and lower speed limits would likely provide the greatest benefit and lower risk for insect pollinators, though more research is need into the balance of potential hazards and benefits for pollinators in roadside verge habitats. Creating a mowed buffer zone directly alongside the road, with wildflowers planted at least 3 meters away from the edge of the road, may also reduce the risk of collision and contaminant exposure for pollinators (Meinzen et al., 2024).

The greatest human concern for roadsides is road safety, visibility, fire risk, and soil erosion prevention. Wildfires are becoming more common and more extreme in many areas, so the assessment of fire risk along roads is vital. The climate conditions of a region, the amount of dead plant matter, and the flammability of plant species can all impact the likelihood of ignition as well as the duration and intensity of a wildfire (Silva et al., 2014; Molina et al., 2019). Certain plant species are more flammable due to their moisture content and physical and chemical properties (Molina et al., 2019). Roadside design and maintenance can help reduce fire risk by properly assessing these factors and selecting lower risk plants for establishing in verges (Ree et al., 2015; Molina et al., 2019). In the United States, California has experienced frequent largescale wildfires in recent years, especially during drought conditions (Keeley and Syphard, 2021). Global regions like this, which are at high risk of drought conditions and wildfires, should prioritize fire safety near roadsides. Any added wildflower species for pollinators should be selected for low flammability. Mowing and removal of dead plant matter may also be required, which could increase labor costs of roadside maintenance. Though these verges have great potential for pollinator habitat the safety and usability of roads for humans has to be given priority.

2.4 Rights-of-way: powerline easements

Another right-of-way that has been proposed for habitat restoration is the land running along powerlines. In the US, powerline easements take up a sizeable area of land, around 5 million acres in total (Russell et al., 2005). These clearings can offer a different array of flowers and grass species than forested areas, and often a higher diversity of plant species. Instead of frequently mowing around powerline strips, the land along them could be converted into semi-natural grasslands (Eldegard et al., 2017) and pollinator habitat (Figure 2). Converted habitat around powerline easements can host early successional flowering plants and can have a greater diversity of pollinators than forested areas (Wagner et al., 2019) or other resource-poor landscapes (Du Clos et al., 2022), and can also support a diversity of species other than pollinators (Garfinkel et al., 2022). In Pennsylvania, nearly 30% of known bee species in the state were collected along a single powerline easement over a two-year study (Russo et al., 2021). Successful management for pollinator-friendly powerline easements would involve reduced herbicide usage, as well, as heavy usage of broad-spectrum herbicides correlated with lowered bee species richness in these habitats (Russo et al., 2021). It would be beneficial to add cues of care to such pollinator habitats, as well, to prevent the easements from seeming abandoned and unmaintained. These could include adding mowed borders around the tall grasses and flowers or adding signs that identify the area as restored prairie habitat for pollinators.

As with roadside verges, however, powerline easements can contribute to wildfire risk, especially in vulnerable and drought-prone regions. Powerline corridors are high risk areas for starting wildfires, as faults in the electrical grid, due to equipment failure or falling trees, can ignite surrounding vegetation (Arab et al., 2021).

FIGURE 2
Illustration showing converted land around powerline easements into pollinator habitat to support pollinator species diversity.

Most fire prevention schemes around powerline include removing trees from growing too close to the lines (Mitchell, 2013; Arab et al., 2021). Taller vegetation, like trees, pose the greatest risk of falling onto or against powerlines, and starting a wildfire. Conversely, trees and larger vegetation tend to only ignite at a higher temperature compared to smaller grasses, twigs, and leaves. As such, they are less likely to catch fire, but these canopy fires can be more devastating than surface fires over low growing grasslands (Jahn et al., 2022). When it comes to adding wildflowers and pollinator habitats to powerline easements, fire safety and prevention must remain a higher priority. Low growing, early successional plants pose little risk of interfering with powerlines or with increasing biomass within the easements (Clarke and White, 2008). In regions of high wildfire chance, low flammability species and ease of management should be prioritized, in order to maintain human and environmental safety.

3 Supplementing landscapes with nesting materials

Any conservation schemes to benefit pollinator populations must consider the habitat requirements of the bees in order to survive and successfully reproduce. Along with floral resources, bees need undisturbed nesting sites that are close to their foraging areas (Kline and Joshi, 2020). Several native bees, including many in the family Megachilidae, nest in existing cavities. Nest boxes or "bee hotels," especially those with a variety of nesting substrates can promote bee nesting for tunnel-nesting species (Fortel et al., 2016). These tube nest boxes need frequent monitoring and maintenance, however, to keep out parasites and predators. Nest tube liners, such as paper straws, can be used to reduce mites and other pests, but need to be replaced annually (Wilkaniec and Giejdasz, 2003; Joshi et al., 2020). Many of these tunnel-nesting bees also use mud, leaf pulp, or resin in their nest construction, and need those materials available close to their nest boxes (Torchio, 1989). Most bee species, however, are ground nesting, preferring to dig tunnels into soil. The preferences of bees, as far as soil compaction, texture, alkalinity, can vary greatly by species (Cane, 1991). Providing safe areas for these bees can involve leaving patches of untilled and exposed ground within wildflower gardens. One study in France found that many ground nesting bee species were willing to nest in more artificial nests, as well such as wood frame boxes filled with soil (Fortel et al., 2016). Many studies have shown that diverse floral resources can improve pollinator abundance and species richness, but safe nesting sites near these flower planting can also greatly benefit pollinator populations (Bortolotti et al., 2016).

4 Conclusions

Anthropogenic habitats can offer the potential to aid in pollinator conservation, as long as the land use requirements of both the humans and insect pollinators are considered. For humans, the safety, effectiveness, and perception of the land are important. Any conversion of managed land into pollinator habitat cannot be so drastic as to lose the original function of the land, and collaborations between ecologist and other stakeholders such as landscape architects could strengthen conservation efforts to maximize biodiversity in urban areas (Kiers et al., 2022). For pollinators, both generalist and specialist feeders can benefit from a diverse selection of flowering plants, with staggered bloom times throughout the bee foraging seasons (Aronson et al., 2017), as well as undisturbed nesting sites. Low frequency mowing and reduced pesticide usage can also greatly benefit pollinator populations (Blaydes et al., 2021; Russo et al., 2021). As a result of different conservation efforts, it is likely that the benefits to pollinator populations will be greatest in areas with more intensive agriculture and urbanization, which may have declines in their pollinator communities. Additionally, increased pollinator populations in urban, suburban, and industrial areas have the potential to spill over into agricultural and even natural lands (Blitzer et al., 2012). Most of the research in this field has been done in Europe, and to a lesser extent North America, and so more information is needed globally to better plan pollinator conservation schemes effectively. Effective pollinator conservation schemes rely on the coordination of research entomologists, landowners, and other stakeholders (Stout and Dicks, 2022), but they have great potential to mitigate some of the recent pollinator population declines and aid in enhancing pollinator populations in these developed areas.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The manuscript presents research on animals that do not require ethical approval for their study.

Author contributions

OK: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. NJ: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. OK and NJ were supported by USDA-NIFA (Project # ARK02710) and the UA System Division of Agriculture.

Acknowledgments

Authors are thankful to the USDA-NIFA (Project # ARK02710) and the UA System Division of Agriculture for the support. The views and opinions presented in this article are solely those of the authors and do not represent affiliated organizations. Mention of companies or commercial products does not imply recommendation or endorsement by the U.S. Department of Agriculture over others not mentioned. USDA neither guarantees nor warrants the standard of any product mentioned. Product names are mentioned solely to report factually on available data and to provide specific information.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Alison, J., Botham, M., Maskell, L. C., Garbutt, A., Seaton, F. M., Skates, J., et al. (2022). Woodland, cropland and hedgerows promote pollinator abundance in intensive grassland landscapes, with saturating benefits of flower cover. *J. Appl. Ecol.* 59, 342–354. doi: 10.1111/1365-2664.14058

Allen-Perkins, A., Magrach, A., Dainese, M., Garibaldi, L. A., Kleijn, D., Rader, R., et al. (2022). CropPol: A dynamic, open and global database on crop pollination. *Ecology* 103, e3614. doi: 10.1002/ecy.3614

Arab, A., Khodaei, A., Eskandarpour, R., Thompson, M. P., and Wei, Y. (2021). Three lines of defense for wildfire risk management in electric power grids: A review. *IEEE Access* 9, 61577–61593. doi: 10.1109/ACCESS.2021.3074477

Armstrong, A., Ostle, N. J., and Whitaker, J. (2016). Solar park microclimate and vegetation management effects on grassland carbon cycling. *Environ. Res. Lett.* 11, 74016. doi: 10.1088/1748-9326/11/7/074016

Aronson, M. F., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., MacIvor, J. S., et al. (2017). Biodiversity in the city: key challenges for urban green space management. *Front. Ecol. Environ.* 15, 189–196. doi: 10.1002/fee.1480

Baldock, K. C. R., Goddard Mark, A., Hicks Damien, M., Kunin William, E., Nadine, M., Osgathorpe Lynne, M., et al. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proc. R. Soc. B: Biol. Sci.* 282, 20142849. doi: 10.1098/rspb.2014.2849

Bates, C., Gerst, R., Schafer, C., and Vreeken, K. (2023). *Bees & Golf: an unlikely yet impactful partnership*. Ann Arbor, Michigan: The University of Michigan. doi: 10.7302/7129

Belsky, J., and Joshi, N. K. (2019). Impact of biotic and abiotic stressors on managed and feral bees. *Insects* 10, .233. doi: 10.3390/insects10080233

Belsky, J., and Joshi, N. K. (2020). Effects of fungicide and herbicide chemical exposure on Apis and non-Apis bees in agricultural landscape. *Front. Environ. Sci.* 8, 81. doi: 10.3389/fenvs.2020.00081

Berardi, U., GhaffarianHoseini, A., and GhaffarianHoseini, A. (2014). State-of-the-art analysis of the environmental benefits of green roofs. *Appl. Energy* 115, 411–428. doi: 10.1016/j.apenergy.2013.10.047

Billeisen, T. L., Kilpatrick, L. D., Seth-Carley, D., and Brandenburg, R. L. (2021). Presence of pollinator-friendly habitat on pollinator communities in managed turfgrass systems. *Int. Turfgrass Soc. Res. Journals.* 14 (1), 295-303. doi: 10.1002/its2.56

Blaydes, H., Gardner, E., Whyatt, J. D., Potts, S. G., and Armstrong, A. (2022). Solar park management and design to boost bumble bee populations. *Environ. Res. Lett.* 17, 044002. doi: 10.1088/1748-9326/ac5840

Blaydes, H., Potts, S. G., Whyatt, J. D., and Armstrong, A. (2021). Opportunities to enhance pollinator biodiversity in solar parks. *Renewable Sustain. Energy Rev.* 145, 111065. doi: 10.1016/j.rser.2021.111065

Blitzer, E. J., Dormann, C. F., Holzschuh, A., Klein, A.-M., Rand, T. A., and Tscharntke, T. (2012). Spillover of functionally important organisms between managed and natural habitats. *Agricul Ecosyst. Environ.* 146, 34–43. doi: 10.1016/j.agee.2011.09.005

Bloom, E. H., Graham, K. K., Haan, N. L., Heck, A. R., Gut, L. J., Landis, D. A., et al. (2022). Responding to the US national pollinator plan: a case study in Michigan. *Front. Ecol. Environ.* 20, 84–92. doi: 10.1002/fee.2430

Bortolotti, L., Bogo, G., de Manicor, N., Fisogni, A., and Galloni, M. (2016). Integrated conservation of bee pollinators of a rare plant in a protected area near Bologna, Italy. *Conserv. Evidence* 13, 51–56.

Braman, S. K., and Griffin, B. (2022). Opportunities for and impediments to pollinator conservation in urban settings: A review. *J. Integrated Pest Manage.* 13, 6. doi: 10.1093/jipm/pmac004

Briberg, J. (2016).Utility & Community solar should use native landscaping. In: *CleanTechnica*. Available online at: https://cleantechnica.com/2016/03/15/utility-and-community-solar-should-use-native-landscaping/ (Accessed May 24, 2019).

Cameron, S. A., Lozier, J. D., Strange, J. P., Koch, J. B., Cordes, N., Solter, L. F., et al. (2011). Patterns of widespread decline in North American bumble bees. *PNAS* 108, 662–667. doi: 10.1073/pnas.1014743108

Campanelli, J., Kuzovkina, Y. A., and Kocurek, S. (2023). Current impediments for new england DOTs to transition to sustainable roadside practices for strengthening pollinator habitats and health. *Sustainability* 15, 3639. doi: 10.3390/su15043639

Cane, J. H. (1991). Soils of ground-nesting bees (Hymenoptera: apoidea): texture, moisture, cell depth and climate. *J. Kansas Entomol Soc.* 64, 406–413.

Clarke, D. J., and White, J. G. (2008). Towards ecological management of Australian powerline corridor vegetation. *Landscape Urban Plann.* 86, 257–266. doi: 10.1016/j.landurbplan.2008.03.005

Colla, S. R., and Packer, L. (2008). Evidence for decline in eastern North American bumblebees (Hymenoptera: Apidae), with special focus on Bombus affinis Cresson. *Biodivers Conserv.* 17, 1379. doi: 10.1007/s10531-008-9340-5

Colla, S. R., Willis, E., and Packer, L. (2009). Can green roofs provide habitat for urban bees (Hymenoptera: Apidae)? *Cities Environ.* 2, 12. doi: 10.15365/cate.2142009

Dániel-Ferreira, J., Berggren, ÅCheckt. a. e., Bommarco, R., Wissman, J., and Öckinger, E. (2022). Bumblebee queen mortality along roads increase with traffic. *Biol. Conserv.* 272, 109643. doi: 10.1016/j.biocon.2022.109643

Davis, R. (2016).Can solar sites help save the bees? | Bee culture. In: *Bee culture: the magazine of american beekeeping*. Available online at: https://www.beeculture.com/can-solar-sites-help-save-bees/ (Accessed May 16, 2019).

Degrandi-Hoffman, G., Graham, H., Ahumada, F., Smart, M., and Ziolkowski, N. (2019). The economics of honey bee (Hymenoptera: apidae) management and overwintering strategies for colonies used to pollinate almonds. *J. Econ Entomol* 112, 2524–2533. doi: 10.1093/jee/toz213

Dehon, M., Engel, M. S., Gérard, M., Aytekin, A. M., Ghisbain, G., Williams, P. H., et al. (2019). Morphometric analysis of fossil bumble bees (Hymenoptera, Apidae, Bombini) reveals their taxonomic affinities. *Zookeys* 891, 71–118. doi: 10.3897/zookeys.891.36027

Derby Lewis, A., Bouman, M. J., Winter, A. M., Hasle, E. A., Stotz, D. F., Johnston, M. K., et al. (2019). Does nature need cities? Pollinators reveal a role for cities in wildlife conservation. *Front. Ecol. Evol.* 7. doi: 10.3389/fevo.2019.00220

DiDonato, S., and Gareau, B. J. (2022). Be (e) coming pollinators: Beekeeping and perceptions of environmentalism in Massachusetts. *PloS One* 17, e0263281. doi: 10.1371/journal.pone.0263281

Dietzel, S., Rojas-Botero, S., Kollmann, J., and Fischer, C. (2023). Enhanced urban roadside vegetation increases pollinator abundance whereas landscape characteristics drive pollination. *Ecol. Indic.* 147, 109980. doi: 10.1016/j.ecolind.2023.109980

Dobbs, E. K. (2013). *Enhancing beneficial insect biodiversity and biological control in turf: mowing height, naturalized roughs, and operation pollinator*. Available online at: https://www.semanticscholar.org/paper/ENHANCING-BENEFICIAL-INSECT-BIODIVERSITY-AND-IN-AND-Dobbs/860de794de4230348779429b0daee3472e60a8d5 (Accessed July 1, 2021).

Dobbs, E. K., and Potter, D. A. (2015). Forging natural links with golf courses for pollinator-related conservation, outreach, teaching, and research. *Am. Entomologist* 61, 116–123. doi: 10.1093/ae/tmv021

Du Clos, B., Drummond, F. A., and Loftin, C. S. (2022). Effects of an early mass-flowering crop on wild bee communities and traits in power line corridors vary with blooming plants and landscape context. *Landsc Ecol.* 37, 2619–2634. doi: 10.1007/s10980-022-01495-9

Duque-Trujillo, D., Hincapié, C. A., Osorio, M., and Zartha-Sossa, J. W. (2023). Strategies for the attraction and conservation of natural pollinators in agroecosystems: a systematic review. *Int. J. Environ. Sci. Technol.* 20, 4499–4512. doi: 10.1007/s13762-022-04634-6

Eldegard, K., Eyitayo, D. L., Lie, M. H., and Moe, S. R. (2017). Can powerline clearings be managed to promote insect-pollinated plants and species associated with semi-natural grasslands? *Landscape Urban Plann.* 167, 419–428. doi: 10.1016/j.landurbplan.2017.07.017

Fauviau, A., Fiordaliso, W., Fisogni, A., Fortel, L., Francis, F., Geslin, B., et al. (2024). Larger cities host richer bee faunas, but are no refuge for species with concerning conservation status: empirical evidence from Western Europe. *Basic Appl. Ecol.* 79, 131–140. doi: 10.1016/j.baae.2024.06.002

Feás, X., Vidal, C., and Remesar, S. (2022). What we know about sting-related deaths? Human fatalities caused by hornet, wasp and bee stings in europe, (1994–2016). *Biology* 11, 282. doi: 10.3390/biology11020282

Fitzpatrick, Ú., Murray, T. E., Byrne, A. W., Paxton, R. J., and Brown, M. J. F. (2006). *Regional red list of Irish bees* (N. Ireland: National Parks and Wildlife Service (Ireland) and Environment and Heritage Service). Available online at: https://researchrepository.ucd.ie/handle/10197/5341 (Accessed November 7, 2019).

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., et al. (2005). Global consequences of land use. *Science* 309, 570–574. doi: 10.1126/science.1111772

Forman, R. T. T., Sperling, D., Bissonette, J. A., Clevenger, A. P., Cutshall, C. D., Dale, V. H., et al. (2003). *Road ecology: science and solutions* (Washington D.C.: Island Press).

Fortel, L., Henry, M., Guilbaud, L., Mouret, H., and Vaissière, B. E. (2016). Use of human-made nesting structures by wild bees in an urban environment. *J. Insect Conserv.* 20, 239–253. doi: 10.1007/s10841-016-9857-y

Gallai, N., Salles, J.-M., Settele, J., and Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Economics* 68, 810–821. doi: 10.1016/j.ecolecon.2008.06.014

Garbuzov, M., Fensome, K. A., and Ratnieks, F. L. W. (2015). Public approval plus more wildlife: twin benefits of reduced mowing of amenity grass in a suburban public park in Saltdean, UK. *Insect Conserv. Diversity* 8, 107–119. doi: 10.1111/icad.12085

Garfinkel, M., Hosler, S., Whelan, C., and Minor, E. (2022). Powerline corridors can add ecological value to suburban landscapes when not maintained as lawn. *Sustainability* 14, 7113. doi: 10.3390/su14127113

Garibaldi, L. A., Steffan-Dewenter, I., Kremen, C., Morales, J. M., Bommarco, R., Cunningham, S. A., et al. (2011). Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecol. Lett.* 14, 1062–1072. doi: 10.1111/ele.2011.14.issue-10

Glenny, W., Runyon, J. B., and Burkle, L. A. (2022). A review of management actions on insect pollinators on public lands in the United States. *Biodivers Conserv.* 31, 1995–2016. doi: 10.1007/s10531-022-02399-5

Golden, D. B. K. (2017). "Chapter 15 - insect allergy," in *Middleton's allergy essentials*. Eds. R. E. O'Hehir, S. T. Holgate and A. Sheikh (Elsevier), 377–393. doi: 10.1016/B978-0-323-37579-5.00015-5

Goulson, D., Nicholls, E., Botías, C., and Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* 347, 1255957. doi: 10.1126/science.1255957

Graham, M., Ates, S., Melathopoulos, A. P., Moldenke, A. R., DeBano, S. J., Best, L. R., et al. (2021). Partial shading by solar panels delays bloom, increases floral abundance during the late-season for pollinators in a dryland, agrivoltaic ecosystem. *Sci. Rep.* 11, 7452. doi: 10.1038/s41598-021-86756-4

Grixti, J. C., Wong, L. T., Cameron, S. A., and Favret, C. (2009). Decline of bumble bees (*Bombus*) in the North American Midwest. *Biol. Conserv.* 142, 75–84. doi: 10.1016/j.biocon.2008.09.027

Guenat, S., Kunin, W. E., Dougill, A. J., and Dallimer, M. (2019). Effects of urbanisation and management practices on pollinators in tropical Africa. *J. Appl. Ecol.* 56, 214–224. doi: 10.1111/1365-2664.13270

Hall, D. M., and Steiner, R. (2019). Insect pollinator conservation policy innovations at subnational levels: Lessons for lawmakers. *Environ. Sci. Policy* 93, 118–128. doi: 10.1016/j.envsci.2018.12.026

Hopwood, J. L. (2008). The contribution of roadside grassland restorations to native bee conservation. *Biol. Conserv.* 141, 2632–2640. doi: 10.1016/j.biocon.2008.07.026

Hopwood, J. L., Black, S., and Fleury, S. (2015).Roadside best management practices that benefit pollinators | Ecosystem and vegetation system management. In: *Environmental review toolkit* (FHWA. US Department of Transportation). Available online at: https://www.environment.fhwa.dot.gov/env_topics/ecosystems/Pollinators_Roadsides/BMPs_pollinators_landscapes.aspx (Accessed July 6, 2023).

Horváth, G., Blahó, M., Egri, Á., Kriska, G., Seres, I., and Robertson, B. (2010). Reducing the maladaptive attractiveness of solar panels to polarotactic insects. *Conserv. Biol.* 24, 1644–1653. doi: 10.1111/j.1523-1739.2010.01518.x

Hünicken, P. L., Morales, C. L., Aizen, M. A., Anderson, G. K. S., García, N., and Garibaldi, L. A. (2021). Insect pollination enhances yield stability in two pollinator-dependent crops. *Agricul Ecosyst. Environ.* 320, 107573. doi: 10.1016/j.agee.2021.107573

IEA (2019). *Renewables 2019 – analysis and forcast to 2024* (International Energy Agency). Available online at: https://www.iea.org/reports/renewables-2019 (Accessed July 6, 2021).

Jacobson, M. M., Tucker, E. M., Mathiasson, M. E., and Rehan, S. M. (2018). Decline of bumble bees in northeastern North America, with special focus on Bombus terricola. *Biol. Conserv.* 217, 437–445. doi: 10.1016/j.biocon.2017.11.026

Jahn, W., Urban, J. L., and Rein, G. (2022). Powerlines and wildfires: overview, perspectives, and climate change: could there be more electricity blackouts in the future? *IEEE Power Energy Magazine* 20, 16–27. doi: 10.1109/MPE.2021.3122755

Joshi, N. K., Naithani, K., and Biddinger, D. J. (2020). Nest modification protects immature stages of the Japanese orchard bee (Osmia cornifrons) from invasion of a cleptoparasitic mite pest. *Insects* 11, 65. doi: 10.3390/insects11010065

Keeley, J. E., and Syphard, A. D. (2021). Large California wildfires: 2020 fires in historical context. *fire Ecol.* 17, 22. doi: 10.1186/s42408-021-00110-7

Kiers, A. H., Krimmel, B., Larsen-Bircher, C., Hayes, K., Zemenick, A., and Michaels, J. (2022). Different jargon, same goals: collaborations between landscape architects and ecologists to maximize biodiversity in urban lawn conversions. *Land* 11, 1665. doi: 10.3390/land11101665

Klein, A.-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., et al. (2007). Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B: Biol. Sci.* 274, 303–313. doi: 10.1098/rspb.2006.3721

Kline, O., and Joshi, N. K. (2020). Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. *Agriculture* 10, 115. doi: 10.3390/agriculture10040115

Lafitte, A., Sordello, R., de Crespin de Billy, V., Froidevaux, J., Gourdain, P., Kerbiriou, C., et al. (2022). What evidence exists regarding the effects of photovoltaic panels on biodiversity? A critical systematic map protocol. *Environ. Evidence* 11, 36. doi: 10.1186/s13750-022-00291-x

Lerman, S. B., Contosta, A. R., Milam, J., and Bang, C. (2018). To mow or to mow less: Lawn mowing frequency affects bee abundance and diversity in suburban yards. *Biol. Conserv.* 221, 160–174. doi: 10.1016/j.biocon.2018.01.025

Levenson, H. K., Sharp, A. E., and Tarpy, D. R. (2022). Evaluating the impact of increased pollinator habitat on bee visitation and yield metrics in soybean crops. *Agricul Ecosyst. Environ.* 331, 107901. doi: 10.1016/j.agee.2022.107901

Lowenstein, D. M., Matteson, K. C., and Minor, E. S. (2015). Diversity of wild bees supports pollination services in an urbanized landscape. *Oecologia* 179, 811–821. doi: 10.1007/s00442-015-3389-0

MacIvor, J. S., Ruttan, A., and Salehi, B. (2015). Exotics on exotics: Pollen analysis of urban bees visiting Sedum on a green roof. *Urban Ecosyst.* 18, 419–430. doi: 10.1007/s11252-014-0408-6

McCall, J., Macdonald, J., Burton, R., and Macknick, J. (2023). Vegetation management cost and maintenance implications of different ground covers at utility-scale solar sites. *Sustainability* 15, 5895. doi: 10.3390/su15075895

Meinzen, T. C., Burkle, L. A., and Debinski, D. M. (2024). Roadside habitat: Boon or bane for pollinating insects? *Bioscience* 74, 54–64. doi: 10.1093/biosci/biad111

Mitchell, J. W. (2013). Power line failures and catastrophic wildfires under extreme weather conditions. *Eng. Failure Anal.* 35, 726–735. doi: 10.1016/j.engfailanal.2013.07.006

Molina, J. R., Lora, A., Prades, C., and Rodríguez y Silva, F. (2019). Roadside vegetation planning and conservation: New approach to prevent and mitigate wildfires based on fire ignition potential. *For. Ecol. Manage.* 444, 163–173. doi: 10.1016/j.foreco.2019.04.034

Moore, S., Graff, H., Ouellet, C., Leslie, S., and Olweean, D. (2022). Can we have clean energy and grow our crops too? Solar siting on agricultural land in the United States. *Energy Res. Soc. Sci.* 91, 102731. doi: 10.1016/j.erss.2022.102731

Muratet, A., and Fontaine, B. (2015). Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. *Biol. Conserv.* 182, 148–154. doi: 10.1016/j.biocon.2014.11.045

Nagamitsu, T., Inari, N., Matsumura, T., Nakamura, S., and Taki, H. (2024). Wild bee surveys across 60 years reveal remarkable reduction of bee abundance in urban green areas in northern Japan. *Ecol. Res.* 39, 42–53. doi: 10.1111/1440-1703.12416

Ollerton, J., Winfree, R., and Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos* 120, 321–326. doi: 10.1111/j.1600-0706.2010.18644.x

Pham, M. A., Scott, S. B., Fyie, L. R., and Gardiner, M. M. (2022). Sustainable landscaping programs in the United States and their potential to encourage conservation and support ecosystem services. *Urban Ecosyst.* 25, 1481–1490. doi: 10.1007/s11252-022-01241-8

Phillips, B. B., Wallace, C., Roberts, B. R., Whitehouse, A. T., Gaston, K. J., Bullock, J. M., et al. (2020). Enhancing road verges to aid pollinator conservation: A review. *Biol. Conserv.* 250, 108687. doi: 10.1016/j.biocon.2020.108687

Proske, A., Lokatis, S., and Rolff, J. (2022). Impact of mowing frequency on arthropod abundance and diversity in urban habitats: A meta-analysis. *Urban Forestry Urban Greening* 76, 127714. doi: 10.1016/j.ufug.2022.127714

Ramer, H., Nelson, K. C., Spivak, M., Watkins, E., Wolfin, J., and Pulscher, M. (2019). Exploring park visitor perceptions of 'flowering bee lawns' in neighborhood parks in Minneapolis, MN, US. *Landscape Urban Plann.* 189, 117–128. doi: 10.1016/j.landurbplan.2019.04.015

Randle-Boggis, R. J., White, P. C. L., Cruz, J., Parker, G., Montag, H., Scurlock, J. M. O., et al. (2020). Realising co-benefits for natural capital and ecosystem services from solar parks: A co-developed, evidence-based approach. *Renewable Sustain. Energy Rev.* 125, 109775. doi: 10.1016/j.rser.2020.109775

Rasmont, P., Pauly, A., Terzo, M., Patiny, S., Michez, D., Iserbyt, S., et al. (2005). The survey of wild bees (Hymenoptera, apoidea) in Belgium and France. *Food Agric. Organisation Rome* 18.

Ree, R., Smith, D. J., and Grilo, C. (2015). *Handbook of road ecology* (John Wiley & Sons).

Reilly, J. R., Artz, D. R., Biddinger, D., Bobiwash, K., Boyle, N. K., Brittain, C., et al. (2020). Crop production in the USA is frequently limited by a lack of pollinators. *Proc. R. Soc. B* 287, 20200922. doi: 10.1098/rspb.2020.0922

Rucker, R. R., Thurman, W. N., and Burgett, M. (2012). Honey bee pollination markets and the internalization of reciprocal benefits. *Am. J. Agric. Econ* 94, 956–977. doi: 10.1093/ajae/aas031

Russell, K. N., Ikerd, H., and Droege, S. (2005). The potential conservation value of unmowed powerline strips for native bees. *Biol. Conserv.* 124, 133–148. doi: 10.1016/j.biocon.2005.01.022

Russo, L., Stout, H., Roberts, D., Ross, B. D., and Mahan, C. G. (2021). Powerline right-of-way management and flower-visiting insects: How vegetation management can promote pollinator diversity. *PloS One* 16, e0245146. doi: 10.1371/journal.pone.0245146

Sáez, A., Aizen, M. A., Medici, S., Viel, M., Villalobos, E., and Negri, P. (2020). Bees increase crop yield in an alleged pollinator-independent almond variety. *Sci. Rep.* 10, 3177. doi: 10.1038/s41598-020-59995-0

Samuelson, A. E., Gill, R. J., Brown, M. J. F., and Leadbeater, E. (2018). Lower bumblebee colony reproductive success in agricultural compared with urban environments. *Proc. R. Soc. B: Biol. Sci.* 285, 20180807. doi: 10.1098/rspb.2018.0807

Semeraro, T., Scarano, A., Santino, A., Emmanuel, R., and Lenucci, M. (2022). An innovative approach to combine solar photovoltaic gardens with agricultural production and ecosystem services. *Ecosys. Serv.* 56, 101450. doi: 10.1016/j.ecoser.2022.101450

Shephard, A. M., Agnew, L., Herdtle, A., Mitchell, T. S., Borer, E. T., and snell-rood, E. (2022). Traffic patterns, more than adjacent land use, influence element content of roadside forbs for insect pollinators. *Ecol. Solutions Evidence* 3, e12195. doi: 10.1002/2688-8319.12195

Silva, F. R., Martínez, J. R. M., and González-Cabán, A. (2014). A methodology for determining operational priorities for prevention and suppression of wildland fires. *Int. J. Wildland Fire* 23, 544–554. doi: 10.1071/WF13063

Stout, J. C., and Dicks, L. V. (2022). From science to society: implementing effective strategies to improve wild pollinator health. *Philos. Trans. R. Soc. B: Biol. Sci.* 377, 20210165. doi: 10.1098/rstb.2021.0165

Száz, D., Mihályi, D., Farkas, A., Egri, Á., Barta, A., Kriska, G., et al. (2016). Polarized light pollution of matte solar panels: anti-reflective photovoltaics reduce polarized light pollution but benefit only some aquatic insects. *J. Insect Conserv.* 20, 663–675. doi: 10.1007/s10841-016-9897-3

Theodorou, P., Radzevičiūtė, R., Lentendu, G., Kahnt, B., Husemann, M., Bleidorn, C., et al. (2020). Urban areas as hotspots for bees and pollination but not a panacea for all insects. *Nat. Commun.* 11, 576. doi: 10.1038/s41467-020-14496-6

Torchio, P. F. (1989). In-nest biologies and development of immature stages of three osmia species (Hymenoptera: megachilidae). *Ann. Entomol Soc. Am.* 82, 599–615. doi: 10.1093/aesa/82.5.599

Turley, N. E., Biddinger, D. J., Joshi, N. K., and López-Uribe, M. M. (2022). Six years of wild bee monitoring shows changes in biodiversity within and across years and declines in abundance. *Ecol. Evol.* 12, e9190. doi: 10.1002/ece3.9190

Turley, N. E., Hogan, J., Diehl, G. J., Stack, A. C., and Sharanowski, B. J. (2020). Nationwide survey on the barriers to converting turfgrass lawns to pollinator-friendly native wildflowers. *bioRxiv* 2020, 6.02.129452. doi: 10.1101/2020.06.02.129452

Turo, K. J., and Gardiner, M. M. (2019). From potential to practical: conserving bees in urban public green spaces. *Front. Ecol. Environ.* 17, 167–175. doi: 10.1002/fee.2015

Wagner, D. L., Metzler, K. J., and Frye, H. (2019). Importance of transmission line corridors for conservation of native bees and other wildlife. *Biol. Conserv.* 235, 147–156. doi: 10.1016/j.biocon.2019.03.042

Wenzel, A., Grass, I., Belavadi, V. V., and Tscharntke, T. (2020). How urbanization is driving pollinator diversity and pollination – A systematic review. *Biol. Conserv.* 241, 108321. doi: 10.1016/j.biocon.2019.108321

Wilkaniec, Z., and Giejdasz, K. (2003). Suitability of nesting substrates for the cavity-nesting bee Osmia rufa. *J. Apicultural Res.* 42, 29–31. doi: 10.1080/00218839.2003.11101084

Wu, T. (2019). "Abundance and diversity of pollinators on green roofs are affected by environmental factors," in *IOP Conf. Ser.: Earth Environ. Sci*, Vol. 358. 022053. doi: 10.1088/1755-1315/358/2/022053

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., and Dorn, S. (2010). Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. *Biol. Conserv.* 143, 669–676. doi: 10.1016/j.biocon.2009.12.003