Conservation Biology

Essay

The city as a refuge for insect pollinators

Damon M. Hall,[1]* Gerardo R. Camilo,[2] Rebecca K. Tonietto,[1] Jeff Ollerton,[3] Karin Ahrné,[4] Mike Arduser,[5] John S. Ascher,[6] Katherine C. R. Baldock,[7] Robert Fowler,[8] Gordon Frankie,[9] Dave Goulson,[8] Bengt Gunnarsson,[10] Mick E. Hanley,[11] Janet I. Jackson,[3] Gail Langellotto,[12] David Lowenstein,[12] Emily S. Minor,[13] Stacy M. Philpott,[14] Simon G. Potts,[15] Muzafar H. Sirohi,[3] Edward M. Spevak,[16] Graham N. Stone,[17] and Caragh G. Threlfall[18]

[1]Center for Sustainability, Saint Louis University, Des Peres Hall, 203E; 3694 West Pine Mall; St. Louis, MO 63108, U.S.A.
[2]Department of Biology, Saint Louis University, 3507 Laclede Avenue, St. Louis, MO 63103, U.S.A.
[3]Department of Environmental and Geographical Sciences, University of Northampton, Boughton Green Road, Northampton, NN2 7AL, U.K.
[4]Swedish Species Information Centre-ArtDatabanken, Swedish University of Agricultural Sciences, Box 7007, SE-750 07 Uppsala, Sweden
[5]Missouri Department of Conservation, 2360 Highway D, St. Charles, MO 63304, U.S.A.
[6]Department of Biological Sciences, National University of Singapore, 14 Science Drive 4, Singapore 117543, Singapore
[7]Biological Sciences & Cabot Institute, University of Bristol, 24 Tyndall Avenue, Bristol BS8 1TQ, U.K.
[8]School of Life Sciences, University of Sussex, Sussex, BN 1 9QG, U.K.
[9]Department of Environmental Science, Policy, & Management, University of California Berkeley, 130 Mulford Hall #3114, Berkeley, CA 94720, U.S.A.
[10]Department of Biological and Environmental Sciences, University of Gothenburg, Box 100, S-405 30 Gothenburg, Sweden
[11]School of Biological Sciences, University of Plymouth, Drake Circus, Plymouth PL4 8AA, U.K.
[12]Department of Horticulture, Oregon State University, 2750 SW Campus Way, Corvallis, OR 97331, U.S.A.
[13]Department of Biological Sciences, University of Illinois-Chicago, SES 3346, M/C 066, 845 West Taylor Street, Chicago, IL 60607, U.S.A.
[14]Environmental Studies, University of California, Santa Cruz, 1156 High Street, Mailstop: ENVS, Santa Cruz, CA 95064, U.S.A.
[15]Centre for Agri-Environmental Research, School of Agriculture, Policy and Development, University of Reading, Reading RG6 6AR, U.K.
[16]WildCare Institute Center for Native Pollinator Conservation, IUCN SSC Bumblebee Specialist Group, Saint Louis Zoo, One Government Drive, St. Louis, MO 63110, U.S.A.
[17]Institute of Evolutionary Biology, The University of Edinburgh, The Kings Buildings, West Mains Road, Edinburgh EH9 3JT, U.K.
[18]Green Infrastructure Research Group, The University of Melbourne, Parkville Victoria 3010, Australia

Abstract: *Research on urban insect pollinators is changing views on the biological value and ecological importance of cities. The abundance and diversity of native bee species in urban landscapes that are absent in nearby rural lands evidence the biological value and ecological importance of cities and have implications for biodiversity conservation. Lagging behind this revised image of the city are urban conservation programs that historically have invested in education and outreach rather than programs designed to achieve high-priority species conservation results. We synthesized research on urban bee species diversity and abundance to determine how urban conservation could be repositioned to better align with new views on the ecological importance of urban landscapes. Due to insect pollinators' relatively small functional requirements—habitat range, life cycle, and nesting behavior—relative to larger mammals, we argue that pollinators put high-priority and high-impact urban conservation within reach. In a rapidly urbanizing world, transforming how environmental managers view the city can improve citizen engagement and contribute to the development of more sustainable urbanization.*

*email dmhall@slu.edu
Paper submitted February 8, 2016; revised manuscript accepted September 5, 2016.

DOI: 10.1111/cobi.12840

Keywords: communication, conservation planning, ecosystem services, funding and philanthropy, governance, politics and policy, sustainability science, urban ecology

La Ciudad como Refugio para Insectos Polinizadores

Resumen: *Las investigaciones sobre los insectos polinizadores urbanos están cambiando las percepciones sobre el valor biológico y la importancia ecológica de las ciudades. La abundancia y la diversidad de las especies nativas de abejas en los paisajes urbanos, que además están ausentes en los terrenos rurales cercanos, evidencian el valor biológico y la importancia ecológica de las ciudades y tienen implicaciones para la conservación de la biodiversidad. A paso lento detrás de esta imagen revisada de las ciudades están los programas de conservación urbana que históricamente han invertido en la educación y el alcance en lugar de los programar diseñados para adquirir resultados de conservación para especies de prioridad alta. Sintetizamos las investigaciones sobre la diversidad de especies de abejas urbanas y la abundancia para determinar cómo la conservación urbana podría ser reposicionada para alinearse de mejor manera con las nuevas visiones sobre la importancia ecológica de los paisajes urbanos. Debido a los requerimientos funcionales relativamente pequeños de los insectos polinizadores – extensión del hábitat, ciclo de vida, comportamiento de anidamiento - en relación con los mamíferos más grandes, argumentamos que los polinizadores colocan a la conservación urbana de alta prioridad y alto impacto dentro de nuestro alcance. En un mundo rápidamente urbanizado, transformar la forma en que los administradores ambientales ven a las ciudades puede mejorar la participación ciudadana y contribuir al desarrollo de una urbanización más sustentable.*

Palabras Clave: ciencia de la sustentabilidad, comunicación, ecología urbana, financiamiento y filantropía, gobernanza, planeación de la conservación, políticas y leyes, servicios ambientales

Natural resource management (NRM) investments in urban conservation are largely aimed at connecting people to nature. Historically, urban conservation directives have sought to garner broad public support by funding outreach, recreation facilities, and education rather than high-priority conservation efforts (McCleery et al. 2014; USFWS 2015). Cities are primarily viewed in terms of their political value (where the voters are) rather than for their ecological value. The inherited historical view of the general public, that urban environments are biological deserts, seems reasonable because research has shown how sprawling urban development is responsible for high rates of species' extinctions (McKinney et al. 2003; Luck 2007; McKinney 2008) and how large-scale transformation of landscapes (Ehrlich & Holdren 1971; Pejchar et al. 2007) are associated with extensive and persistent losses of native species (Pickett et al. 1992; Hansen et al. 2005). However, urban ecology routinely necessitates reassessing established ideas in biophysical ecology (e.g., linear responses of biodiversity to habitat destruction [Collins et al. 2010; Ramalho & Hobbs 2012; Grove et al. 2015]), and advances in this field are transforming the ecological importance of cities.

Since 2006, research on wild bees in cities shows that diverse populations of bees live in urban landscapes. In the midst of a pollination crisis, where insect pollinator populations are experiencing significant declines (Jaffe et al. 2010; Pleasants & Oberhauser 2013; Goulson et al. 2015), studies of native bee richness and abundance indicate that diverse communities of wild bees persist in cities in many parts of the world such as Berlin, Germany (Saure et al. 1998); Birmingham, Bristol, Cardiff, Dundee, Edinburg, Glasgow, Hull, Leeds, Leicester, London, Northampton, Reading, Sheffield, Southampton, and Swindon in the United Kingdom (Goulson et al. 2008; Baldock et al. 2015; Sirohi et al. 2015); Melbourne, Australia (Threlfall et al. 2015); Guanacaste Province, Costa Rica (Frankie et al. 2013); Vancouver, Canada (Tommasi et al. 2004); and Berkeley (Frankie et al. 2005; 2016), Chicago (Tonietto et al. 2011; Lowenstein et al. 2014), New York City (Matteson et al. 2008; Matteson & Langellotto 2009), Phoenix (Cane et al. 2006), San Francisco (McFrederick & LeBuhn 2006), and St. Louis in the United States. Bees in these cities include both solitary and eusocial species, especially species that are cavity nesters and pollen generalists (Hernandez et al. 2009; Cariveau & Winfree 2015; Sirohi et al. 2015) and specialized species indicative of high-quality habitat (e.g., pollen specialists and their cleptoparasites) (Tonietto et al. 2011; Sheffield et al. 2013). In several cases, more diverse and abundant populations of native bees live in cities than in nearby rural landscapes (Cane et al. 2006; Matteson et al. 2008; Osborne et al. 2008; Frankie et al. 2009; Verboven et al. 2014; Baldock et al. 2015; Sirohi et al. 2015) (for counter examples, see Bates et al. [2011], Geslin et al. [2013], and Deguines et al. [2016]). For bumblebees in particular, urban areas can harbor greater species richness than rural or natural areas (McFrederick & LeBuhn 2006; Winfree et al. 2007; Gunnarsson & Federsel 2014; Baldock et al. 2015). Cities often contain greater bee species diversity than expected under a traditional view of urban areas.

Loss of habitat has been a long-term contributor to pollinator declines (Goulson et al. 2008; Potts et al. 2010; Vanbergen et al. 2013; Harrison & Winfree 2015);

technological advances in agricultural efficiencies are increasingly homogenizing farmlands (Benton et al. 2003). Increasing losses of natural areas to farming expansion and transition of traditional agricultural lands to those less hospitable to pollinators (e.g., monoculture commodity crops or indoor livestock operations) mean there is less floral forage over shorter periods (Ollerton et al. 2014; Scheper et al. 2014). Habitat loss and homogenization, innovations in systemic pesticides and herbicides (chemicals applied to seed, absorbed by plants, and circulated throughout), and greater efficiency of chemical application have negatively affected wild pollinator populations in rural areas (Whitehorn et al. 2012; Simon-Delso et al. 2014; Goulson et al. 2015; van der Sluijs et al. 2015). Although the protection and restoration of undeveloped lands are important for conservation of wild pollinators and serve an obvious role in pollinator health (species diversity and abundance), urban landscapes must not be overlooked as habitat for pollinators. Surrounded by increasingly less hospitable rural and suburban landscapes, the city, with its variety of forage and nesting sites, can become a refuge for insect pollinators.

Advances in pollinator conservation in rural landscapes are proliferating across governance scales (President's Task Force Strategy on Pollinator Health of 2015, Xerces Society, Pollinator Partnership, Intergovernmental Platform on Biodiversity & Ecosystem Services review, National Pollinator Strategy for England 2015; All-Ireland Pollinator Plan; Wales Pollinator Action Plan, and others), but only a few governments are targeting urban landscapes and funding such efforts (Natural Environment Research Council, Welsh Action Plan for Pollinators, Living with Environmental Change Partnership; Urban Pollinators Project). As urban ecology advances the science of ecology, the role of NRM agencies should similarly update their understanding of the role of cities in landscape-scale conservation (IPBES 2016). Engaging city planners and residents in enhancing habitat of insect pollinators is a legitimate conservation practice and has well-understood educational value. Implementing relevant programs requires collaborations and programing that change the view of cities as biological deserts to one of cities as valuable habitat for declining insect species.

This shift in perspective offers direct conservation benefits across a diversity of pollinator populations (cf. Kleijn et al. 2015) and provides ecosystem services for humans (e.g., pollination of vegetables and fruit and cultural services associated with an interest in natural history [e.g., Peterson et al. 2010]), plants (e.g., increased reproductive success), and animals (prey for species from higher trophic levels such as birds). Furthermore, improving the wild pollinator populations in urban areas may also improve species richness and abundance in nearby agricultural lands via a spillover effect (Goulson et al. 2010), although the relative importance of cites as sources or sinks for pollinators is largely unknown (Gill et al. 2016).

Intensifying conservation efforts for urban insect pollinators constitutes an opportunity for meaningful urban conservation—conservation that moves beyond traditional education and recreation programing toward programing with cascading benefits throughout rural and urban landscapes. Matching conservation planning to the ecological complexity of cities benefits NRM agencies because it provides more direct connections to their constituency in population centers (Sanderson & Huron 2011). Conservation *for* the city garners an audience for agencies' other conservation efforts and likely, favor at the ballot box.

Pollinators put high-priority and high-impact urban conservation within reach. The relatively small spatial and temporal scales of insect pollinators in terms of functional ecology (for example, habitat range, life cycle, and nesting behavior compared with larger mammals) offer opportunities for small actions to yield large benefits for pollinator health. The approach for improving the habitat value within urban areas is relatively simple and easily understood by urban residents. Several analyses and meta-analyses of urban insect pollinators show the consistent variable correlated with pollinator health is forage (i.e., the presence of flowers) (Bates et al. 2011; Hennig & Ghazoul 2012; Cariveau & Winfree 2015). These findings extend to forage species planted on urban vacant lands (Gardiner et al 2013), and these plantings have similar effects on specialist and generalist insect pollinators (Williams et al. 2010). Urban residential spaces play a role in pollinator abundance and diversity. Thus, individual decisions concerning yard management can affect conservation of threatened and endangered species (Goddard et al. 2010; Shwartz et al. 2013).

The city as refuge for insect pollinators opens many potential areas of research. Inventorying and monitoring is an essential practice to validate, improve, and communicate results of conservation efforts among partners and taxonomic experts. Understanding what works well in various locations engenders transferable practices that could aid decision makers across multiple scales of governance. More research is needed to evaluate the effectiveness of pollinator seed mixes (Garbuzov & Ratnieks 2014). However, bees and other insect pollinators benefit from both native and nonnative plants (e.g., Matteson & Langellotto 2011; Hanley et al. 2014; Pardee & Philpott 2014; da Silva Mouga et al. 2015), although for managerial purposes natives are preferred (Williams et al. 2011). Other underexplored topics include social dimensions of self-organizing neighbors who transform lawns (and their affiliated cultural models) to attract bees and butterflies for conservation (van Heezik et al. 2012) and the effectiveness of different citizen conservation activities (Asah & Blahna 2013). Legal, political, and institutional questions regarding public land use, planting decisions, institutional policies, organizational norms, and municipal ordinances that affect actors'

capacities to increase pollinator habitat also require further investigation.

Cities offer several advantages for exploring conservation practices, such as a lack of agriculture pesticides (Larson et al. 2013; Muratet & Fontaine 2015) (although home- and horticultural use of pesticides may be widespread) and few large herbivores (e.g., deer), factors that allow some sensitive plants to be grown. Restoration work is fostered by relevant institutions, resources (e.g., museum collections), expert personnel (e.g., staff at botanical gardens), and volunteers who can install and maintain restoration plantings. Many of these urban resources are absent in rural areas. Cities also have concentrations of philanthropic donors, funding resources, and development specialists who can mobilize resources for conservation projects.

Coupling insect-pollinator habitat enhancement with species monitoring is one of the goals of the long-term wild bee monitoring being conducted in Chicago, Illinois, Detroit, Michigan, and St. Louis, Missouri (U.S.A.) (Tonietto et al. 2011; Burr et al. 2016). These projects are exploring social and cultural drivers of wild bee diversity and abundance in green spaces across these cities. An increase in bee diversity in St. Louis seems to be associated with human population density and income. For example, bee diversity is higher in low-income neighborhoods with low population densities than in more densely populated high-income neighborhoods (Tonietto et al. 2011; Lowenstein et al. 2014). Low-income, less-populated areas contain more vacant lots and abandoned and crumbling infrastructure. Residential pesticide use is lower in low-income neighborhoods than in higher income areas (Cook et al. 2012). More research is needed to determine the relationships between bee diversity and patterns of residential land use across shrinking and growing cities. Partnerships among city planners, conservation scientists, and policy makers targeting pollinator conservation can improve local food security and community development. Improving global pollinator species diversity and abundance across landscapes requires attending to populations of urban pollinators.

Research on urban insect pollinators is changing how the biological value and ecological importance of cities is viewed. Conservation must be repositioned within this unfolding image of the city. Rather than treating urban conservation as solely outreach and education aimed to improve political capital, NRM agencies can develop programing that improves natural capital thereby engaging urban citizens in improving the quality of life for threatened species in cities. It is estimated that by 2050, 67% of the world's population will live in cities (United Nations 2014); much of these city landscapes have yet to be built (Grove et al. 2015). Attending to the needs of insect pollinators in conjunction with a suite of other conservation measures (e.g., green-infrastructure and environmental quality-of-life provision and climate-change mitigation) can inform current and future generations how to urbanize sustainably. To do so, requires an ecological understanding of the city and a requisite conservation that fits the city: conservation *for* the city.

Acknowledgments

We acknowledge E. Main, L. Mata, and the anonymous reviewers.

Literature Cited

Asah ST, Blahna DJ. 2013. Practical implications of understanding the influence of motivations on commitment to voluntary urban conservation stewardship. Conservation Biology **27:**866–875.

Baldock KCR, et al. 2015. Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proceedings of the Royal Society of London B: Biological Sciences **282** DOI: 10.1098/rspb.2014.2849.

Bates AJ, Sadler JP, Fairbrass AJ, Falk SJ, Hale JD, Matthews TJ. 2011. Changing bee and hoverfly pollinator assemblages along an urban-rural gradient. PLOS ONE **6** (e23459) DOI: http://dx.doi.org/10.1371/journal.pone.0023459.

Benton TG, Vickery JA, Wilson JD. 2003. Farmland biodiversity: Is habitat heterogeneity the key? Trends in Ecology & Evolution **18:**182–188.

Burr A, Schaeg N, Muñiz P, Camilo GR, Hall DM. 2016. Wild bees in the city: reimagining urban spaces for native bee health. Consilience: The Journal of Sustainable Development **16:**96–121.

Cane JH, Minckley RL, Kervin LJ, Roulston TAH, Williams NM. 2006. Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation. Ecological Applications **16:**632–644.

Cariveau D, Winfree R. 2015. Causes of variation in wild bee responses to anthropogenic drivers. Current Opinion in Insect Science **10:**104–109.

Collins SL, et al. 2010. An integrated conceptual framework for long-term social-ecological research. Frontiers in Ecology and the Environment **9:**351–357.

Cook EM, Hall SJ, Larson KL. 2012. Residential landscapes as social-ecological systems: a synthesis of multi-scalar interactions between people and their home environment. Urban Ecosystems **15:** 19–52.

da Silva Mouga DMD, Feretti V, de Sena JC, Warkentin M, dos Santos AKG, Ribeiro CL. 2015. Ornamental bee plants as foraging resources for urban bees in Southern Brazil. Agricultural Sciences **6:** 365–381.

Deguines N, Julliard R, Flores M, Fontaine C. 2016. Functional homogenization of flower visitor communities with urbanization. Ecology and Evolution **6:**1967–1976.

Ehrlich PR, Holdren JP. 1971. Impact of population growth. Science **171:**1212–1217.

Frankie GW, Guerrero SL, Pawelek JC, Thorp R, Schindler M, Coville RE, Rizzaesi MA, Guinon M. 2016. Bees, flowers, and people in urban–agricultural–wildland interfaces. Transactions of the North American Wildlife and Natural Resources Management Conference **80:**1–9.

Frankie GW, Thorp RW, Schindler M, Hernandez J, Ertter B, Rizzardi M. 2005. Ecological patterns of bees and their host ornamental flowers in two northern California cities. Journal of the Kansas Entomological Society **78:**227–246.

Frankie GW, Thorpe RW, Hernandez J, Rizzardi M, Ertter B, Pawelek JC, Witt SL, Schindler M, Coville R, Wojick VA. 2009. Native bees are a rich natural resource in urban California gardens. California Agriculture **63:**113–120.

Frankie GW, Vinson SB, Rizzardi MA, Griswold TL, Coville RE, Grayum MH, Martinez LES, Foltz-Sweat J, Pawelek JC. 2013. Relationships of bees to host ornamental and weedy flowers in urban northwestern Guanacaste Province, Costa Rica. Journal of Kansas Entomological Society **86:**325–351.

Garbuzov M, Ratnieks FL. 2014. Listmania: the strengths and weaknesses of lists of garden plants to help pollinators. BioScience **64:**1019–1026.

Gardiner MM, Burkman CE, Prajzner SP. 2013. The value of urban vacant land to support arthropod biodiversity and ecosystem services. Environmental Entomology **42:**1123–1136.

Geslin B, Gauzens B, Thébault E, Dajoz I. 2013. Plant pollinator networks along a gradient of urbanisation. PLOS ONE **8** (e63421) DOI: http://dx.doi.org/10.1371/journal.pone.0063421.

Gill RJ, et al. 2016. Protecting an ecosystem service: approaches to understanding and mitigating threats to wild insect pollinators. Advances in Ecological Research **54:**135–206.

Goddard MA, Dougill AJ, Benton TG. 2010. Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution **25:**90–98.

Goulson D, Lepais O, O'Connor S, Osborne JL, Sanderson RA, Cussans J, Goffe L, Darvill B. 2010. Effects of land use at a landscape scale on bumblebee nest density and survival. Journal of Applied Ecology **47:**1207–1215.

Goulson D, Lye GC, Darvill B. 2008. Decline and conservation of bumble bees. Annual Review of Entomology **53:**191–208.

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

Grove JM, Cadenasso ML, Pickett STA, Machlis GE, Burch Jr. WR. 2015. The Baltimore school of urban ecology: space, scale, and time for the study of cities. Yale University Press, New Haven, Connecticut.

Gunnarsson B, Federsel LM. 2014. Bumblebees in the city: abundance, species richness and diversity in two urban habitats. Journal of Insect Conservation **18:**1185–1191.

Hanley ME, Awbi AJ, Franco M. 2014. Going native? Flower use by bumblebees in English urban gardens. Annals of Botany **113:**799–806.

Hansen AJ, Knight RL, Marzluff JM, Powell S, Brown K, Gude PH, Jones K. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications **15:**1893–1905.

Harrison T, Winfree R. 2015. Urban drivers of plant–pollinator interactions. Functional Ecology **29:**879–888.

Hennig EI, Ghazoul J. 2012. Pollinating animals in the urban environment. Urban Ecosystems **15:**149–166.

Hernandez JL, Frankie GW, Thorp RW. 2009. Ecology of urban bees: a review of current knowledge and directions for future study. Cities and the Environment **2:**3.

IPBES (Intergovernmental Platform on Biodiversity and Ecosystem Services). 2016. Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. IPBES, Bonn, Germany.

Jaffe R, et al. 2010. Estimating the density of honeybee colonies across their natural range to fill the gap in pollinator decline censuses. Conservation Biology **24:**583–593.

Kleijn D, et al. 2015. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications **6** DOI: 10.1038/ncomms8414.

Larson JL, Redmond CT, Potter DA. 2013. Assessing insecticide hazard to bumble bees foraging on flowering weeds in treated lawns. PLOS ONE **8** (e66375) DOI: http://dx.doi.org/10.1371/journal.pone.0066375.

Lowenstein DM, Matteson KC, Xiao I, Silva AM, Minor ES. 2014. Humans, bees, and pollination services in the city: the case of Chicago, IL (USA). Biodiversity and Conservation **23:**2857–2874.

Luck GW. 2007. A review of the relationships between human population density and biodiversity. Biological Reviews **82:**607–645.

Matteson KC, Ascher JS, Langellotto GA. 2008. Bee richness and abundance in New York City urban gardens. Annals of the Entomological Society of America **101:**140–150.

Matteson KC, Langellotto GA. 2009. Bumble bee abundance in New York City community gardens: implications for urban agriculture. Cities and the Environment **2:**5.

Matteson KC, Langellotto GA. 2011. Small scale additions of native plants fail to increase beneficial insect richness in urban gardens. Insect Conservation and Diversity **4:**89–98.

McCleery RA, Moorman CE, Peterson MN. 2014. Urban wildlife conservation: theory and practice. Springer, New York.

McFrederick QS, LeBuhn G. 2006. Are urban parks refuges for bumble bees *Bombus spp*. (Hymenoptera: Apidae)? Biological Conservation **129:**372–382.

McKinney ML. 2008. Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems **11:**161–176.

McKinney ML, Schoch RM, Yonavjak L. 2003. Environmental science: systems and solutions. Jones & Bartlett Learning, Burlington, Massachusetts.

Muratet A, Fontaine B. 2015. Contrasting impacts of pesticides on butterflies and bumblebees in private gardens in France. Biological Conservation **182:**148–154.

Ollerton J, Erenler H, Edwards M, Crockett R. 2014. Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science **346:**1360–1362.

Osborne JL, Martin AP, Shortall CR, Todd AD, Goulson D, Knight ME, Hale RJ, Sanderson RA. 2008. Quantifying and comparing bumblebee nest densities in gardens and countryside habitats. Journal of Applied Ecology **45:**784–792.

Pardee GL, Philpott SM. 2014. Native plants are the bee's knees: local and landscape predictors of bee richness and abundance in backyard gardens. Urban Ecosystems **17:**641–659.

Pejchar L, Morgan PM, Caldwell MR, Palmer C, Daily GC. 2007. Evaluating the potential for conservation development: biophysical, economic, and institutional perspectives. Conservation Biology **21:**69–78.

Peterson MJ, Hall DM, Feldpausch AM, Peterson TR. 2010. Obscuring ecosystem function with application of the ecosystem services concept. Conservation Biology **24:**113–119.

Pickett STA, Parker VT, Fiedler PL. 1992. The new paradigm in ecology: implications for conservation biology above the species level. Pages 65–68 in Fielder PL, Jain SK, editors. Conservation biology: the theory and practice of nature conservation preservation and management. Springer, New York, New York.

Pleasants JM, Oberhauser KS. 2013. Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population. Insect Conservation and Diversity **6:**135–144.

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. 2010. Global pollinator declines: trends, impacts and drivers. Trends in Ecology & Evolution **25:**345–353.

Ramalho CE, Hobbs RJ. 2012. Time for a change: dynamic urban ecology. Trends in Ecology & Evolution **27:**179–188.

Sanderson EW, Huron A. 2011. Conservation in the city. Conservation Biology **25:**421–423.

Saure C, Burger F, Dathe HH. 1998. Die Bienenarten von Brandenburg und Berlin (Hym. Apidae). Entomologische Nachrichten und Berichte **42:**155–166.

Scheper J, Reemer M, van Kats R, Ozinga WA, van der Linden GTJ, Schaminée JHJ, Siepel H, Kleijn D. 2014. Museum specimens reveal

loss of pollen host plants as key factor driving wild bee decline in The Netherlands. Proceedings of the National Academy of Sciences of the United States of America **111:**17552–17557.

Sheffield CS, Pindar A, Packer L, Kevan PG. 2013. The potential of cleptoparasitic bees as indicator taxa for assessing bee communities. Apidologie **44:**501–510.

Shwartz A, Muratet A, Simon L, Julliard R. 2013. Local and management variables outweigh landscape effects in enhancing the diversity of different taxa in a big metropolis. Biological Conservation **157:**285–292.

Simon-Delso N, et al. 2014. Systemic insecticides (neonicotinoids and fipronil): trends, uses, mode of action and metabolites. Environmental Science and Pollution Research **22:**5–34.

Sirohi MH, Jackson J, Edwards M, Ollerton J. 2015. Diversity and abundance of solitary and primitively eusocial bees in an urban centre: a case study from Northampton (England). Journal of Insect Conservation **19:**487–500.

Threlfall CG, Walker K, Williams NSG, Hahs AK, Mata L, Stork N, Livesley SJ. 2015. The conservation value of urban green space habitats for Australian native bee communities. Biological Conservation **187:**240–248.

Tommasi D, Miro A, Higo HA, Winston ML. 2004. Bee diversity and abundance in an urban setting. The Canadian Entomologist **136:**851–869.

Tonietto R, Fant J, Ascher J, Ellis K, Larkin D. 2011. A comparison of bee communities of Chicago green roofs, parks and prairies. Landscape and Urban Planning **103:**102–108.

United Nations. 2014. Our urbanizing world. Populations facts. UN Department of Economic and Social Affairs, New York, New York. Available from http://www.un.org/en/development/desa/population/publications/pdf/popfacts/PopFacts_2014-3.pdf (accessed October 2015).

United States Fish & Wildlife Service (USFWS). 2015. Urban wildlife conservation program, United States. USFWS, Washington, D.C. Available from http://www.fws.gov/urban/index.php (accessed October 2016).

van der Sluijs JP, et al. 2015. Conclusions of the Worldwide Integrated Assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning. Environmental Science and Pollution Research **22:**148–154.

van Heezik YM, Dickinson KJM, Freeman C. 2012. Closing the gap: communicating to change gardening practices in support of native biodiversity in urban private gardens. Ecology and Society **17** DOI: 10.5751/ES-04712-170134.

Vanbergen AJ, et al. 2013. Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecology and the Environment **11:**251–259.

Verboven HAF, Uyttenbroeck R, Brys R, Hermy M. 2014. Different responses of bees and hoverflies to land use in an urban-rural gradient show the importance of the nature of the rural land use. Landscape and Urban Planning **126:**31–41.

Whitehorn PR, O'Connor S, Wackers FL, Goulson D. 2012. Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science **336:**351–352.

Williams NM, Cariveau D, Winfree R, Kremen C. 2011. Bees in disturbed habitats use, but do not prefer, alien plants. Basic and Applied Ecology **12:**332–341.

Williams NM, Crone EE, Roulston TAH, Minckley RL, Packer L, Potts SG. 2010. Ecological and life-history traits predict bee species responses to environmental disturbances. Biological Conservation **143:**2280–2291.

Winfree R, Williams NM, Dushoff J, Kremen C. 2007. Native bees provide insurance against ongoing honey bee losses. Ecology Letters **10:**1105–1113.