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Abstract:

Urban ecology research is changing how we view the biological value and ecological importance of cities. Lagging behind this revised image of the city are natural resource management agencies' urban conservation programs that historically have invested in education and outreach rather than programs designed to achieve high-priority species conservation results. This essay synthesizes research on urban bee species diversity and abundance to suggest how urban conservation can be repositioned to better align with a newly unfolding image of urban landscapes. 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 while exploring more sustainable practices of urbanization.

Keywords:
Urban ecology, Pollinator, Insects < Animals, Communications, Conservation planning, Governance, Funding and philanthropy, Politics and policy

Natural resource management[1] (NRM) investments in urban conservation programming are largely aimed at connecting people to nature, rather than efforts believed to achieve high conservation impact. Historically, urban conservation directives have sought to garner broad public support by funding outreach, recreation facilities, and education rather than high-priority conservation outcomes (USFWS, 2015; McCleery, et al. 2014). Cities are viewed first in terms of their political value (where the voters are) rather than for the ecological values they may possess. The inherited historical view by general publics that urban environments are "biological deserts" seems reasonable as research has shown how sprawling urban development is responsible for high extinction rates (Luck 2007; McKinney & Schoch 2003: 298; McKinney 2008), extensive and persistent losses of native species (Hansen et al. 2005; Pickett et al. 1992) via large-scale transformation of landscapes (Ehrlich & Holdern 1971; Pejchar et al. 2007). However, urban ecology routinely necessitates re-assessing established ideas in biophysical ecology (e.g., linear responses of biodiversity to habitat destruction; Ramalho & Hobbs 2012; Collins et al. 2010; Grove et al. 2015) and advances in this field are transforming how we understand the ecological importance of our cities.

Such is the findings from the past decade of research on wild bees in cities. In the midst of a "pollination crisis" where insect pollinator populations are experiencing significant declines (Goulson et al. 2015; Jaffe et al. 2010; Pleasants & Oberhauser 2013), studies of native bee richness and abundance indicate diverse communities of wild bees persisting 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 UK (Goulson et al. 2008; Baldock et al. 2015; Sirohi et al. 2015), Melbourne, Australia (Threfall et al. 2015), Guanacaste Province, Costa Rica (Frankie et al. 2013), Vancouver, Canada (Tommasi et al. 2004), and in the USA: Berkeley, CA (Frankie et al. 2005; 2016), Chicago, IL (Tonietto et al. 2011; Lowenstein et al. 2014), New York City, NY (Matteson et al. 2008; Matteson & Langellotto 2009), Phoenix, AZ (Cane et al. 2006), San

[1] We use "natural resource management" to broadly refer to nations' governing bodies responsible for wildlife and land management such as a nation's Ministry or Department of the Environment.

Francisco, CA (McFrederick & LeBuhn 2006), St. Louis, MO, and others. Bees found in these cities include both solitary and eusocial species, especially species that are cavity nesting and pollen generalists (Cariveau & Winfree 2015; Hernandez et al. 2009; Sirohi et al. 2015), even including specialized species indicative of high-quality habitat (e.g., pollen specialists and their cleptoparasites, Sheffield et al. 2013; Tonietto et al. 2011). In several cases, more diverse and abundant populations of native bees live in cities than in nearby rural landscapes (Baldock et al. 2015; Cane et al. 2006; Frankie et al., 2009; Matteson et al. 2008; Osborne et al. 2008; Verboven et al. 2014; Sirohi et al. 2015; for counter examples see Bates et al. 2011; Deguines et al. 2016; Geslin et al. 2013). For bumblebees in particular, urban areas can foster more species richness than rural or natural areas (Baldock et al. 2015; Gunnarsson & Federsel 2014; Winfree et al. 2007; McFrederick & LeBuhn 2006). Cities often contain greater bee species diversity than what would be expected from a more traditional viewpoint of urban areas.

Loss of habitat has been a long-term contributor to pollinator declines (Goulson et al. 2008; Harrison & Winfree 2015; Potts et al. 2010; Vanbergen 2013) while technological advances in agricultural efficiencies are increasingly homogenizing farmlands (Benton et al. 2003). Additional 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) provides less floral forage over shorter periods of time (Ollerton et al. 2014; Scheper et al. 2014). Habitat loss and homogenization coupled with innovations of systemic pesticides and herbicides along with greater efficiency of chemical application have negatively affected wild pollinator populations in rural areas (Goulson et al. 2015; van der Sluijs et al. 2015; Simon-Delso et al. 2014; Straub et al. 2016; Whitehorn et al. 2012). While the protection and restoration of undeveloped lands are important for wild pollinator conservation and serve an obvious role in pollinator health, urban landscapes must not be overlooked. Surrounded by increasingly less hospitable rural and suburban landscapes[2], the city, with its variety of forage and nesting sites, becomes a refuge for insect pollinators.

[2] Relatively little is known about how urbanization affects ecological networks, but a few studies have emerged recently. Gotlieb et al. (2011; Central Jordan Rift Valley, Israel) and Geslin et al. (2013; Paris, France) on plant-

Advances in pollinator conservation in rural landscapes are proliferating across governance scales (President's Task Force Strategy on Pollinator Health, 2015; Xerces Society; Pollinator Partnership, Intergovernmental Platform on Biodiversity & Ecosystem Services review, All-Ireland Pollinator Plan; Wales Pollinator Action Plan; others) but only a few governments are targeting urban landscapes and supporting these with funding (Natural Environment Research Council's National Pollinator Strategy for England 2015; Welsh Action Plan for Pollinators; Living with Environmental Change Partnership). 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 priorities (see IPBES 2016). Engaging city planners and residents in enhancing insect pollinator habitat is a legitimate conservation practice in addition to its well-understood educational value. Implementing relevant programs requires collaborations, partnerships, and programming that reimagine the ecological value of urban lands: from "biological deserts" to valuable habitat for declining insect species.

This approach offers direct conservation benefits across a diversity of pollinator populations (cf. Kleijn et al. 2015) and the associated benefits across ecosystem services for humans (e.g. pollination of vegetables and fruit, cultural services associated with an interest in natural history, Peterson et al. 2010, others), plants (e.g. increased reproductive success), and animals (prey for higher trophic level species such as birds). Further, improving the wild pollinator populations in urban areas improve richness and abundance in nearby agricultural lands (Samnegård et al. 2011) via a spill-over effect (Goulson et al. 2010) though 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

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pollinator networks showed that the network became simplified with increased urbanization levels. A similar conclusion was reached by Rodewald et al. (2014) on plant-bird networks in Ohio, USA. In contrast, Sirohi et al. (in prep.) and Baldock et al. (2015) found that networks of flower visitors and their forage plants were no less complex in urban compared to rural settings, though there were significant differences in network structure and specialization of plants and insects, which was related to the larger number of plants in urban areas. The number of published studies is currently too limited, however, to make generalizations about how urbanization might affect plant-pollinator networks.

programming towards programming with cascading benefits throughout rural and urban landscapes. Matching conservation planning to the complexity of the city benefits NRM agencies via more direct connections to their constituency in population centers (Sanderson and Huron 2013). Conservation *for* the city finds 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 (habitat range, lifecycle, nesting behavior compared with larger mammals for example) offer opportunities for small actions to yield large benefits for pollinator health (cf. Frankie et al. 2014). The approach for improving the habitat value within urban areas is relatively simple and easily understood by urban residents. Several analyses and meta-analysis of urban insect pollinators found the consistent variable correlated with pollinator health is diverse forage—the presence of flowers (Bates et al. 2011; Cariveau and Winfree 2015; Hennig and Ghazoul 2012). These findings extend to forage species planted on urban vacant lands (Gardiner et al 2013) and rural lands (Scheper et al. 2013) with 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 have implications for 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 and where is necessary for transferable practices across geographies which could aid decision makers across multiple scales. More research is needed to evaluate effectiveness of pollinator seed mixes (Garbuzov & Ratnieks 2014b), however, it is apparent that bees and other insect pollinators benefit from native and nonnative plants alike (da Silva Mouga 2015; Frankie et al. 2005; Hanley et al. 2014; Matteson & Langellotto 2011; Pardee & Philpott 2014), though for managerial purposes natives are preferred (Williams et al. 2011). Other underexplored areas include social dimensions of self-organizing neighbors transforming lawns (and their affiliated cultural models) to attract bees and butterflies for conservation (Lerman & Milam 2016; van Heezik et al. 2012) and the effectiveness of various models as conservation strategies (Asah & Blahna 2013). Legal, political, and institutional questions regarding public land-uses and planting decision making, as well as institutional policies, organizational norms, and municipal ordinances affecting various actors' capacities of increasing 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 and Fontaine 2015; even though "home" and horticultural pesticides may be widely used) and fewer large herbivores (e.g., deer) which 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 enhancements with long-term species monitoring is one of the goals of the long-term wild bee monitoring being conducted in Chicago, IL, Detroit, MI, and St. Louis, MO (Tonietto et al. 2011). These projects are exploring social and cultural drivers of wild bee diversity and abundance in a variety of green spaces across these cities. Bee diversity in St. Louis, MO, seems to be responding to a combination of population density and income. For example, in low-income neighborhoods with low population density, bee diversity is higher than in denser and higher income ones (similar findings in Lowenstein et al. 2014; Lowenstein & Minor 2016). Not surprisingly, low-income, less-populated areas contain more vacant lots, and abandoned and crumbling infrastructure. Residential pesticide use is also reduced in low-income neighborhoods compared to higher income areas (Cook et al. 2012). More research is needed to understand the relationships between bee diversity and patterns of residential land-uses across shrinking and growing cities. Partnerships among city planners, citizen groups, conservation scientists, and policy makers targeting pollinator conservation can improve local food security and community development. Improving global pollinator health across landscapes requires attending to populations of urban pollinators.

Research on urban insect pollinators is changing how we view the biological value and ecological importance of cities. Conservation must be repositioned within this newly unfolding image of the city. Rather than treating urban conservation as solely outreach and education aimed to improve political capital, NRM agencies can develop programming that improves natural capital thereby engaging urban citizens in improving the quality of life for threatened species living in cities. In 2050, it is estimated that 67% of the world's population will live in cities (UN 2014), much of these city landscapes have yet to be built (Grove et al. 2015). Attending to the conservation needs of insect pollinators among the suite of other green infrastructure, climate change adaptation, and environmental quality-of-life needs can inform current and future generations how to urbanize sustainably. To do so, requires an ecology *of* the city and its requisite conservation that fits the city: Conservation *for* the city.

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