Biodiversity in the city: key challenges for urban green space management

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Cities play important roles in the conservation of global biodiversity, particularly through the planning and management of urban green spaces (UGS). However, UGS management is subject to a complex assortment of interacting social, cultural, and economic factors, including governance, economics, social networks, multiple stakeholders, individual preferences, and social constraints. To help deliver more effective conservation outcomes in cities, we identify major challenges to managing biodiversity in UGS and important topics warranting further investigation. Biodiversity within UGS must be managed at multiple scales while accounting for various socioeconomic and cultural influences. Although the environmental consequences of management activities to enhance urban biodiversity are now beginning to be addressed, additional research and practical management strategies must be developed to balance human needs and perceptions while maintaining ecological processes.

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Urbanization poses one of the greatest threats to global biodiversity (Seto *et al.* 2012). Yet, surprisingly, cities can be critical for native biodiversity conservation (Ives *et al.* 2016), mainly through planning, conservation, and management of urban green spaces (UGS). These spaces include all-natural, semi-natural, and artificial ecological systems within and around a city (Cilliers *et al.* 2013) and comprise a range of habitat types from remnant patches of native vegetation, urban wastelands (ie brownfields, vacant lots), gardens, and yards, to highly engineered green infrastructure such as bioswales and green roofs (Figure 1). Despite common misconceptions that cities are species poor, new evidence suggests otherwise and that UGS are vital for supporting urban biodiversity (Aronson *et al.* 2014; Beninde *et al.* 2015; Ives *et al.* 2016).

In a nutshell:

- Urban green spaces (UGS) provide a range of benefits to humans and are important for biodiversity conservation
- Common management practices – such as maintenance of turf grass lawns, tree and shrub pruning, pesticide and herbicide applications, and introduction of non-native plant species – threaten the biodiversity of cities
- Socioeconomic and cultural dynamics, governed by multiple stakeholders, are important determinants of management decisions of UGS for biodiversity conservation
- A key challenge for UGS conservation, design, and management is balancing human perceptions, needs, and use with ecological requirements for preserving and enhancing biodiversity
- Research and collaboration among scientists and resource managers will enhance our ability to conserve and manage biodiversity in UGS

Given the various ecosystem services that they provide (eg Gómez-Baggethun *et al.* 2013), UGS have been integrated into urban planning and design, particularly in developed countries (Hansen *et al.* 2015). However, the roles of UGS in supporting biodiversity and the linkages among biodiversity, human health, and ecosystem function have so far received insufficient attention (Sandifer *et al.* 2015; Ziter 2016). As natural areas are rapidly converted to urban land cover, particularly in biodiversity hotspots (Seto *et al.* 2012), understanding the drivers of biodiversity in UGS is valuable to global biodiversity conservation. In particular, how UGS are managed at city, neighborhood, and parcel scales affects both their capacity to support biodiversity as well as their provision of critical ecosystem services.

The ability of UGS to support biodiversity varies with landscape configuration (ie patch size, shape, connectivity), biotic interactions, land-use history, human population density of the surrounding urban matrix, economic input, and management activities. The relative importance of these factors will differ according to the neighborhood, city, region, and taxa under study. Given the wide variety of potential uses of UGS, resource management in cities

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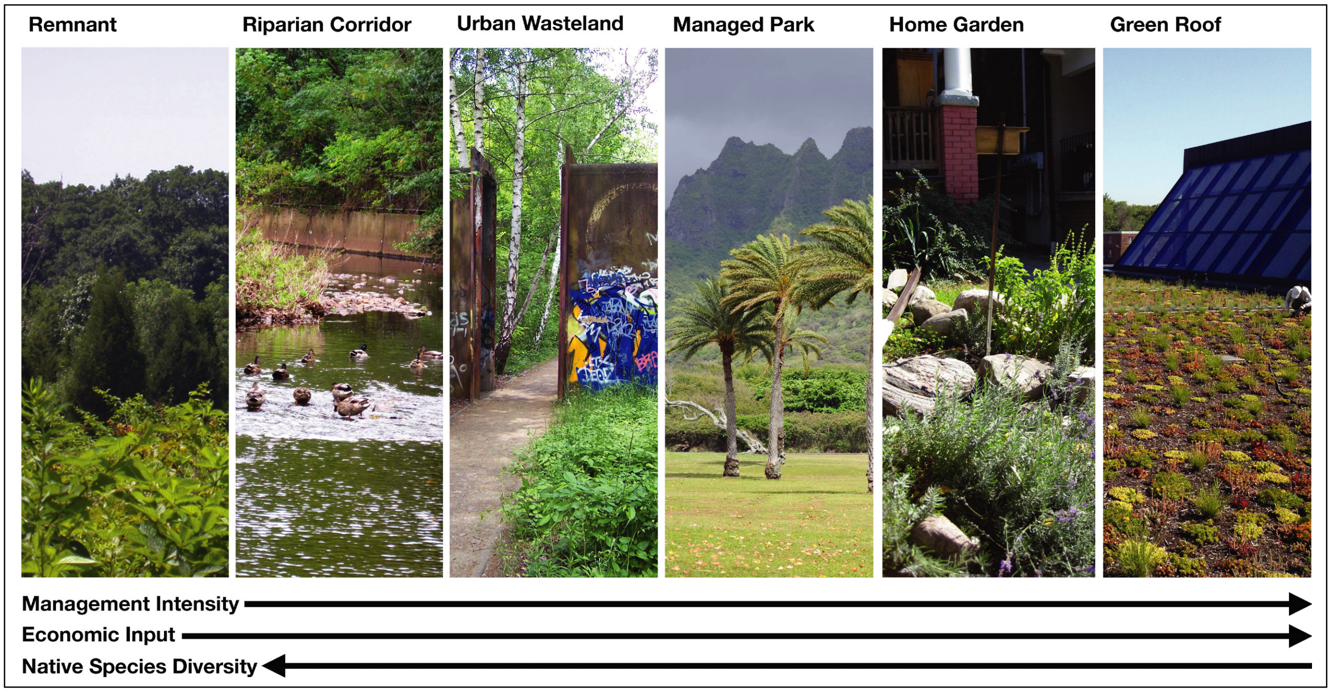

Figure 1. *Urban green spaces include a range of habitat types that cross a continuum from intact remnant patches of native vegetation to green infrastructure habitats such as green roofs. Often, economic input, population density, and management intensity follow this same gradient, with remnant habitats found at the edges of cities receiving the least management and costly green infrastructure found in the center of cities receiving the greatest management. Understanding the ecology of these green spaces individually and within a network is essential for biodiversity conservation.*

requires compromise and trade-offs between human use and biodiversity conservation (WebTable 1). For a range of different taxa, habitat quality varies not only among different types of UGS, according to their internal characteristics, surrounding land use, and connectedness to other UGS, but also within a specific UGS. Additionally, UGS design is often subject to competing or incompatible objectives, including biodiversity conservation, stormwater management, aesthetics, and human well-being. However, there is increasing interest in more holistic designs that address multiple factors (social, environmental, and economic) so that biodiversity is integrated into the desired functions (Lovell and Taylor 2013).

Addressing the issues unique to UGS management is of particular importance given the continued growth of urban areas, development of new cities, promotion of artificial ecological systems (eg green roofs), and that, to date, most UGS research has been conducted in cities distant from biodiversity hotspots. Management of UGS for biodiversity faces a series of challenges (Gaston *et al.* 2013), including involvement of multiple stakeholders (at the city scale) and the difficulties in understanding how socioeconomic and cultural factors influence landowner goals, values, and decision making (at the neighborhood and individual parcel scales). Without a wider understanding of and coordination at the neighborhood or city scale, common management practices at smaller scales can be largely incompatible with goals for supporting biodiversity. Our focus here is explicitly on managing existing UGS to maximize biodiversity, rather than addressing the land-sharing versus land-sparing debate in the context of urban growth. In particular, we identify four main challenges to managing biodiversity in cities and in each case discuss the multi-scalar properties of social and ecological trade-offs at city, neighborhood, and parcel scales.

Public and private green spaces are managed individually

One challenge prevalent in urban ecosystems is how best to harness the cumulative management activities of multiple land managers in a coordinated way. The spatial scale of such activities often does not match the scale of ecological processes (Borgström *et al.* 2006) and many species depend on multiple habitat patches within the landscape to sustain populations. At the neighborhood scale, property ownership is often embedded in a matrix of multiple stakeholders (eg private residence, small business, public lands, educational and religious institutions), which can make common goals for green space management difficult to attain (Figure 2). Finding mutually agreeable management outcomes at local – and especially at landscape – scales becomes increasingly challenging as the number of stakeholders increases. In Leicester, UK, for instance, 80% of the city's green space is privately managed and 40% of this private land is the responsibility of 123,000 households (Gaston *et al.* 2013). This multitude of private landowners equates to the "tyranny of small decisions" (Odum 1982), whereby the consequences of household-scale management choices have maximized habitat heterogeneity at the parcel scale, to the potential detriment of species that require larger areas of contiguous habitat, which encompass the neighborhood scale.

Empirical studies are just beginning to determine the importance of managing yards at coarser scales within the urban landscape. For example, in the US city of Chicago, while individual yards managed in a wildlife-friendly manner were important for native bird richness, the aggregate effect of closely grouped yards was most significant for native bird conservation (Belaire *et al.* 2014). In other words, yard design and management decisions aggregated at neighborhood scales increased native bird diversity. While many adjacent landowners engage in similar green space and wildlife habitat maintenance on their properties (Goddard *et al.* 2013), most are unaware of how their management decisions affect biodiversity potential in neighboring yards and how to foster coordinated management across yards. A further understanding and promotion of how yards can support ecological processes at landscape scales will enhance biodiversity across the city.

In the case of large parks and other public UGS (>5 ha) that are managed by a single organization (eg a local government), land managers have the opportunity to coordinate activities within and across UGS. In practice, managers of large urban parks and reserves tend to behave like householders and maximize habitat diversity within their own patch. Most parks contain areas of amenity grassland, woodland, and wetland, and this provides habitat heterogeneity at the local (eg park) scale, but may not provide the large areas of contiguous habitat or connected habitats that are required to support large and mobile taxa. Instead, UGS need to be planned and managed within a common theme as part of a long-term, citywide green space strategy. Some models for city-wide strategies exist, but these have not been adapted generally. For instance, green space networks and greenways, such as those in Nanjing City, China (Jim and Chen 2003) and the West Midlands region of the UK (Box *et al.* 1994), may lead to the creation of a mosaic of "habitat zones" across a city, within which the management of UGS can maximize the coverage of a specific habitat type, including woodlands or wetlands (Goddard *et al.* 2010). This mosaic approach can also capitalize on economies of scale where management costs are decreased due to large areas of contiguous habitat. To achieve this holistic approach to urban biodiversity management will require better coordination within local governmental organizations and improved communication between the various stakeholders, including urban planners, ecologists, local green space managers, and community groups.

Figure 2. *The majority of UGS in cities are small, privately owned gardens and yards, exemplified here by allotment (community) gardens in Munich, Germany. These small parcels can be connected to natural areas and managed at the neighborhood scale to better support wildlife populations.*

To date, no single approach has served as a "magic bullet" for solving the multiple stakeholder problem, in part because issues differ based on governance structure, land tenure, and socioeconomics. However, there are good examples of how multiple stakeholders have been able to work together to manage UGS, such as the Milwaukee River Greenway, 355 ha (an area equivalent to Central Park in New York City) of riparian habitats composed of a mosaic of public and private land (http://riverrevitalizationfoundation.org/greenway). The Greenway is managed by a coalition of stakeholders, including the county and city of Milwaukee, homeowners associations, city and neighborhood NGOs, and a religious organization, all with the aims of creating and enhancing urban biodiversity and providing recreational opportunities to residents. The success of this coalition is primarily credited to their common resolve in protecting and restoring the river corridor, but this complex level of management requires substantial time and resources to coordinate. Future research to address this challenge includes understanding the metapopulation dynamics of multiple taxa in urban areas, promoting connections among multiple stakeholders, and finding a suite of tools that can lead to improved green spaces management across the city.

■ UGS management decisions are driven by various interacting economic, social, and cultural factors

Socioeconomic and cultural factors drive many aspects of green space management. Demonstrating a positive correlation between wealth (or indices of wealth) and biodiversity, the well-known "luxury effect" (Grove *et al.* 2014) has been found in an increasing number of cities around the world. For instance, in towns of the Eastern Cape, South Africa, street trees are more diverse in affluent areas (Kuruneri-Chitepo and Shackleton 2011) and in Phoenix, Arizona, higher-income neighborhoods support the greatest number of native lizard species (Ackley *et al.* 2015). The luxury effect is partly driven by a combination of positive associations among house prices, access to green space (Brander and Koetse 2011), and the ability of individual householders to buy plants and landscape their yards. That is, in many cities worldwide, individuals have varying degrees of ability to directly affect the green space on or near their home via habitat modification. In Tlokwe City Municipality, South Africa, plant diversity across the municipality increased with increasing socioeconomic status, driven by planting of non-native horticultural species in yards and gardens of landowners of higher socioeconomic status (Lubbe *et al.* 2010).

Although such patterns have been demonstrated across several cities, contrasting patterns do exist, making generalizations difficult. So, for instance, there is no strong relationship between socioeconomic status and the prevalence of wildlife-friendly features in gardens in Sheffield, UK (Gaston *et al.* 2007). Economic factors alone do not determine the distribution of biodiversity across urban areas. Negative relationships among biodiversity, access to green space, and occurrence of racial minorities have been documented in both northern and southern hemisphere cities, primarily driven by socioeconomics and segregation legacies (Perkins *et al.* 2004; Lubbe *et al.* 2010). Lifestyles and life stages, irrespective of income, are also important determinants of UGS management (Grove *et al.* 2014).

Household decision making regarding garden and yard management is complex. In many regions, cultural traditions drive garden management, such as the Tswana tshimo (home gardens) of the Batswana people in the North West province of South Africa; there, the area around the house is kept devoid of vegetation but other areas of the yard incorporate both native and non-native plants in medicinal and food gardens, in addition to a separate natural area garden (Lubbe *et al.* 2010). Human perceptions of nature also have a strong influence on behaviors associated with maintaining UGS (Clayton 2007). Aesthetics, safety, property values, and social pressures often drive management goals for both public and private UGS (Nassauer 1995). As a result, a mix of individual preferences and neighbor perceptions influences yard management (Goddard *et al.* 2013). These social pressures can lead to negative outcomes for biodiversity where harmful management practices are reinforced (eg use of lawn chemicals; Fraser *et al.* 2013) or positive outcomes where neighborhood mimicry results in diffusion of wildlife-friendly management practices (Goddard *et al.* 2013). The direction and extent to which these outcomes play out in different UGS is unknown but is likely to vary with sociodemographic and cultural contexts. Sustainable yard management practices that spread through social diffusion have the potential to foster ecological connections between private yards and gardens across landscape scales, maximizing biodiversity management at ecologically relevant scales. Local stewardship and other social organizations, such as homeowner and neighborhood associations, have the opportunity to influence and coordinate biodiversity-friendly management across yards (Lerman *et al.* 2012).

Ultimately, understanding how to incorporate the multiple factors associated with household and land manager decision making into tools to encourage biodiversity-friendly and cost-effective management is paramount for biodiversity conservation in cities. Financial rewards have been proposed, such as the Chicago Sustainable Backyards Program, which encourages biodiversity-friendly management including native tree planting and converting lawns to natural habitats by offering rebates on native plants. However, household interviews suggest financial rewards alone are unlikely to incentivize biodiversity-friendly management (Goddard *et al.* 2013). Citizen science also offers great potential for perpetuating improved biodiversity management across residential neighborhoods by establishing connections between urban residents and the scientific community. Participatory approaches that include and engage citizens and organizations in environmental justice and local knowledge can strengthen bottom-up approaches to biodiversity conservation and encourage municipalities to act.

Many pervasive management techniques are barriers to biodiversity conservation

Many common and widespread management practices are detrimental to conservation priorities that seek to improve urban biodiversity and ecological function. Understanding how biodiversity is affected by management activities across different UGS is an important unresolved question. Four green space management activities that have important implications for biodiversity include: (1) maintenance of turfgrass lawns; (2) removal of habitat, including pruning and leaf litter removal; (3) simplification of habitat structure; and (4) pesticide and herbicide applications.

Lawns are a ubiquitous feature of urban areas, comprising 70–75% of UGS worldwide (Ignatieva *et al.* 2015). The intensive management of vast swathes of lawn in yards, public parks, and road verges is a principal barrier (after habitat destruction) to biodiversity provision in urban landscapes worldwide. Research on turfgrass alternatives and understanding how different lawn mowing regimes (eg frequency, height) affect population dynamics and community structure could greatly enhance this ubiquitous type of green space for biodiversity (Smith *et al.* 2015). Although lawns are not all biodiversity "wastelands" (Panel 1), there is a growing realization that alternative management regimes can be both cost effective and more sustainable than monocultures of turf grass (Smetana and Crittenden 2014). For instance, the replacement of lawns and ornamental flower beds with "naturalistic" plantings or flower meadows is increasingly frequent throughout the UK (eg the London Olympic Park, http://bit.ly/2kPXheg). Experimental studies are now underway to quantify the potential biodiversity and ecosystem service benefits of urban flower meadows (eg the UK Urban Pollinators Project, http://bit.ly/2ldHiaG; Biodiversity and Ecosystem Service Sustainability (BESS) project, www.nerc-bess.net; Figure 3) and practices such as the restoration of native prairie vegetation along roadsides has been shown to increase bee species richness (Hopwood 2008). However, economic ramifications of new management approaches are poorly studied. This represents an important avenue for research as sharing information on the cost–benefits of alternative management activities with the full range of stakeholders is likely to help improve UGS management for biodiversity. Such analyses are particularly important over time spans relevant for management as improving habitats for biodiversity can be costly in the short term (eg where turfgrass is removed and flower seeds are sown) but ultimately result in conversion to habitats that require less annual maintenance and cost.

Alteration of habitat, by pruning and removing trees, shrubs, and leaf litter, dramatically simplifies the structure of UGS. Urban foresters often clear away dead wood for potential safety and aesthetic reasons, yet this negatively affects species that rely on coarse woody debris (eg woodpeckers; Kane *et al.* 2015). Studies that assess the impact of pruning and human risk trade-offs would improve current understanding of how human activities can work in concert with ecological processes. In areas of frequent human use, for example, risk mitigation must be prioritized over retaining wildlife habitat. However, selective pruning, rather than full tree removal, can reconcile management goals for human safety with wildlife habitat (Kane *et al.* 2015). Tools that help land managers assess risks, economic costs, and value for wildlife of pruning and woody plant removal would benefit both municipalities and biodiversity. In Gainesville, Florida, a small city of approximately 130,000 people, the 2007 pruning budget was US$240,270, which was the third most expensive and frequent UGS maintenance activity in the city (Escobedo and Seitz 2012).

Removal of leaf litter is another costly and common management activity (US$73,550 in Gainesville, FL; Escobedo and Seitz 2012) with negligible benefits to urban wildlife. While the direct impact of leaf blowers and seasonal raking has not been assessed to inform wildlife management, leaf litter provides essential resources for invertebrates and the ground foraging birds that consume them (Figure 4). In Australia, the presence of leaf litter increased bird species richness by more than 30% (Stagoll *et al.* 2010), in part because leaf litter supports a more diverse arthropod community. Identifying thresholds for management activities that benefit urban biodiversity and consider human acceptance of more natural-looking landscapes will help inform effective management practices of UGS, leading to richer wildlife communities.

Figure 3. *Alternative management regimes, such as conversion of lawns into (a) grassy meadows or (b) pollinator meadows, not only improve green spaces for biodiversity but also reduce annual maintenance activities and cost.*

The vegetation structure of UGS is often homogeneous, with short turfgrass lawns and tall trees, providing insufficient structural complexity in between. In contrast, complex and heterogeneous vegetation structure (eg mix of tall grasses, shrubs, and trees) promotes abundant and diverse insect and bird assemblages in UGS (Cook *et al.* 2012). Green spaces with such structural complexity support multiple taxa. For example, the golf courses, parks, and residential gardens of Melbourne, Australia, that retain a diversity of native species and understory vegetation structure have the greatest richness of birds and bats compared to UGS that do not retain vegetation structure (Threlfall *et al.* 2016). Although unkempt green spaces are unpopular among the public, given appropriate "cues

Figure 4. *Urban green spaces can support rich wildlife communities, but management activities are often at odds with wildlife needs, such as the removal of leaf litter. The presence of leaf litter is essential for foraging birds such as the Campo flicker* (Colaptes campestris)*, pictured here at Parque Natural Chico Mendes, Sorocaba, São Paulo, Brazil.*

to care" (Nassauer 1995), such as maintaining a short mown area around a longer patch of meadow, alternative management practices are more likely to be accepted and mimicked by householders and bring wide-ranging benefits to urban biodiversity (Hunter and Hunter 2008).

Although responsible for reductions in both target and non-target animal and plant species (eg Bertoncini *et al.* 2012; Muratet and Fontaine 2015), pesticides and herbicides continue to be widely used in public and private UGS. In Paris, France, untreated lawns had higher plant species richness, greater numbers of rare species, and more insect-pollinated species than pesticide-treated lawns (Bertoncini *et al.* 2012). Recent work suggests that urban bee and butterfly communities may be more vulnerable to pesticide and herbicide use than those in rural areas. When comparing rural and urban home gardens across France, Muratet and Fontaine (2015) found herbicides and insecticides reduced bumblebee and butterfly abundance, and this negative effect was greater in urban landscapes than rural ones. These results indicate that the population dynamics of pollinator communities are less resilient to chemical control of plants and insects in fragmented urban habitats. Few detailed studies have examined impacts related to the amount and type of chemical applications in urban areas, and more work is needed to educate all stakeholders on alternatives to chemical control.

UGS support novel plant and animal communities

In many contexts, UGS can be considered novel ecosystems because they house a mix of both native and non-native species. Vegetation composition has implications for plant and animal diversity, but the degree to which native versus non-native plant species influence population dynamics of higher trophic levels is known from only a few studies. The replacement of native plants with non-native ornamentals has the capacity to disrupt urban food webs, and UGS with native plants support a greater diversity of insects and, hence, insectivorous birds (Burghardt *et al.* 2009). For instance, using native plants in landscaping in suburban Pennsylvania resulted in significant increases in caterpillar density and diversity and greater insectivorous bird abundance, diversity, and number of breeding pairs (Burghardt *et al.* 2009). Similarly, using native plants in yards typically increases pollinator abundance and diversity (Salisbury *et al.* 2015). While more research is needed, available data suggest that landscaping UGS with native plants supports and enhances biodiversity (Pardee and Philpott 2014). However, in many countries, landscaping with non-native ornamental species is standard practice. Collaboration between ecologists and the landscape architecture and horticultural industries is vital to support biodiversity-friendly landscaping.

Although some argue for tolerance of non-native species in green spaces, as novel ecosystems are the "new ecological world order" (Hobbs *et al.* 2006), the science that underlies acceptance and what entails appropriate management targets and goals for these systems is lacking (Murcia *et al.* 2014). How many (if any) invasive species should we tolerate in UGS? Which non-native species are beneficial to urban biodiversity? How do ecological processes operate in novel plant communities? Finally, what are the costs of continual invasive plant removal and are there thresholds that balance invasive plant management with ecological function? For example, the New York City natural areas crew at Prospect Park, in Brooklyn, spent 43% of their time during 2010 removing invasive plants in previously restored areas of the park with no apparent biodiversity gain in response to removal (DiCicco 2014). To adequately address the above-mentioned questions, scientists must conduct research that provides a general understanding of how different management regimes affect patterns and processes within these novel ecosystems and their role in supporting urban biodiversity.

Conclusions

Ensuring the future of urban biodiversity will require effective management of plant and animal populations in UGS. The first step is to improve the biodiversity potential by enhancing habitat quality of existing UGS through coordinated and heterogeneous management of yards, neighborhoods, parks, and other urban natural areas. The cumulative impact of such management will necessarily scale up to create a network of high-quality UGS in which biodiversity can flourish. Ultimately, trade-offs will always exist between the amount and

Panel 1. Can lawns play a role in conserving urban biodiversity?

Because they are often intensively managed through frequent mowing or pesticide/herbicide applications, lawns are often assumed to have limited biodiversity. However, a substantial proportion of urban lawns do not receive intensive management, resulting in an unexpected amount of botanical diversity. For instance, 52 lawns in Sheffield, UK, were found to contain 159 plant species, 90% of which were native (Thompson *et al.* 2004); 100 lawns in Paris, France, included 79 plant species, 91% of which were native (Bertoncini *et al.* 2012). Outside of Europe, botanical diversity of urban lawns remains high, but is dominated by non-native species (primarily of European origin). In Christchurch, New Zealand, 127 species (87% non-native) were found in 327 lawns (Stewart *et al.* 2009) and in Santiago, Chile, 41 plant species (95% non-native) were found in 15 urban park lawns (Fischer *et al.* 2016). Some animal species, such as the American robin (*Turdus migratorius*), use lawns for foraging (Figure 5). Similarly, the native mason bee (*Osmia pumila*) obtains large quantities of pollen from the naturalized lawn colonizer *Trifolium repens* (MacIvor *et al.* 2014). Lawns also play critical roles in supporting important urban ecosystem services (sequestering carbon and nitrogen, reducing runoff, controlling erosion) as well as human well-being and connections to nature (Bertoncini *et al.* 2012). Contrary to the perception of some ecologists, lawns can therefore make a contribution to maintaining urban biodiversity, depending on management activities.

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Figure 5. *Depending on management techniques, lawns can play a role in urban biodiversity conservation and in fostering wider public interest in nature conservation. Many animal species, such as the American robin (*Turdus migratorius*), rely on lawns for foraging.*

connectivity of habitat provided by UGS and the pressure of human population growth.

Primary overarching issues for biodiversity planning and management are gaps between science and policy, local government access to research findings, and communication of research to stakeholders. To conserve biodiversity in UGS, diverse stakeholders – including ecologists, managers, developers, students, and citizens – should be encouraged to join in collaborative networks to share data, engage in interdisciplinary research, and discuss urban biodiversity management, design, and planning. Such networks include UrBioNet: A Global Network for Urban Biodiversity Research and Practice (http://urbionet.weebly.com) and URBIO – International Network for Urban Biodiversity and Design (www.urbionetwork.org). Furthermore, city-based scientific research requires dedicated funding mechanisms and should incorporate practitioner experience and knowledge.

By identifying four key challenges to maintaining biodiversity in green spaces within cities, we offer a research agenda to help implement more effective, biodiversity-friendly management strategies. Ultimately, biodiversity is fundamental to resilient cities and healthy citizens.

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