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ABSTRACT

Cities tend to be built in areas of high biodiversity, and the accelerating pace of urbanization threatens the persistence of many species and ecological communities globally. However, urban environments also offer unique prospects for biological conservation, with multiple benefits for humans and other species. We present seven ecological principles to conserve and increase the biodiversity of cities, using metaphors to bridge the gap between the languages of built-environment and conservation professionals. We draw upon John Ruskin's famous essay on the seven lamps of architecture, but more generally on the thinking of built-environment pioneers such as Patrick Geddes (1854–1932) who proposed a synoptic view of the urban environment that included humans and non-humans alike. To explain each principle or 'lamp' of urban biodiversity, we use an understanding from the built-environment disciplines as a base and demonstrate through metaphor that planning for the more-than-human does not require a conceptual leap. We conclude our discussion with ten practical strategies for turning on these lamps in cities. Urban planners, architects, landscape architects, engineers and other built-environmental professionals have a key role to play in a paradigm shift to plan for the more-than-human, because of their direct influence on the evolving urban environment. This essay is intended to increase dialogue between ecologists and members of these professions, and thus increase the biodiversity of cities around the world.

1. Introduction

As humans increasingly live in cities and chaotically dominate Earth's natural processes through planetary urbanization (Brenner, 2014), there is a need to inspire those who control and plan cities to

consider the more-than-human – the other species with which we share our urban spaces (Maller, 2018; Rupprecht, 2017). For urban citizens of the nineteenth century, acknowledging other species was a practical necessity given that much of life in cities was powered by animals (Atkins, 2012; Taylor, Butt, & Amati, 2017), while at various stages

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during the twentieth century, ecological considerations have inspired broader thinking about urban environments (Braun, 2005). Prominent applications of ecologically sensitive principles to spatial planning include Frederick Law Olmsted's design of urban parks in the USA (1863–1903) (Olmsted, 1997) and the combination of ecology with early town planning by Patrick Geddes (1915) to invent regional planning. The latter's ideas were interpreted and further elaborated by Jaqueline Tyrwhitt (1905–1983) (Tyrwhitt, 2015). More recent examples include designing with nature from Ian McHarg (1969), Anne Whiston-Spirm's (1984) visionary demonstration of the role of biota in place-making, and Jack Ahern's ABC model linking the abiotic, biotic and cultural functions of cities (Ahern, 2007). Modern planning approaches such as landscape urbanism, ecological urbanism and ecological landscape urbanism also highlight the importance of integrating nature and natural processes into city planning (Mostafavi & Doherty, 2016; Steiner, 2011; Waldheim, 2012).

The potential to consider the more-than-human has been a latent part of urbanization. Cities and towns were historically built in productive landscapes, with a range of natural resources available to support their human population (Luck, 2007). These landscapes also tended to support high levels of biodiversity (Ives et al., 2016; Kuhn, Brandl, & Klotz, 2004; Vačkář, Chobot, & Orlitová, 2012). A correlation between human-population density and biodiversity is still apparent today, with people preferentially settling in species-rich areas (Cincotta, Wisniewski, & Engelman, 2000; Luck, Ricketts, Daily, & Imhoff, 2004). Physical urbanization such as land-use change has likely caused the local extinction of thousands of species throughout human history, even without considering regional and planetary effects over the longer term. For example, McDonald, Kareiva, and Forman (2008) estimated that 420 species (8%) of those included on the IUCN Red List were threatened by urbanization, while a recent study of birds and plants from 54 cities around the world revealed substantial declines in the species richness of both groups following urban development (Aronson et al., 2014).

However, planetary urbanization and planning for the more-than-human may remain as abstract ideas, especially when compared to the day-to-day, mundane aspects of running a city's processes and negotiating land uses. In addition, much of planning theory privileges a human-centric view of the world, deepening the eco-social crisis at the heart of the Anthropocene (Houston, Hillier, MacCallum, Steele, & Byrne, 2017). In this article, we extend the work of Houston et al. (2017) to develop language about planning for the more-than-human through the use of metaphor, a well-known means of communicating and acquiring new abstract concepts (Jamrozik, Mcquire, Cardillo, & Chatterjee, 2016). In planning theory, metaphors have been used to analyze the uptake of abstract ideas such as complexity theory (Chettiparamb, 2006). Our aim is to use a set of relational metaphors to aid understanding and form a bridge between the lived experiences of urban decision-makers and the abstract idea of planning for the more-than-human, by providing a range of tools to increase biodiversity in urban environments. Each relational metaphor contains a target and a base, which share relations or systems of relations with each other (Jamrozik et al., 2016). For example, in the statement “the city is an organism”, the equipment for pumping and supplying water around the city (the base) shares the same set of relationships as the work of the circulatory system in a living creature (the target). In fact, some metaphors, such as those of the organism (sensu Clements, 1916), have separate but parallel histories in the planning and ecological literature.

Effectively incorporating and conserving biodiversity in urban landscapes requires input from a wide range of disciplines (Ahern, 2013). Built-environment professionals such as planners, architects, landscape architects and urban designers have a central role to play in the persistence of urban biodiversity because of their direct influence on the evolving form and fabric of the urban environment. While crossing boundaries is a challenge, a shared common language and world view are important first steps. The framework we apply to guide

our use of metaphors is drawn from the architectural critic John Ruskin (1819–1900) whose famous essay, *The Seven Lamps of Architecture*, associates each of seven lamps with a character and a principle to guide architectural practice (the lamps of sacrifice, truth, power, beauty, life, memory and obedience; Ruskin, 1849). Ruskin's essay is one of the foundational texts in modern architecture, acting as an inspiration for the Arts and Crafts Movement and forming the groundwork of an orthodoxy that persists today (Roberts, Hague, Roberts, & Punter, 2002). Ruskin's work has also had an important influence on the discipline of urban planning (e.g., Lang, 1993; Parker, 2004). Here, we present seven ecological lamps (or principles) as a series of targets to metaphorically bridge the human and the more-than-human in cities. We then describe how concepts from one or more built-environment disciplines form a base to understand the corresponding ecological principle or target.

2. The seven lamps of planning for biodiversity in the city

2.1. The first lamp: protection

The first principle or lamp of urban biodiversity is to identify and protect areas of high biodiversity (both current and potential) in and around cities (McKinney, 2002). While areas with lower biodiversity are also valuable, we cannot preserve everything in mixed-use urban landscapes and must focus in the first instance on areas where we have the most to lose (or the most to gain). It is rarely possible to recreate entire ecological communities or ecosystems once they are lost, and it is often more effective to keep existing biodiverse areas than to attempt to recreate them in the future (Jackson & Hobbs, 2009). Such areas may include patches of remnant vegetation, wetlands, drained lines and rocky outcrops, or larger green spaces containing varied habitat types with both amenity and biodiversity value (e.g., Bekessy et al., 2012; Threlfall et al., 2015). The valorization of remnant habitats supporting high biodiversity is analogous to the preservationist history in planning (Matless, 1998), which finds its contemporary expression in the work of civil society groups such as the National Trust (ICOMOS (International Council on Monuments and Sites), 1987; Table 1). Heritage sites can come from any period, including important sites for First Peoples, colonial buildings, or brutalist housing from the 1960s. In the same way, sites supporting high current or potential biodiversity may include

Table 1

The seven lamps of planning for biodiversity in the city (metaphorical targets), with analogous concepts from one or more built-environment disciplines (metaphorical bases).

Concepts (built-environment base)	The seven lamps (more-than-human target)
Heritage	
1a. Low-impact development	1b. Protection of remaining ecological assets and habitats
Mobility	
2a. Walkability	2b. Connectivity of biological populations and habitats
Heterophilia	
3a. Designing a wide typology of spaces	3b. Construction of diverse and complex habitats to attract or retain biodiversity
Integrated water management	
4a. Distributed and decentralized systems	4b. Cycles that mimic natural flows
Neighborhood theory	
5a. Biophilic urbanism	5b. Interactions within and between ecosystem elements
Health, safety and wellbeing of all people	
6a. Crime prevention through environmental design	6b. Benevolence of urban infrastructure to reduce negative impacts on biodiversity
Urban/industrial renewal	
7a. New urbanism	7b. Novelty of urban ecosystems and ecological communities

features that are relatively pristine (in an ecological sense), but also disturbed features such as golf courses, old quarries that have flooded to become wetlands, and areas of secondary forest.

2.2. *The second lamp: connectivity*

The second principle of urban biodiversity is to maintain or re-establish connectivity between areas of habitat to allow the movement of animals and the propagules of fungi and plants (spores, pollen and seeds) across the urban landscape (Kong, Yin, Nakagoshi, & Zong, 2010; Lapoint, Balkenhol, Hale, Sadler, & van der Ree, 2015). Such movement is important for the maintenance of genetic diversity and the long-term persistence of populations and diverse ecological communities (Epps et al., 2005; Saunders, Hobbs, & Margules, 1991). As adults, many animals move daily and/or seasonally between patchily distributed resources, while juveniles may disperse away from their natal site to establish new territories. The movement of individuals between discrete areas of habitat can help support viable metapopulations (groups of populations separated in space but linked by dispersal), rescue declining populations, and aid recolonization of vacant habitat (Ahern, 2013; Delaney, Riley, & Fisher, 2010; Vergnes, Kerbiriou, & Clergeau, 2013).

For built-environment professionals, connectivity is also considered essential for mobility and urban viability (Ewing & Cervero, 2010), but in a different way. When judging connectivity for non-human species, our moral motivations are framed in terms of population viability or its converse, local extinction. Urban planning was briefly used as a tool for supporting population viability in the 1920s, for example in France's experimental eugenic housing (Greene, 2012). However, when judging human connectivity now, our moral motivations are more usually associated with justice. The idea of 'rights to the city' (Harvey, 2003) is intimately connected to mobility (Cresswell, 2006). In cities that demonstrate inequitable access to certain areas – in the most extreme cases, gated communities alongside informal settlements – the equivalent of splitting contiguous habitat is known as 'splintering urbanism' (Graham & Marvin, 2001).

2.3. *The third lamp: construction*

The third principle of urban biodiversity is to construct ecological features that can provide habitat for a range of plant and animal species. Urban development can result in both an extensive loss of habitat and a reduction in habitat complexity for many species of flora and fauna (Alberti et al., 2003; Grimm et al., 2008; Luck & Smallbone, 2011; Paul & Meyer, 2001). The structural complexity of habitat encompasses vertical and horizontal features across space and time, and provides critical resources for organisms; even in human-altered landscapes, high structural diversity increases animal diversity (Tews et al., 2004). Consequently, to retain biodiversity, cities need to construct ecosystem components that enhance not just the number but also the diversity of spaces for species (Fig. 1a, b, h), including constructed habitat analogues such as green roofs and walls (Kattwinkel, Biedermann, & Kleyer, 2011; Lundholm & Richardson, 2010; Melles, Glenn, & Martin, 2003; Williams, Lundholm, & MacIvor, 2014). While construction, planning and design are core concerns for built environment professionals, the construction of ecological systems remains limited to a small part of the profession. Landscape architects integrate complexity in their constructions for the purposes of both layering and aesthetics (e.g., Hes & du Plessis, 2015), while planners improve the liveability of neighborhoods with long-term, multi-year plans in which elements of complexity gradually accumulate (Marshall & Bauer, 2013). This mirrors the approach of ecological restoration projects that start with key vegetation elements and the expectation that other elements of biodiversity will establish as the restored area ages (e.g., Zhang, Han, Huang, & Zou, 2013).

2.4. *The fourth lamp: cycles*

Water, nutrient and energy cycling are critical for sustaining ecosystem services and biodiversity; conversely, the ecosystem services these cycles provide (such as clean water and the removal of pollutants) depend on diverse biological communities (Andersson et al., 2014; Cardinale et al., 2012; Pataki et al., 2011). Ecosystem cycles are often dramatically altered in urban environments. For example, many cities are marked by an excess of water because impervious surfaces such as rooftops, paved roads and concrete footpaths generate large volumes of runoff after rainfall events. This water is then transported to local streams and other receiving waters via stormwater-drainage systems (Booth, Hartley, & Jackson, 2002; Imberger, Thompson, & Grace, 2011; Roy et al., 2014; Walsh et al., 2005), rather than being cycled back to the atmosphere via evapotranspiration after infiltration and storage in catchment soils (Walsh, Fletcher, & Burns, 2012). Urbanization also disrupts the cycling of organic matter in soils through the loss of topsoil during construction (Booth et al., 2002) and removal of grass clippings and leaves (Acosta, Faz, Martínez-Martínez, & Arocena, 2014; Craul, 1994). Managing biogeochemical cycles at the local scale to improve biodiversity in urban environments is consistent with the long history of considering urban metabolism in planning (Duvigneaud & Denayeyer-De Smet, 1977; Wolman, 1965). More recently, urban planning has moved towards decentralized, integrated management of waste, water and energy (Novotny, 2013), and from a linear to a circular urban metabolism (Kennedy, Cuddihy, & Engel-Yan, 2007; Kennedy, Pincetl, & Bunje, 2011).

2.5. *The fifth lamp: interactions*

Biological interactions including competition for resources, symbiosis, herbivory, predation, pollination and parasitism are important processes that shape the biodiversity of a given location. For example, strong predator-prey effects can influence the abundance, biomass and/or productivity of a species or functional group across multiple links in a food web (Pace, Cole, Carpenter, & Kitchell, 1999). Urbanization may disrupt interactions between species by reducing the abundance of top predators such as large mammalian carnivores, which in turn leads to an increase in the abundance of secondary, medium-sized predators (Ritchie & Johnson, 2009) and a resulting decrease in populations of primary predators and herbivores (Estes et al., 2011; Faeth, Warren, Shochat, & Marussich, 2005). Pollination of flowering plants is crucial for the maintenance of native plant diversity in cities and for the success of urban-farming initiatives such as private and community food gardens (Normandin, Vereecken, Buddle, & Fournier, 2017; Threlfall et al., 2015). A decline in the diversity and abundance of pollinators – including native bees, butterflies, wasps and nectar-feeding birds – across an urban landscape can lead to the local extinction of plant species that depend on these pollinators (Pauw, 2007; Pauw & Hawkins, 2011). In the built environment, planners have a long history of encouraging interactions between people in cities. These include design-based solutions, such as Jan Gehl's (2010) *Cities for People*. They also include long-standing recognition of the importance of key sites for human interaction, such as the street and the 'daily ballet' of informal random interaction that it supports (Jacobs, 1961).

2.6. *The sixth lamp: benevolence*

One often-overlooked aspect of urban ecology is the importance of a benevolent urban form. Urban infrastructure can have obvious adverse effects on biodiversity by increasing mortality (e.g., through wildlife-vehicle collisions, or birds striking the windows of buildings), but in many cases, negative impacts are more subtle. For example, artificial light at night can interfere with circadian rhythms, sleep patterns and navigation in animals (Gaston, Davies, Bennie, & Hopkins, 2012; Witherington, 1992) while urban noise can hinder their acoustic



Fig. 1. Examples of planning for biodiversity in the city. a) Time and space: Louis Le Roy's Eco-Cathedral project in Mildam, The Netherlands. b) Careful control: In Malmo, Sweden, new urban design succeeds in integrating natural systems into development. c) Designed replacement: The High Line project in New York. d) Visible care: At a grassland in Melbourne, Australia, a fragile remnant is protected through visibly valuing the site and inviting community access. e) Great artifice: This portion of the Cheonggyecheon creek was previously beneath a freeway but now sees daylight. f) On the rural edge: The new development of Kronsberg in Hannover, Germany, achieves its ecological goals in part by building at high density and including substantial green infrastructure, such as the green roofs pictured here. g) Catalyst: Derelict land planted with sunflowers in Melbourne, Australia, creates a space for intense engagement with nature in an otherwise hostile urban landscape. h) Urban style: A sophisticated appreciation of the possibilities of urban plantings is apparent in this streetscape from Barcelona, Spain.

communication (Brumm & Slabbekoorn, 2005; Parris & McCarthy, 2013; Parris, Velik-Lord, & North, 2009), with significant cumulative impacts (Halfwerk, Holleman, Lessells, & Slabbekoorn, 2011; Ogden, 2014; Rhodes et al., 2011). Although modern urban infrastructure strives to be environmentally friendly through improved energy and water efficiency, 'green' building codes do not necessarily consider or provide benefits for biodiversity (Kajikawa, Inoue, & Goh, 2011; Reed & Krajcinovic-Bilos, 2013).

Modifying current design practices and standards by incorporating

ecological knowledge and evidence can help mitigate impacts associated with the hostility of built structures. 'Softer' urban structures can provide, rather than restrict, habitat for animals and plants (Gunnell, Grabt, & Williams, 2012) while simple modifications to the windows of buildings can reduce bird strikes (Ogden, 2014). Similarly, built-environment professionals need to cater for the requirements of different groups in human society; for example, those who drive, those who walk and those with impaired mobility. At its broadest, such an appreciation engenders a call for "universal design" (Kose, 1998), yet this concept of

universalism does not currently include non-human species. On the other hand, the slow city movement has the benevolent aims of reducing car traffic and allowing more space in cities for pedestrians, bicyclists and nature (Cittaslow, 2016; Gehl, 2010).

2.7. The seventh lamp: novelty

Novel ecological communities and novel ecosystems are characterized by the presence of new combinations of native and exotic species, without historical analogue (Hobbs et al., 2006; Kowarik, 2011). For biodiversity to persist or increase in urban environments, areas supporting novel ecological communities need to be acknowledged as important habitats even though their abiotic and biotic conditions may differ from those of remnant ecosystems. Urban biodiversity exists not only in reserves and parks, but also in ecosystems such as private gardens, constructed wetlands, business parks, wastelands and post-industrial sites (Chester & Robson, 2013; Serret et al., 2014; Threlfall et al., 2016). While there are different cultural perceptions and levels of acceptance of these systems in different parts of the world, they are gaining increased recognition for the ecosystem services and biodiversity they can provide (Andersson et al., 2014; Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007). For example, post-industrial brownfield sites in Europe support biodiverse plant and animal communities, including rare species (Gardiner, Burkman, & Prajzner, 2013; Hartley, Dickinson, Riby, & Shutes, 2012; Kattwinkel et al., 2011). The pragmatic attitude towards novelty as the mixing of native and exotic built form without historical analogue is demonstrated by the cycles of reappraisal of the built environment and the general condition of postmodernity (Harvey, 1989; Venturi, Brown, & Izenour, 1972), which finds its expression in the commemoration of industrial landscapes such as waterfronts and factories in modern developments. This facilitates the combination of the remnant with the novel in cities, leading to a mix of historical buildings, inherited spatial structures and new constructions. In the absence of these elements, ‘traditions’ such as new urbanism are recreated from scratch (Leccese & McCormick, 2000).

3. Turning on the lamps

Here, we present ten practical actions to increase the biodiversity of cities. These actions cover a range of spatial and temporal scales, and involve planners, designers, landscape architects, engineers, landscape managers, regulators, naturalists, citizen scientists and the general public. Each action has the potential to ‘turn on’ multiple lamps and thus provide multiple biodiversity benefits in the urban landscape (Table 2).

3.1. Design to preserve features of high biodiversity

Preserving features of high biodiversity within the urban landscape, such as an area of remnant vegetation or a natural wetland, requires good planning and design as well as good management. The boundary

of a remnant habitat is the interface between the remnant and the larger urban environment; there are many ways to approach the design of this interface to actively maintain the biodiversity and ecosystem function of the feature of interest. For example, buffer plantings of native vegetation can reduce weed invasion into remnant woodlands and grasslands (Lunt & Morgan, 2000) and constructing roads and sidewalks to slope away from remnants can prevent the entry of stormwater runoff that carries weeds and nutrient pollution (Marshall, 2013; Williams, 2005). At a social level, urban-design guidelines should also encourage the local community to care for, value and engage with areas of high biodiversity (Marshall, 2013; Nassauer, 1995; Fig. 1d). On a larger spatial scale, guidelines such as the biodiversity-sensitive urban design protocol (BSUD) aim to create suburbs and precincts that will provide a net benefit for native species and ecosystems through the provision of essential habitat and food resources (Garrard, Bekessy, & van Wijnen, 2015; Garrard, Williams, Mata, Thomas, & Bekessy, 2018).

3.2. Preserve natural drainage lines (focus on the stream)

Low-impact development (LID) or Sustainable Urban Drainage Systems (SUDS) is increasingly being used to reduce the impacts of urban stormwater runoff on receiving aquatic ecosystems (Fletcher et al., 2015). The basic objective of LID is to replicate the hydrological conditions of the pre-developed landscape via dispersed retention systems (such as rainwater tanks and rain-gardens) and conservation of existing natural elements (Coffman & France, 2002; TRCA/CVCA (Toronto and Region Conservation Authority, Credit Valley Conservation Authority), 2010). However, achieving this at a scale that is sufficiently large to restore or protect the ecological structure and function of a stream has remained elusive, because of two underlying requirements (Dietz & Clausen, 2008; Roy et al., 2008; Roy et al., 2014).

First, the preservation of upland drainage lines (first-order streams) is required to allow natural drainage. This has only been realized in a few cases (e.g., the Village Homes development of Davis, California, and its descendants (Karvonen, 2011); Kronsberg Neighborhood near Hannover, Germany (Dagenais et al., 2011; Rumming, 2004; Fig.1f)), which have also been successful in other ways as the networks of linear parks formed by the drainage lines provide connected green space and promote local biodiversity (Coates, 2013; Dagenais, Paquette, Fuamba, & Thomas-Maret, 2011; Von Haaren & Reich, 2006). Second, drainage management that seeks to maintain pre-development water balance must become standard practice (Roy et al., 2008; Walsh, Fletcher, & Burns, 2012). This requires capture of stormwater near its source in storages large enough to mimic the pre-development soil storage capacity. Drainage design should of course ensure that stormwater exceeding the capacity of storages is conveyed safely to the reserved drainage lines (Walsh et al., 2016).

Table 2
Ten actions to light the lamps of planning for biodiversity in the city.

Action	1. Protection	2. Connectivity	3. Construction	4. Cycles	5. Interactions	6. Benevolence	7. Novelty
1. Design to preserve features of high biodiversity	X		X	X	X	X	
2. Preserve natural drainage lines (focus on the stream)	X	X	X	X	X	X	
3. Retain and use stormwater to enhance biodiversity	X			X		X	
4. Take advantage of urban turnover	X		X			X	X
5. Use temporary or neglected spaces				X	X		X
6. Engage the community	X			X	X	X	X
7. Coordinate public and private actions	X	X	X	X	X	X	X
8. Use carrots and sticks	X	X	X	X		X	
9. Incorporate biodiversity-sensitive practices into existing management			X	X	X		
10. Promote the “Green and Biodiverse City”	X	X	X			X	X

3.3. Retain and use stormwater to enhance biodiversity

The retention and use of runoff from impervious surfaces (building roofs and paved/sealed ground surfaces) to irrigate green spaces in cities is a relatively new and underutilized strategy (Walsh, Fletcher, & Burns, 2012). Collecting and redirecting urban runoff from small, impervious catchments into multiple locations nearby has a range of benefits in addition to a reduced volume of water feeding into the conventional stormwater system. These include urban cooling through greater evapotranspiration (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012), flood mitigation (Burns, Fletcher, Walsh, Ladson, & Hatt, 2012), the potential to increase biodiversity in parks, private gardens and other urban green spaces (Cook & Faeth, 2006; Katti et al., 2014), and the provision of refugia for biota vulnerable to drought or heat (Welbergen, Klose, Markus, & Eby, 2008). For example, irrigated (mesic) residential yards in Phoenix, Arizona support a greater diversity and abundance of arthropods than non-irrigated (xeric) residential yards, including detritivores, herbivores and predators (Cook & Faeth, 2006). A mosaic of irrigated and non-irrigated areas within a single park, across a neighborhood and throughout a city would provide a greater diversity and complexity of habitats, and thus support an increased diversity of fungi, plants, invertebrates and vertebrates (Cook & Faeth, 2006; Hahs & McDonnell, 2007; Katti et al., 2014; Newbound, McCarthy, & Lebel, 2010; Straka, Lentini, Lumsden, Wintle, & van der Ree, 2016).

3.4. Take advantage of urban turnover

There is debate in both the urban planning and ecological literature regarding the benefits of designing for biodiversity in new urban developments versus retro-fitting habitat spaces for biodiversity into existing urban areas (Dallimer et al., 2012; Dunham-Jones & Williamson, 2011; Lin & Fuller, 2013). The vision of a biodiverse city dovetails well with the creative architectural and planning process. Yet, cities are dynamic landscapes where development occurs on a daily basis. In the suburbs, densification or demolition and redevelopment are ongoing processes. Single-dwelling redevelopments (e.g., in which an existing house is demolished to make way for one or more new dwellings, often with a net loss of permeable surface and vegetation; Brunner & Cozens, 2012) have largely escaped the notice of urban planners and urban ecologists (Randolph & Freestone, 2012; Wiesel, Freestone, & Randolph, 2013). However, we must recognize that development occurring at any scale within the urban landscape can constitute a threat to biodiversity, or conversely provide an opportunity for biodiversity policy to intervene at the relevant regulation and approval point. Until now, most projects that have integrated biodiversity objectives into urban turnover have focused on large scale, industrial wasteland sites, such as Emscher Park in the Ruhr Valley (Pinch & Adams, 2013) or the Schöneberger Railway Park in Berlin (Kowarik & Langer, 2005). Similar, albeit smaller, opportunities need to be recognized and seized amongst the rapid turnover occurring in the suburbs of cities around the world.

3.5. Use temporary or neglected spaces

Opportunities for increasing biodiversity exist well beyond the creation of new, permanent urban green spaces such as parks. Many current practices introduce biodiversity either on a temporary basis (e.g., pop-up parks, derelict industrial areas; Fig. 1g), or into urban spaces not traditionally considered for greening (e.g., roofs and walls; Fig. 1f). These actions are not usually driven by a primary concern for biodiversity per se, but rather a desire to increase urban green cover for amenity or other functions such as water retention or urban cooling. However, these actions may also bring about biodiversity gains, if installations are designed using ecological principles (Williams, Lundholm, & MacIvor, 2014).

Temporary installations often require planning in conjunction with local authorities or developers, but are limited only by imagination. For instance, PARK(ing) Day, “an annual worldwide event where artists, designers and citizens transform metered parking spots into temporary public parks” (e.g., <http://www.dublinparkingday.org>), has taken off in many cities globally. Pop-up parks will be most beneficial when strategically located for high human use, while also catering for biodiversity by providing critical resources during times of the year when they are naturally limited (Hahs & McDonnell, 2014). Green roofs can also provide habitat for a wide range of native bee species that are themselves important pollinators, despite being more cryptic than the honey bee (e.g., Colla, Willis, & Packer, 2009; Tonietto, Fant, Ascher, Ellis, & Larkin, 2011).

3.6. Engage the community

Successful conservation of existing biodiversity and strategies to improve urban biodiversity rely on the involvement and support of local communities. Involvement may be reactive, in response to development that threatens biodiversity, or proactive, when communities become emotionally invested in biodiversity on a daily basis (e.g., Cooper, Dickinson, Phillips, & Bonney, 2007; Grant & Littlejohn, 2001; Standish, Hobbs, & Miller, 2013). Either mode of involvement may focus on a specific site, individual species, or suite of species that can galvanize the community into a cohesive, unified group. Some of the earliest examples of urban environmentalism were inspired by threats to biodiversity. For example, the proposed development of Kelly's Bush in Sydney in the 1970s led to calls for ‘Green Bans’ or environmental strikes to halt development (Iveson, 2014).

In contrast, a local community in Seattle, Washington worked to return salmon to the Pipers Creek watershed through proactive efforts involving more than \$2 million. After thousands of volunteer hours and more than 30 years of creek restoration, the salmon returned (Karvonen, 2011). Engagement around a focal species or site that is selected with ecological understanding can serve as an umbrella initiative, which also conserves or enhances less-emblematic elements of biodiversity that nonetheless provide essential ecosystem functions and services (Hahs & McDonnell, 2014). City dwellers around the world are also becoming increasingly engaged with nature in urban environments through citizen science, with the opportunity to survey and submit records of a wide range of taxa including birds, frogs, dolphins, insects and fungi. Many of these records are now freely accessible through databases such as the Global Biodiversity Information Facility (<https://www.gbif.org>).

3.7. Coordinate public and private actions

Most urban green space is under private ownership. Hence, to better promote urban biodiversity, public and private actions need to be well coordinated (e.g. Hostetler, Allen, & Meurk, 2011). The habitat value of private residential gardens can be improved by adding specific resources such as ponds, coarse woody debris, leaf litter, flowering shrubs and trees, tussock grasses and/or butterfly food plants (Gaston, Smith, Thompson, & Warren, 2005), while green roofs and green façades can be installed to increase available habitat area (Williams, Lundholm, & MacIvor, 2014). Educating residents about wildlife gardening practices such as plant selection to benefit local faunal biodiversity is a simple and effective tool (e.g., Barthel, 2005; Hostetler et al., 2011), as is the addition of refuges or artificial nest sites for birds, mammals and other groups as appropriate (e.g. Gaston et al., 2005). Coordinating wildlife gardening efforts between houses, or to complement government conservation actions in nearby natural areas, may provide greater biodiversity benefits at the neighborhood or landscape scale than isolated, individual gardens (Goddard, Dougill, & Benton, 2010).

3.8. Use carrots and sticks

Incentive schemes (carrots) and regulatory approaches (sticks) that aim to limit the loss of habitat and encourage restoration will promote the integration of biodiversity into future urban planning, landscape design and construction. Preservation of existing, biodiverse urban features requires strong regulation, as there are many powerful interest groups that could benefit from their destruction. The need for regulation is particularly urgent where there are cumulative impacts of multiple, small-scale losses (Bekessy et al., 2012; Garrard et al., 2015). Other incentive schemes apply nudge theory via the use of urban sustainability-rating systems. There are opportunities to incorporate biodiversity objectives into existing schemes and thus provide incentives for environmental actions. It will be challenging yet important for these to include consistent measures of biodiversity-related performance that are sufficiently detailed to capture important ecological processes, but simple enough to be used by non-experts.

3.9. Incorporate biodiversity-sensitive practices into existing management

Urban green spaces and aquatic systems require ongoing management for multiple purposes. One of the easiest and most cost-effective ways to switch on the lamps of biodiversity in the city is to subtly modify existing management practices for biodiversity gain (Rosenzweig, 2003). For example, altering the frequency and timing of mowing in public green spaces increases invertebrate diversity (Helden & Leather, 2004). Retaining, instead of removing, understorey vegetation, fallen branches and leaves promotes nutrient cycling and provides important habitat for a variety of flora and fauna (Imberger et al., 2011; Threlfall, Williams, Hahs, & Livesley, 2016). Ornamental wetlands can act as breeding habitat for native amphibians in urban parks and reserves. Vertical walls of concrete or stone lining a wetland may render it unsuitable for ground-dwelling amphibian species (Parris, 2006), but simply modifying the pond design by removing these walls can overcome the problem. Similarly, providing crevices within artificial seawalls increases inter-tidal habitat heterogeneity and thus the diversity of algal and sessile invertebrate communities, while still fulfilling the original design intent and structural role of these features (Chapman & Blockley, 2009).

3.10. Promote the “green and biodiverse city”

The rise of eco-tourism and green-liveability standards presents an economic business case to increase urban biodiversity. Cities around the world are leveraging the attractiveness of their landscape and green spaces to increase tourism, and to retain talented people and high-value, knowledge-intensive industries. Individual cities are seeking to brand themselves as icons of urban greenery and sustainability. For example, Singapore has marketed and reconfigured itself as “a city in a garden” to attract tourists and improve liveability (<https://www.nparks.gov.sg/about-us/city-in-a-garden>). Seattle, Washington (USA) has invented a new term to capture its nature appeal: Metronatural™ (Karvonen, 2010). In Europe, cities vie for the Green Capital Award, evaluated on twelve environmental indicators including ‘nature and biodiversity’ (<http://ec.europa.eu/environment/europeangreencapital/>). While the concept of biodiversity does not yet feature prominently in these green-image schemes, the appeal of green spaces and iconic natural phenomena in cities could be increased by the explicit inclusion – and marketing – of biodiversity.

4. Discussion: evidence of a paradigm shift in urban planning and design

More than a hundred years ago, Patrick Geddes used a map of the metropolis of London to compare its spreading form to a vast coral reef (Geddes, 1915). Amid its ‘stony skeleton’ could be found ‘living

polypes’. Corals rely on a symbiotic relationship between polyps and algae that allows them to survive and proliferate. In other words, if we are to extend this biological metaphor, we must broadly consider our symbiotic relations with non-human species in the construction of our cities. This paradigm shift is already underway at scales ranging from individual buildings to entire cities, and will only accelerate as citizens and city governments recognize the health, environmental, sustainability and financial benefits that urban biodiversity provides. We intend the present essay to further this acceleration by increasing understanding and dialogue between ecologists and practitioners of the urban form. Its novel theoretical contribution lies in its presentation of seven principles of planning for biodiversity in the city, linked through metaphors to existing concepts that are familiar to planners and other built-environment professionals. This use of metaphor highlights existing common ground and provides a language for future communication and collaborative, multidisciplinary action in the urban realm.

Perhaps the most obvious example of a movement to consider the more-than-human in cities is the widespread adoption of Sustainable Urban Drainage Systems (SUDS) (also known as Water Sensitive Urban Design (WSUD), and Low Impact Development (LID)) as cities around the world seek to improve the quality of receiving waters, promote localized cooling and reduce the costs of upgrading expensive sewer and stormwater systems (Fletcher et al., 2015; Walsh et al., 2016). Green roofs, walls and façades are also becoming increasingly prevalent, both as a vision of design practitioners and as a built reality. Although only a small proportion of these green-infrastructure features are explicitly designed to benefit biodiversity (Williams, Lundholm, & MacIvor, 2014), the normally barren roofs and walls of our cities have great potential to provide habitat for other species while also providing multiple additional benefits to humans (e.g., Berndtsson, 2010; Lee, Williams, Sargent, Farrell, & Williams, 2014; Mayrand & Clergeau, 2018; Sailor, 2008). Restoration of urban biodiversity is also being used as a strategy to make cities more resilient to threats from climate change, including extreme heat events and destructive storms (Abdollahi, Ning, & Appeaning, 2000; Bowler, Buyung-Ali, Knight, & Pullin, 2010). Many cities are seeking to increase the diversity of their urban forests and thus improve their resilience to pests, disease and climatic changes, while also expanding these forests to cool vulnerable neighborhoods and reduce the incidence of heat stress (C40 Cities Climate Leadership Group, 2014).

Urban residents generally respond positively to biodiversity restoration programs. Ambitious projects such the High Line and Brooklyn Bridge Park in New York (Fig. 1c) and the restoration of Cheonggyecheon Stream in Seoul (Fig. 1e) have captured the public imagination, attracting tens of thousands of local and international visitors annually while improving amenity, increasing local biodiversity and providing valuable ecosystem services. Importantly, such projects have also been an economic success, revitalizing neighborhoods and driving increases in property prices. And at the grass-roots level, there are many examples of residents embracing opportunities to expand the space for nature and enhance urban biodiversity, such as the Green Alleys (Ruelles Vertes) citizens' initiative in Montreal (www.eco-quartiers.org/ruelle_verte) and various wildlife-gardening programs run by local councils around Australia (Shaw, Miller, & Westcott, 2013).

The time is ripe for a movement that embraces biodiversity in the city – for the benefit of humans and non-humans alike. Urban planners, architects, landscape architects, engineers and urban designers have a key role to play in this movement, by working to turn on the seven lamps of planning for biodiversity in the city. Urban areas provide a multitude of opportunities for local conservation actions where people live and work (Miller & Hobbs, 2002; Snep, WallisDeVries, & Opdam, 2011). To realize these opportunities, we require better integration of planning and ecology in university curricula, for example through the inclusion of ecologists in studios and that of planners and designers in ecology classes, such that our future professionals become fully

bilingual. Also, we propose that ecologists be included in multi-disciplinary planning and design teams, to ensure that biodiversity will be considered alongside other values from the beginning of a project rather than as an afterthought. Multidisciplinarity has been a prerequisite for the successful integration of SUDS in urban planning (Dagenais et al., 2014; Fryd, Bergen Jensen, Toft, Jappesen, & Jacob, 2010), and so it is likely to be for biodiversity. We hope this essay provides a practical way forward to realizing this vision.

Declarations of interest

None.

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