Introduction: "Looking up" to Green Roofs to Understand Urban Biodiversity—A Decade On

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Background

A decade ago, the journal *Urban Habitats*—the precursor to *Urban Naturalist*—devoted a special issue to the topic of green roof biodiversity. At the time, green roof research was exclusive to some regions and not widely distributed, and the special issue was the first published in English that collected important ecological work on green roofs from around the world. The special issue has been widely read and attracted many new researchers to the study of green roofs, initiating a network of colleagues that today continues to push this exciting field forward.

In the last 10 years, green roof installations have increased around the world, with the term "green roof" joining the vernacular of the everyday citizen. In some cities, hundreds of green roofs have been constructed, many of which have been supported through municipal by-laws, construction standards, and incentives. A multi-pronged approach to encourage green roofs in cities integrates new and interesting design, ecosystem service delivery, and climate-change preparedness. Green roofs provide many benefits (Oberndorfer et al. 2007), and the original special issue in *Urban Habitats* was focused on the contribution of green roofs to habitat for local flora and fauna. Our aim in this special issue is to expand the conversation on green roofs as habitat, and call for prioritization of research that links green roofs, biodiversity, and conservation in cities.

Here we revisit the topics covered in the 6 papers included in the original special issue and introduce the 5 papers presented in this new special issue. In synthesizing knowledge of biodiversity on green roofs, we aspire to inform how plant communities and other design factors can be selected and maintained by planners and practitioners, and inspire new generations of scientists to pursue research that addresses complex environmental challenges that cities face today and tomorrow.

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“Frontiers in Green Roof Ecology”: A Decade Later

The articles presented in the original special issue have stimulated new research and nearly 1000 citations (Google Scholar, as of December 2017). In the most cited paper in the special issue, Brenneisen (2006) acknowledged that the spatial configuration of green roofs in cities presents an opportunity to connect potential habitats, and identified ways to encourage wildlife on green roofs through the addition of logs, large stones, and greater diversity in substrate mixtures and topography. These approaches have spurred research and green-roof applications in cities around the world, including incentives (SIA 312 “Begrünung von Dächern”, Switzerland) and best practices guidelines, such as those put forth by BugLife in London, UK, and the Guidelines for Biodiverse Green Roofs in Toronto, ON, Canada (Torrance et al. 2013).

In another highly cited paper, Kadas (2006) provided evidence for green roofs as habitat for invertebrates including rare spider and beetle species in London, UK. These findings have inspired entomologists to survey green roofs, leading to the discovery of many more rare species and unique communities (MacIvor and Lundholm 2011, Pétremand et al. 2017, Toneitto et al. 2012). These investigations provide insight into broader questions in ecology as green roofs are built from scratch (e.g., species assembly) and vertically isolated from ground level (e.g., fragmentation) (Braaker et al. 2014). Evaluating species recruitment and patterns in biodiversity following the installation of a new green roof can provide the foundation for advances in how we understand species conservation in urban environments (Rosenzweig 2016).

In this current special issue, 2 papers evaluate insects on green roofs. Starry et al. (2018) build on previous single-city studies by comparing beetle communities from green roofs in 4 cities across Europe and North America. Though a few globally ubiquitous species were identified, the authors found communities to be locally distinct. In a second article, Nagase et al. (2018) investigate how culturally significant green roof designs in Japan compare to biophilic ones and find the latter to be more biodiverse. Generalizations about how to support insects on green roofs are often made (MacIvor and Ksiazek 2015), but it is clear that local solutions are needed for designs that consider factors such as plant and substrate selection, the surrounding landscape, green-roof size, and other building characteristics (e.g., building height; MacIvor 2016).

Green roofs foster new habitat in cities in support of species conservation. In his paper, Grant (2006) described ways to support red-listed species on green roofs with a case study from London, UK, where replicating conditions of local brownfields onto green roofs promoted the preferred habitat of the *Phoenicurus ochruros* (S.G. Gmelin) (Black Redstart), a red-listed bird species that quickly took to green roofs designed this way. In contrast, Baumann (2006) showed that ground-nesting *Vanellus vanellus* (L.) (Northern Lapwing) select extensive green roofs as nesting substrates, but chicks perish due to shallow substrates of pumice and lava rock, and minimal vegetation that did not support the abundance of invertebrate prey needed to sustain them. This study provided limited evidence that green roofs could act as ecological traps; however, her team manipulated the roof design to improve conditions for the birds by adding organic substrate and vegetation to create habitat for insects, and places for water to accumulate. In just a few years, Baumann and Kasten (2010) documented the first successful fledglings, and this monitoring continues with further successes noted (N. Baumann, pers. observ.). The creation of habitat on green roofs is certainly a work in progress with many critical factors misunderstood (Williams et al. 2014). Green roofs as habitat for birds has received increasing attention, as birds are highly mobile and could either benefit from additional foraging or nesting sites, or be harmed due to green roof proximity to windows thereby increasing collisions (Fernandez-Canero et al. 2010). A need to understand how to successfully integrate bird habitat so as to avoid green roofs acting as ecological traps has instigated new and exciting research (Eakin et al. 2015, Washburn et al. 2016).

No 2 green roofs are the same, and a challenge for practitioners is to observe and interpret which environmental conditions define their project, and match these to local habitat condition from which they can select plants. In the original special issue, Lundholm (2006) introduced a conceptual framework for green-roof species selection in this manner, termed the "habitat template approach". His recommendation to use regionally appropriate native plant species on green roofs has led to the testing of many different plant communities found local to study sites (Aloisio et al. 2017, Benvenuti 2014, Dvorak and Volder 2010, Sutton et al. 2015). In this special issue, Lundholm and Walker (2018) revisit this approach and evaluate studies that have tested the concepts developed in the original paper. While the approach does not always deliver a list of species that will thrive on a green roof without further testing, experimental results with local plant species and their combinations have greatly expanded the number of publications on green-roof ecology and discussion on how green roofs contribute to urban habitat.

Many of the green roofs described in the original issue continue to be studied today. Long-term monitoring is critical as green roofs can persist over many decades with plant species recruitment and community composition changing through time (Köhler 2006, Rowe et al. 2011). These successional processes may have impacts on ecosystem functioning, and Köhler (2006) recommended that long-term surveys generate a better understanding of green roofs and are needed. Monitoring flora and fauna simultaneously on green roofs will yield further information on how they act as constructed ecosystems and deliver services that benefit the city (Williams et al. 2014). In the new special issue, Ksiazek-Mikenas et al. (2018) examine some of the same green roofs investigated by Köhler (2006) and, after establishing a chronosequence, find incremental additions in invertebrate species richness, but no other patterns, indicating the importance of being cautious when interpreting the contribution of green roofs over a single or a few seasons only. Green roofs are colonized spontaneously by many plant species (Nagase et al. 2013), some of which might enhance the stress tolerance of green roofs, or additional ecosystem services that could be promoted via adaptive green-roof management (Catalano et al. 2016). The height of green roofs from ground level does influence the spontaneous plant communities that colonize them, and in this special issue, McKinney and Sisco

(2018) show high rise buildings had similar numbers of colonizers—but different compositions—as low-rise buildings, and there were no life-history traits solely associated with either green roof type.

Green Roofs as "Designed Experiments": A Call for Research

As cities expand, so do the number of buildings onto which green roofs could be installed. Since green roofs are constructed from scratch and it is possible to manipulate design features for comparison between projects, several or more planned simultaneously represent potentially excellent opportunities for the development of "designed experiments" (Felson and Pickett 2005). Designed experiments integrate a systematic approach, involving replication and experimental controls, into design projects so that data is collected that supports both sustainable urban design and the advancement of ecological knowledge.

Box 1. Looking forward, these are key questions to address in the study of green-roof biodiversity.

1. As the number of green roofs increase in cities, does this reduce fragmentation between habitats (e.g., Braaker et al. 2014)?
2. Which functional traits are selected for among wildlife on green roofs and how can design influence food-web structure and stability?
3. How do interactions between plants and microbial and fungal communities in substrate alter ecosystem-service delivery (e.g., John et al. 2017)?
4. Which factors limit wildlife communities on green roofs, for example, drought conditions, green-roof size, quality of the surrounding ground-level landscape (e.g., Kyrö et al. 2017), or at which height are green roofs effectively vertically isolated (e.g., MacIvor 2016)?
5. Can green roofs act as ecological traps and contribute to reduced fitness of target wildlife? If so, how do practitioners avoid creating ecological traps?
6. How do adding microhabitat features, such as rocks and logs, contribute empirically to green-roof biodiversity?
7. At which scales can heterogeneity on green roofs (e.g., plantings, substrate) contribute to wildlife habitat?
8. Can green-roof biodiversity improve how people experience nature?
9. Does native vegetation and substrates on green roofs improve wildlife habitat?
10. To improve wildlife habitat on green roofs, how should ecologists be engaged in the planning, installation, and maintenance process?

Urban planners and practitioners can play a pivotal role in improving our understanding of urban ecological systems by partnering with scientists to initiate designed experiments. We call on all those involved in green-roof practice to consider how better communication and collaboration could lead to the coordinated design and evaluation of multiple green roofs within and across cities. Considering green roofs as designed experiments within an urban matrix offer highly suitable study sites for testing basic questions in ecological sciences. We conclude with an offering of 10 key questions in urban ecology that could be empirically evaluated with green roofs (Box 1), and urge ecologists to "look up" to green roofs for future research and partnerships that can shape the health and sustainability of future cities.

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