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If you build it, they will come: invertebrates on green roofs

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ABSTRACT

Since the industrial revolution, urban expansion has leapt forward and shows no sign of slowing (Horák et al., 2022; Shafique et al., 2018; Wang et al., 2022). This development has led to extensive loss and fracturing of habitat (Cameron et al., 2012; Horák et al., 2022; Parker & Zingoni de Baro, 2019). Retention of remnant vegetation is known to support functional urban ecosystems (Kabisch et al., 2017), therefore, the creation of new green spaces in cities could better support urban biodiversity (Cameron et al., 2012; Kabisch et al., 2017; Mathey et al., 2015; Parker & Zingoni de Baro, 2019). In addition to the ecological benefits that this brings, urban greenery has been seen to improve the mental and physical health of urban residents (Burley, 2018; Kabisch et al., 2017; Suppakittpaisarn et al., 2017; Tzoulas et al., 2007), but also provide community areas for recreation and exercise (Jim & Chen, 2006; Shafique et al., 2018).

Where ground-level space is unavailable or costly, green roofs can provide a unique solution to introducing greenery into urban areas (Cameron et al., 2012; Horák et al., 2022). While the concept of growing plants on roofs has a long history, the modern practice of installing green roofs has existed for less than 100 years (Wang et al., 2022). Here 'green roof' is used as a broad definition encompassing all forms of elevated vegetation built on the roofs of residential, industrial, or administrative buildings. Within the world of green roofs, they can be categorized many ways, such as by substrate depth, vegetation composition, or intended purpose (Chell et al., 2022; Dusza et al., 2020; Jacobs et al., 2022; Rumble et al., 2018; Schrader & Böning, 2006).

Green roofs as ecosystems have received little emphasis in the literature, as most research is focused on the design and construction aspects of green roofs (Dvorak & Volder, 2010; Scolaro & Ghisi, 2022; Shuraik et al., 2022). Other ecosystem contexts such as arid and tropical climates, and the paucity of research available, present an exciting prospect for developing a deeper understanding of how these built green environments can support urban biodiversity, and in particular invertebrates. A diverse array of invertebrates could provide myriad ecosystem services to green roofs (Braaker et al., 2017; Fabián et al., 2021; Gonsalves et al., 2022; Mathey et al., 2015; Shafique et al., 2018). Detritivore invertebrates like earthworms and beetles can catalyse soil nutrient cycles, increasing soil quality and subsequently plant health (Ganault et al., 2022; Santonja et al., 2018). Nectivorous and pollinator invertebrates like bees and butterflies can promote flower blooming and increase aesthetic value of a space (Katumo et al., 2022). Predatory invertebrates such as spiders and ladybeetles can control the populations of pest species (Fabián et al., 2021). In addition, these invertebrate communities can also form part of higher order ecological food chains, in particular insectivorous birds and microbats (Partridge & Clark, 2018).

The lack of green roof specific research in urban invertebrate ecology is a gap in the literature, and it is important to know exactly where the major gaps are before further investigation can take place.

Therefore, we completed a systematic quantitative literature review (SQLR) to identify these gaps, while simultaneously highlighting patterns and common findings in the current research.

Method

The method for this SQLR included the following search syntax: “('Green Roof*' OR 'Roof* Garden*' OR 'Sky Garden*') AND (‘Ecology’ OR ‘Invertebrate*’ OR ‘Arthropod*’ OR ‘Insect*’)”. This syntax was used to search the databases Scopus, Web of Science, and Greenfile. A total of 362 unique experimental articles were found, while were reduced to 34 after title, abstract, and full text screenings to articles specifically focussed on invertebrate ecology. Each of the final articles were analysed thoroughly for bibliographic data, location of experiments, experimental methods, and major findings including those related to building and roof design, immigration barriers, ecological drivers, and taxonomic makeup.

Key results

Articles were predominantly (~76%) of the studies were from temperate climates (as defined by Koppen Climate classification) with the majority from Western Europe or North-East of the United States of America. Continental climates (~21%) studies, and one study (~3%) took place in a tropical climate.
Control selection and sampling method varied, but the most common were comparison between green roofs and conventional roofs (~47% of studies), and pitfall and pan traps (~56% of studies).
There were three common findings across the literature:

1. **Green roofs are restricted from immigration by low mobility, species from nearby ground areas.** Related to this finding was the more frequent observation of substrate-nesting bees on green roofs compared to the ground. In addition, many studies reported that some species found on green roofs were not found at ground level.
2. **The higher diversity of plants installed on green roofs correlated with higher diversity of invertebrates.**
3. **Increased area and heterogeneity of green roof design correlated with increased invertebrate diversity.**

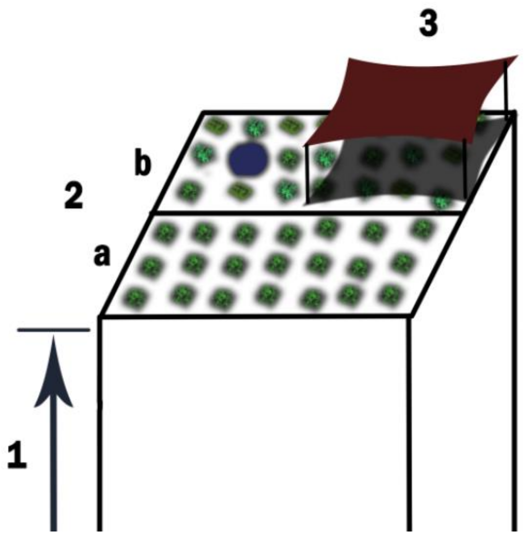

Figure 15 Examples of two green roofs (a and b) showing the main findings of the articles reviewed. 1. That green roofs are restricted from immigration by low mobility species from nearby ground areas. 2. That increased diversity of plants installed on green roofs correlated with higher diversity of invertebrates. And 3. That increased area and heterogeneity of green roof design correlated with increased invertebrate diversity. In this case, roof a. would be presumed to have a lower level of invertebrate diversity compared to roof b, which has a wider variety of plants, and examples of heterogeneous design such as a small pond and shade cloth.

Discussion

Green roofs are more costly than conventional, unvegetated roofs. This cost is the most likely reason that most of the research into invertebrate ecology on green roofs is concentrated in the wealthier parts of Europe and North America. Invertebrate populations on green roofs in arid, monsoonal, rainforest, and even subarctic regions have not been significantly reported on. It is likely that these populations, especially in monsoonal areas, will have vastly different ecosystems from those in more moderate climates (Wang et al., 2017).

Immigration restriction

The restriction of immigration paths to green roofs from ground areas for invertebrates is one of the most common findings throughout the literature reviewed (Braaker et al., 2014; Dromgold et al., 2020; Gonsalves et al., 2022; Jacobs et al., 2022; Kyrö et al., 2018; MacIvor & Lundholm, 2011; Madre et al., 2013; Tonietto et al., 2011). Advantaging more mobile invertebrates can lead to vastly different population ratios on roofs compared to the ground. The primary factor in this barrier being the elevation, but another being the lack of vegetation on the walls that an invertebrate must scale. While the latter could be altered with green walls or garden beds that act like steppingstones, this may not entirely erase the effect of the elevation (Tonietto et al. 2011). This effect being primarily the formation of less diverse assemblages of invertebrates on those green roofs (Dromgold et al. 2020, Fabián et al. 2021, Lin & Chen 2022, and Wooster et al. 2022).

One interesting effect of this barrier was observed by Braaker et al. (2017), Passaseo et al. (2020), and Tonietto et al. (2011). These three articles found substrate-nesting bees to be present at a greater proportion on green roofs than on the ground level. The more well-known cavity-nesting bees were found at similar levels on green roofs as compared to the ground. Substrate-nesting bees are just as mobile at their cavity-nesting cousins and can quickly surmount the elevational barrier provided by green roofs. This allows them to quickly establish a foothold in that green roof habitat, compared to less-mobile substrate-nesting species, which struggle to scale the walls. There are most likely many other population differences on green roofs compared to the ground that were unable to be identified by these papers.

The presence of invertebrate species on roofs that are not present on the ground prompts the question of how they arrived there if not from the ground. There is the possibility that they could have arrived during the construction process, either in soil or attached to the plants themselves. While some of these may be advantageous, like earthworms which provide direct benefits to the soil (Jusselme et al., 2019), there is the possibility of this importing invertebrates from drastically different ecosystems that could be considered pests or invasive species.

Horizontal migration may be another explanation for the presence of species on green roofs while being absent from the ground level ecosystems. This horizontal migration could be caused by building-to-building travel, or by wind dispersal. Wind dispersal consists of light invertebrates being swept up with the wind and deposited sometimes kilometers away, this is observed regularly in spiders (Joimel et al., 2018; Joimel et al., 2022).

The building-to-building travel is exclusive to taxa of invertebrates that can fly under their own power such as flies. Many papers found that a higher density of green roofs resulted in more similar assemblages of invertebrates (Braaker et al., 2014; Fabián et al., 2021; Joimel et al., 2018). This movement and similarity is similar to Island Biogeography Theory, with each building mimicking an island in an archipelago. This theory is an extensive pre-existing field and has been applied to urban habitat fragmentation in the past (Losos et al., 2010; MacArthur & Wilson, 1967; Whittaker & Fernandez-Palacios, 2006). By incorporating an increased density of green roofs into city planning, we can increase the connectivity of these novel habitats, allowing for more robust ecosystems.

Spatial Heterogeneity

Increased structural heterogeneity was found to increase invertebrate diversity along various axes (Braaker et al., 2017; Fabián et al., 2021; Gonsalves et al., 2022; Jacobs et al., 2022; Nash et al., 2016; Rumble et al., 2018). These structural differences, including vegetational differences, allows a wide array of ecological niches which can be exploited by invertebrates. One aspect of vegetational diversity was underrepresented. There was only one article found (Wang et al. 2013) that discussed how trees may affect invertebrate assemblages. The different degrees to which these various axes of heterogeneity can be manipulated to increase biodiversity of invertebrates is an interesting prospect for research.

As noted previously, robust invertebrate populations on green roofs can provide many ecosystems services. While there is a general paucity of research here, there was note of leaf litter breakdown potential and nutrient cycling by Jusselme et al. (2019). While the catalytic effect of invertebrates in this process is quote well-researched in non-urban environments, the effect on urban environments like green roofs is underdeveloped (Ganault et al., 2022; Santonja et al., 2018). With respect to decrease in pest species, Wong & Jim (2016) noted that green roofs had far less mosquitos sampled on green roofs compared to ground and conventional roof environments. While these two examples are relatively new, they show that there may be more unknown services that healthy assemblages of invertebrates can provide for green roofs and urban areas.

Summary

By understanding more about green roofs and the ecosystems of invertebrates that occupy them, we can improve design processes by incorporating the major benefits of those ecosystems. There is still much to understand green roofs, including how some possess species not found at nearby ground levels. Furthermore, the effects of arid, tropical, and subarctic climates are under-researched compared to more temperate climates.

While there is relatively little research into the field so far, the semi-isolated nature of green roofs makes them a novel environment to study. The main summations being brough forward here include the restriction of immigration by low mobility invertebrates onto green roofs, and that this may be significant impacts on the species makeup of green roofs. While green roofs generally have lower invertebrate diversity than ground environments, this can be to an extent countered through heterogeneity in design. This includes vegetation, which has the greatest effect on diversity of invertebrates. More diverse and developed invertebrate populations can provide many services to those ecosystems, such as increasing soil health and decreasing pest levels.

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