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Original article

Local habitat characteristics have a stronger effect than the surrounding urban landscape on beetle communities on green roofs

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ABSTRACT

Green roofs are a promising tool to return nature to cities and mitigate biodiversity loss brought about by urbanization. Yet, we lack basic information on how green roofs contribute to biodiversity and how their placement in the urban landscape affects different taxa and community composition. We studied the effects of local and landscape variables on beetle communities on green roofs. We expected that both local roof characteristics and urban landscape composition shape communities, but that their relative importance depends on species characteristics. Using pitfall traps, we collected beetles during two consecutive years from 17 green roofs in Basel, Switzerland. We evaluated the contribution of six local and six landscape variables to beetle community structure and to the responses of individual species. Communities on the roofs consisted of mobile and open dry-habitat species, with both local and landscape variables playing a role in structuring these communities. At the individual species level, local roof variables were more important than characteristics of the surrounding urban landscape. The most influential factors affecting the abundances of beetle species were vegetation, described as forb and grass cover (mainly positive), and roof age (mainly negative). Therefore, we suggest that the careful planning of green roofs with diverse vegetation is essential to increase their value as habitat for beetles. In addition, while beetle communities on green roofs can be diverse regardless of their placement in the urban landscape, the lack of wingless species indicates the need to increase the connectivity of green roofs to ground level habitats.

1. Introduction

Ecological resources and green infrastructure have historically been given minor roles in urban development (Benedict and McMahon, 2006; Mell et al., 2013). This has allowed the shrinking of urban green areas with negative effects on biodiversity, ecosystem functioning and human well-being (Benedict and McMahon, 2006; Tzoulas et al., 2007; Grimm et al., 2008). In order to halt and reverse the negative ecological and environmental effects of urbanization, scientists, architects and urban planners are searching for solutions that add nature as part of the existing urban infrastructure (Francis and Lorimer, 2011). Green (also called living or vegetated) roofs is one such solution that offers a multitude of ecological benefits without competing for economically valuable urban space (Oberndorfer et al., 2007). Therefore, they have a high potential for reconciliation ecology, i.e. for modifying anthropogenic environments to support wildlife in a way that does not reduce the societal value of the area (Francis and Lorimer, 2011; Rosenzweig, 2016).

An additional advantage of green roofs is that they can be designed for specific purposes, such as the conservation of habitats and species (Landolt, 2001; Kaupp et al., 2004; Kadas, 2006; Brenneisen, 2009). Results from studies on green roof biota have shown that green roofs are indeed able to harbour diverse plant and animal – especially invertebrate – communities (Brenneisen and Hänggi, 2006; MacIvor and Lundholm, 2011; Madre et al., 2013; Gabrych et al., 2016). In addition, green roofs may increase habitat connectivity for mobile invertebrate species by acting as stepping stones (Braaker et al., 2014). Yet, there is a lack of basic information on factors affecting the diversity of green roofs and a demand for such if conservation benefits are to be realized.

An essential question that needs to be addressed (Brenneisen, 2006) is whether local roof characteristics (i.e., local resources), the surrounding landscape (i.e., resources, source populations, dispersal and connectivity), or both, are important in maintaining or promoting biodiversity in the city. Since the occurrence and abundance of species

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are defined by both local and landscape conditions (see Mazerolle and Villard, 1999 for a wide array of habitat types and taxa; Soga and Koike, 2012 for butterflies in urban forests; Zulka et al., 2014 for invertebrate taxa in dry grasslands), the risk exists that green roofs designed for biodiversity may not function as planned, if located in an unfavourable milieu even when the roof is explicitly designed from the perspective of supporting biodiversity. Unfavourable landscapes lack source habitat, or connectivity to such, for example due to a high proportion of impervious surfaces, water, or other unsuitable environments for green roof fauna. In this study, we evaluate the relative contributions of local and landscape characteristics that shape green roof beetle communities and the abundances of individual species. Beetles, particularly carabids, are widely used indicators and model organisms in ecological research, including urban studies, and their ecology and responses to various environmental variables are, thus, well understood (Rainio and Niemelä, 2003; Koivula, 2011; Venn et al., 2013).

Based on previous green roof studies and widely acknowledged ecological theories, such as the island biogeography theory (MacArthur and Wilson, 1967), we hypothesized that local characteristics related to habitat quality, and landscape variables (indicating the availability or lack of potential source populations and permeability of the landscape) are influential in structuring beetle communities and species abundances. We expected the abundances of most species to be positively associated with the percentage cover of forbs and grasses (meadow-type vegetation) on green roofs (see Brenneisen, 2006; Kadas, 2006; Madre et al., 2013). Additionally, we hypothesized that roof area has a positive effect (Rosenzweig, 1995; Connor et al., 2000) and that the effect of roof height is negative due to increased isolation (MacArthur and Wilson, 1967; Rosenzweig 1995, Vasl and Heim, 2016) and the often strong exposure to sun and wind on high roofs. Moreover, we expected the effect of roof age on beetle abundances to peak at intermediate or old roof age, because when roofs are constructed, populations increase with increased probability of colonization, but competition may limit species abundances on older roofs (Fahrig and Jonsen, 1998; Bolger et al., 2000; Vasl and Heim, 2016). Based on previous green roof studies, we expected substrate depth to have variable effects depending on the beetle species (Brenneisen, 2009; Madre et al., 2013). Furthermore, we expected landscape variables, e.g. the proportions of various green space types and impervious surfaces in the surroundings, to have positive or negative influences, based on their hypothesized value as habitat or contribution to connectivity (Braaker et al., 2014). Moreover, we expected the mobility of a species to affect the relative importance of local and landscape variables: local roof characteristics might be more important for sedentary species and landscape variables for highly mobile species (Öckinger et al., 2009; Braaker et al., 2014; Zulka et al., 2014). Finally, because of the complexity of phenomena at the community level, no directional hypotheses were put forth regarding the effects of the above independent variables on the beetle community composition − instead, the variables were simply hypothesised to affect the communities.

2. Material and methods

2.1. Study area and sampling design

We performed this study in the city of Basel (47°34′ N, 7°36′ E), Switzerland. Basel has promoted the building of green roofs since 1996, and since 2002 all new developments with flat roofs were required by the building code of the city (§72) to have green roofs. Since 2006 it has been an obligation to install green roofs during reparation. Consequently, Basel has become one of world's hot spots for green roofs with up to a quarter of the flat roof area covered by vegetation (Kazmierczak and Carter, 2010).

We sampled beetles from 17 green roofs (Fig. 1) that varied in age, size, height, vegetation, and substrate depth and composition (Supplementary material, Table S1). Vegetation on the roofs was either meadow (dominated by forbs and grasses), sedum, or mixtures of meadow and sedum type. Five of the roofs were characterized by within-roof variation in vegetation and amount of bare ground. These roofs were divided into habitat types (according to the number of recognized vegetation types) that were treated as separate trapping sites. Roofs that did not have notable within-roof variation in vegetation type, had only one trapping site, regardless of roof size. Therefore, the total number of trapping sites on the roofs was 24.

The main study was conducted in 2014, after a pilot study in 2013. The beetles were collected in both years using pitfall traps (volume: 125 ml, diameter: 6 cm, depth: 6.8 cm, 10% acetic acid solution with a trace of detergent) from the beginning of April until the end of October, ten traps per trapping site. Thus, the number of trapping sites did not depend on roof size, but varied from one to three according to the number of habitat types on a roof, resulting in 10–30 traps per roof. The roofs were visited every fortnight to empty and re-fill the traps. All samples were stored in 50% ethanol and identified to species level, with the determination keys of "Die Käfer Mitteleuropas", Vol 2–15 (Freude et al., 1976). The catch was pooled per trapping site and year for statistical analyses.

Sampling was repeated in 2014 in a similar way as in 2013, but with a few essential improvements. Unlike the 2013 pilot study, the number of lost traps was recorded for each trapping period in 2014, in order to define the actual trapping effort. In addition, all traps were carefully placed flush with the soil surface, which was sometimes a problem with the 2013 survey. Other initial problems in 2013 were caused by crows pulling out the traps from the substrate. Limitations of the pilot study were taken into account when interpreting the results.

2.2. Environmental variables

The local roof conditions were described using five variables: roof age, size and height, substrate depth and the type of vegetation indicated by the covers of forbs and grasses (Table 1). For statistical analyses, we converted substrate depth into a categorical variable with three classes (1: < 10 cm, 2: 10–15 cm and 3: > 15 cm) because of an overrepresentation of shallow roofs (right-skewed distribution). The other local variables were continuous.

To evaluate the effects of the surrounding landscape on the beetles, we classified the landscape into six land-use classes according to their hypothesised association (habitat value) with beetles on green roofs: 1) open and semi-open green space, where shrubs, single trees or groups of trees may grow, 2) forest, 3) railways, 4) buildings, 5) impervious surfaces, and 6) water (Table 1, Supplementary material, Fig. S2). We analysed the distribution of land cover classes for each roof using QGIS 2.10.1 Pisa (Quantum Development Team, 2015). Land use data were obtained from Geoportal Kanton Basel-Stadt (http://www.geo.bs.ch/). We calculated the proportions of different land-use classes within 100 and 400 m buffers around each green roof (referred to as landscape100 and landscape400 variables) to study the importance of the immediate and the larger landscape on the beetle communities. The choice of the buffers corresponded to the smallest and largest buffer zones of Braaker et al. (2014). For two of the roofs, less than 5% of the 400 m buffer zone extended outside the canton of Basel-Stadt and, for one roof, outside the Swiss border. Our land-use data did not include these areas, but we considered that a minor shortcoming. Semi-open and open green space and railways were considered possible habitat for the green roof beetle fauna. Forests were considered as non-habitat, together with impervious surfaces and water, because green roofs are open and semi-open habitats, not optimal for forest species. Buildings could be considered as habitat or non-habitat, because parts of some of the buildings had green roofs, but the land-use data did not distinguish between vegetated and non-vegetated roofs. However, because green roofs are rather equally distributed in Basel, buildings could be considered a coherent land-use class.