## SHORT NOTES

# Vertical life: impact of roof height on beetle diversity and abundance on wildflower green roofs

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## Abstract

Despite their increasing popularity in an urban setting, we still know relatively little in how well-extensive green roofs support biodiversity in terms of vertical connectivity from terrestrial habitats. Most green roof biodiversity studies have not considered whether the roof height affects community composition and abundance of species present. This study focused on evaluating beetle diversity and abundance in relation to roof height, with emphasis on wildflower roofs. The key results of the study confirm previous studies found that extensive wildflower green roofs are capable of supporting fairly rich beetle communities, including some rare/scarce species. However, an increase of roof height was found to negatively impact both beetle abundance and richness, despite all recorded species being well adapted to active flight and thus dispersal. In addition forb cover decreased with roof height which consequently influenced beetle community structure. These results are therefore indicative that further research is required on species communities found on extensive green roofs that are less adapted to active flight and consequently vertical dispersal. This study further highlights the need for vertical and horizontal connectivity between green roofs and the surrounding natural habitats as a management tool to increase the general ecological value of urban green spaces.

Key words: Coleoptera, diversity, green roofs, roof height, community, dispersal

## Introduction

Though a relatively recent addition, modern green roofs have become an established part of the urban landscape since their invention in the 1960s (Banting et al. 2005; Thuring and Grant 2016). With beneficial characteristics such as habitat creation/mitigation, carbon sequestration, storm water retention, reduction of pollutant run off, energy savings via their insulating properties, aiding in the reduction of the urban heat island effect and improving the aesthetics of the urban landscape creating an improved sense of well-being (Oberndorfer et al. 2007; Getter et al. 2009; Mullen, Lamsal, and Colson 2013; Thuring and Grant 2016), they are becoming ever more popular with developers and even the private sector (Banting et al. 2005; Oberndorfer et al. 2007; Thuring and Grant 2016). Green roofs can be categorized into two general types predominantly based on their substrate depth with extensive roofs having a depth of up to 30 cm (typically 3–10 cm) and intensive roofs with a depth of 30 cm and over (Dvorak and Volder 2010, Zhang et al. 2012).

Green roofs are typically more separated from surrounding habitat patches, both vertically and horizontally, than other urban green spaces (Blank et al. 2017). The resulting degree of isolation and lack of connectivity of green roofs makes them

particularly well suited to the application of island biogeography theory (IBT) in regards to observed diversity and species richness, although on a relatively small scale (MacIvor and Lundholm 2011; Berthon et al. 2015; Blank et al. 2017; Ksiazek-Milenas et al. 2018). Green roofs that are larger or better connected with other habitat patches are expected to have a higher species richness compared with smaller, more distant or more isolated equivalents (Kalmar and Currie 2006; Blank et al. 2017).

The IBT theory states that vegetation establishment and succession in addition to invertebrate species presence on green roofs is therefore dependent on a species' dispersal ability and the degree of isolation of the roof in 3D space (Cook et al. 2002; Berthon et al. 2015; Blank et al. 2017; Ksiazek-Mikenas et al. 2018). Studies have documented vegetation communities on green roofs changing over time as wild species from the surrounding landscape are able to successfully colonize and become established through natural succession, indicating that green roofs are able to play a role in local vegetation distribution dynamics (Dunnett, Nagase, and Hallam 2008; Cook-Patton and Bauerle 2012; Madre et al. 2014). However, these colonisers are typically only able to persist if the species are well adapted to the environmental factors and maintenance regime of the particular roof (Dunnett, Nagase, and Hallam 2008; Madre et al. 2014).

Invertebrate dispersal is more limited, particularly for ground-dwelling species (Sadler et al. 2006). The most common form of invertebrate dispersal is undoubtedly through active flight, observed in pollinators such as species from Apidae and Lepidoptera families, to many members of the order Coleoptera (Sadler et al. 2006; Colla, Willis, and Packer 2009; Matteson and Langellotto 2010). Another dispersal technique is that of passive flight through the assistance of winds and air currents (Ruzicka 1995; Joimel et al. 2018). However, many ground and soil-dwelling species are limited to terrestrial locomotion such as those from the classes Chilopoda, Diplopoda and Isopoda (MacIvor and Lundholm 2011). Such species present upon high green roofs are likely descendants of inadvertent introductions through soil or plant placement during the roof's construction (MacIvor and Lundholm 2011).

This study aimed to investigate and assess Coleoptera assemblages present on green roofs over varying heights from the ground in relation to changes in vegetation cover and beetle community composition. Specifically, it is addressing questions in regard to Coleoptera communities: (i) does Coleoptera community composition change with increasing roof height on an extensive flower green roof? and (ii) what effect does vegetation cover and plant richness have in influencing beetle communities? The results will allow to evaluate whether changes in green roof vegetation habitat influences beetle species richness and community.

## Materials and methods

### Field site

This study was conducted on eight discreet green roofs and a further two sections located upon the Checkland building (50.8605°N, −0.0869°E) at the University of Brighton Falmer site located on the outskirts of the city of Brighton, UK (50.8225°N, −0.1371°E). The site lies within a matrix of urban buildings, arable fields and calcareous grassland habitats interspersed with deciduous woodland patches and is close to the Stanmer Park Local Nature Reserve. The site was chosen for its unique ability to assess invertebrate dispersal over differing roof heights, as

all roofs studied were installed and initially seeded around the same time with the same vegetative communities by Organic Roofs Ltd.

The building has a total of 16 discrete $42 \, m^2$ green roofs over four different heights in 2.5 m increments from 2.5 to 10.0 m, with an additional larger $817 \, m^2$ green roof comprising the uppermost roof of the building at a height of 12.5 m. The roofs had been established for ∼7 years at the time of the study period. The initial vegetation community the roofs were seeded with, consisted of a majority of native calcareous wildflower meadow species. The roofs are maintained on behalf of University of Brighton by Organic Roofs Ltd (2018) and have been mown every 6 months since 2014. Permissions to conduct research on the green roofs were provided by the University of Brighton.

A total of 10 roofs were surveyed at the site: two equal plots of the uppermost roof, comprising an area of $28 \, m^2$ per plot, whereby the selection of surveyed area was dictated by the substrate depth due to variability in roof substrate depth, and a further eight discrete roofs comprised of two sets of four roofs installed in step-like stacks in 2.5 m increments. One set was located on the outside northern stack of the building, whereas the other was located on the inside southerly stack (see Fig. 1) to ensure even distribution of the sites.

Data collection for both vegetation and Coleoptera surveys were conducted during the summer months of August and September 2017 on the defined roofs using the same locations. Daytime air temperatures during this period ranged between 14°C and 29°C with a mean 20°C (Timeanddate.com 2018). Relative humidity ranged between 54% and 100% with a mean 78% (Timeanddate.com 2018). Over the course of the year of 2017, the region of the South East of England, wherein the Brighton and Hove area is located, experienced a mean air temperature of 11°C, 1692.3 h total sunshine and 755.5-mm rainfall over 117.8 days (Met Office UK 2018).

### Vegetation survey methods

Basic vegetation surveys were carried out on the roofs in plots of $0.5 \times 1.0 \, m^2$ where the percentage cover of forbs and grasses were estimated by eye (some roofs also had small amounts of moss cover, leaf litter and bare soil visible). The vegetation survey was conducted once prior to the installation of the pitfall traps. To standardise the sampling effort (as the site had two different sized roofs), the method from Gabrych, Kotze, and Lehvävirta (2016) was used to calculate the required number of sample plots to ensure comparability between roofs. This resulted with five plots on the two $28 \, m^2$ sections of the uppermost roof and seven plots on each of the eight $42 \, m^2$ discreet roofs resulting in a total of 66 plots across all roofs sampled. Locations for all plots were dictated by stratified random sampling methods incorporating a central plot located in the middle of each roof, ensuring data collected were a true representation of the roofs. In an effort to further reduce unrepresentative variation in the data in regards to community changes resulting from the edge effect, care was taken to ensure that all plots were a minimum 0.5-m distance from the edge of the roofs (Donovan et al. 1997; Ewers and Didham 2008). The species list of surveyed plants can be found in the supplementary data.

### Coleoptera survey methods

Invertebrates were surveyed using pitfall traps consisting of plastic cups with a diameter of 7.0 cm (Woodcock and Pywell 2010), filled with a 75 ml solution of water (tap) and pure

**Figure 1:** The 10 roofs surveyed upon the Checkland building, highlighted in green. Each storey increased in height by ~2.5 m. Adapted from Google (2018).

ethylene glycol in a 3:1 respective ratio (Schmidt et al. 2006) and two drops of unscented washing-up liquid. Each trap was set in the ground in the centre of a vegetation survey plot so that the lip of the inner cup was flush to the surface. To prevent rainwater entering the trap, a $15.0 \times 15.0$ cm ceramic tile was placed ~2.0 cm above the trap, balanced atop two $2.0 \times 2.0$ cm wooden blocks placed either side of the pitfall trap at ~2.0 cm distance to the opening. To prevent access by inquisitive seagulls and other birds, several large stones were placed on top of the ceramic tile. Twelve traps were set up on the roofs 2.5–10 m high and 10 traps on the top most roof—this was dictated by the heterogeneity of the substrate depth.

Traps were collected and reset every 7 days for a total of three collections per trap (66 traps per sampling session = 198 traps in total). All Coleoptera were removed from the solution and rinsed with distilled water before being transferred into a labelled phial containing a preservative solution of 70% ethanol and stored prior to identification. Individuals were identified to a species level (Lott and Anderson 2011; Coleoptera.org.uk 2018), apart from a number of very small Staphylinidae individuals (<5 mm with identical morphological features and characteristics that could not be identified), which were listed as a single 'unknown' species.

### Analytical and statistical methods

Coleoptera abundance and richness for each pitfall trap was recorded as well as the vegetation percentage cover and forb family richness for each study plot ($n = 66$). The Shannon–Wiener diversity index ($H'$) was used to look at biodiversity as it is sensitive to changes in the number and abundances of rare species within the community (Waite 2000). All statistical tests were carried out using the program Minitab version 18.1 (Minitab Inc. 2018). As the data were not normally distributed when tested using the Anderson–Darling normality test, all forb variables were transformed by square root to a normal distribution. Data, such as beetle abundance and species richness, which could not be transformed to fit a normal distribution, were analysed using non-parametric tests. A principle components analysis (PCA) test was conducted to explore factors influencing Coleoptera abundance and richness. The variables included were roof height, percentage forb cover, percentage grass cover as well as forb family richness and forb abundance.

Kruskal–Wallis tests (adjusted for ties) assessed the effect of roof height, forb richness, forb abundance, forb percentage cover and grass percentage cover on beetle abundance as well as evaluating the factors that influenced beetle richness and functional feeding groups (FFGs) abundance. Significant differences were highlighted with Tukey pairwise comparisons post hoc tests. Possible correlations between the response variables beetle abundance and species richness and their influencing factors were shown with Spearman's rank-order correlation tests on abundance data and richness data. Pearson correlation evaluated whether roof height influences vegetation cover. Finally, the influence of roof height up to 10 m was assessed on the two most abundant beetle species (predator: *Quedius levicollis* and detritivore: *Megasternum concinnum*) in relation to their FFG with Kruskal–Wallis tests (adjusted for ties).

## Results

Over the study period that consisted of 33 264 trapping hours, a total of 687 individuals of 22 species, spanning 10 families within the order Coleoptera were collected across the 10 roofs (see Table 1). The most abundant and diverse family was that of the Rove beetle (Staphylinidae) representing 71.76% total abundance (493 individuals) and 39.13% total species richness (8 identified species). Of the 22 identified species recorded 16 (73.91%) were represented by <5 individuals. The two most abundant species were *Q. levicollis* (Brullé 1832), and *M. concinnum* (Marsham 1802). Only four species were present across all of the five heights surveyed (17.39%) *M. concinnum*, and three species of rove beetle *Q. levicollis*, *Quedius curtipennis* (Bernhauer 1908) as well as the unknown Staphylinidae species. Two nationally scarce or rare species were also recorded, the small weevil *Protapion filirostre* (Kirby, W. 1808) and the rove beetle *Ocypus* (*Matidus*) *nitens* (Schrank 1781).

Coleoptera abundance declined with increasing roof height with the lowest observed at 12.5 m (see Table 1 for more details*). The highest roofs also had the lowest species diversity with only six species recorded as well as having traps with no beetle collection. The mean abundance values were similar over the roof heights 2.5–10.0 m, with a sharp decline observed at 12.5 m (Kruskal–Wallis $H = 23.94$, $df = 4$, $P < 0.001$), whereas mean species richness values declined from 2.5 to 12.5 m (with

**Table 1:** Complete list of the 23 Coleoptera species* recorded on the different roof heights over the study period ($n = 198$)

| Family | Subfamily | Genus | Species | Roof height (m) 2.5 | 5.0 | 7.5 | 10.0 | 12.5 | Total abundance | FFG |
|---|---|---|---|---|---|---|---|---|---|---|
| Byrrhidae | Byrrhinae | Cytilus | sericeus | | | | | 1 | 1 | H |
| Carabidae | Carabinae | Poecilus | cupreus | 8 | 8 | | 1 | | 17 | P |
| | | Pterostichus | Niger | 1 | | | | | 1 | P |
| | | Pterostichus | Nigrita | | 1 | | 1 | | 2 | P |
| | | Pterostichus | vernalis | | | 1 | 3 | | 4 | P |
| Chrysomelidae | | Phyllotreta | nodicornis | | 1 | | | | 1 | H |
| Curculionidae | Apionidae | Protapion | filirostre | 1 | | | | | 1 | H |
| | | Protapion | fulvipes | | 1 | | | | 1 | H |
| | | Sciaphilus | asperatus | 2 | 1 | | | | 3 | H |
| | | Sitona | lepidus | 2 | | | | | 2 | H |
| | | Sitona | lineatus | | 1 | | 2 | | 3 | H |
| Elateridae | | Agriotes | sputator | 1 | | | | | 1 | H |
| Histeridae | | Hister | unicolor | | 1 | 1 | | | 2 | D |
| Hydrophiloidea | Hydrophilidae | Megasternum | concinnum | 82$^A$ | 9$^B$ | 27$^B$ | 33$^B$ | 4$^B$ | 155 | D |
| Staphylinidae | Proteininae | Metopsia | clypeata | | | | | 1 | 1 | P |
| | Staphylininae | Gauropterus | fulgidus | 1 | 2 | | 1 | | 4 | P |
| | | Ocypus | Nitens | 4 | | | | | 4 | P |
| | | Quedius | curtipennis | 2 | 2 | 5 | 2 | 1 | 12 | P |
| | | Quedius | fuliginosus | 4 | | 2 | 1 | | 7 | P |
| | | Quedius | levicollis | 57$^B$ | 123$^A$ | 153$^A$ | 101$^A$ | 1$^C$ | 435 | P |
| | | Quedius | molochinus | | 2 | | | | 2 | P |
| | | Xantholinus | Linearis | 1 | 2 | | 2 | | 5 | P |
| | Unknown | | | 5 | 2 | 9 | 5 | 2 | 23 | P |
| Total abundance | | | | 171$^A$ | 156$^A$ | 198$^A$ | 152$^A$ | 10$^B$ | 687 | |

P = predator, H = herbivore and D = detritivore. *Significant difference between roof heights indicated by different letters (Tukey post hoc $P < 0.01$).

a spike at 10.0 m; Kruskal–Wallis $H = 16.67$, $df = 4$, $P < 0.05$) (see also Table 2). Both beetle abundance and richness were negatively correlated with increasing roof height (Spearman's rank-order correlation $R = -0.383$, $P < 0.001$ and $R = -0.402$, $P < 0.001$, respectively). This was mainly influenced by the low beetle abundance (linear regression: abundance $= 16.03 - 0.78 \times$ height, $R^2_{adj} = 0.103$, $P < 0.005$) and the subsequent lower number of beetle species found (linear regression: species $= 3.77 - 0.18 \times$ height, $R^2_{adj} = 0.149$, $P < 0.001$) on the 12.5-m roof.

Shannon's diversity indices were relatively low and ranged between 0.80 and 1.61, with the lowest observed at a roof height of 7.5 m and the highest at 12.5 m (Table 2). When assessing the beetle community based on their FFGs, predators were the most abundant, followed by detritivores and a small proportion of herbivores (Kruskal–Wallis $H = 10.126$, $df = 2$, $P < 0.01$). Only predator abundance decreased significantly with roof height (all roofs were included: Kruskal–Wallis $H = 15.71$, $df = 4$, $P < 0.05$; only roofs 2.5–010 m included: Kruskal–Wallis $H = 8.717$, $df = 3$, $P < 0.05$). Even when just considering roofs up to 10 m, the abundance of the most dominant predator *Q. levicollis* decreased with roof height (Kruskal–Wallis $H = 17.09$, $df = 3$, $P < 0.001$). The abundance of the detritivore *M. concinnum* was highest at 2.5 m, decreasing with further height (Kruskal–Wallis $H = 23.02$, $df = 3$, $P < 0.001$).

Vegetation cover changed with roof height whereby percentage forb cover was negatively correlated with increasing roof height (Pearson correlation $R = 0.279$, $P < 0.05$) with the lowest forb cover observed at 12.5 m, whereas percentage grass cover showed no clear correlation with increasing roof height. Interestingly, forb richness was found to be similar across all heights (Table 2). However, the PCA results (see Fig. 2) showed that 70.6% of the variation within the study by the two first

axes. The three most influential eigenvectors comprising the first model were percentage forb cover, forb abundance and percentage grass cover in descending contribution (0.491, 0.484 and −0.407, respectively), whereas the second model comprised of roof height, forb family richness and beetle richness (−0.525, −0.462 and 0.407, respectively).

Both beetle abundance and richness were positively correlated with increased percentage forb cover (Spearman's rank-order correlation $R = 0.463$, $P < 0.001$ and $R = 0.490$, $P < 0.001$, respectively) and negatively correlated with increased percentage grass cover (Spearman's rank-order correlation $R = -0.26$, $P < 0.05$ and $R = -0.299$, $P < 0.05$, respectively). Analysis excluding the highest roof showed a positive significant correlations between beetle richness and forb percentage cover (Spearman's rank-order correlation $R = 0.332$, $P < 0.05$). Interestingly, neither beetle abundance nor richness were subsequently found to be significantly influenced by forb family richness.

## Discussion

The observed Coleoptera abundance and richness in this study supports the premise that wildflower green roofs in the UK act as adequate habitat for certain beetle species forming unique communities: 22 species were identified, including two nationally scarce or rare species (*Protapion filirostre* and *Ocypus nitens*). *Protapion filirostre*, a 2–3-mm long member of the family Apionidae within the superfamily Curculionidae (Morris 1990) is presently listed as uncommon in Great Britain (Natural History Museum 2018b), whereas *O. nitens*, a 17–19-mm long member of the subfamily Staphylininae within the family Staphylinidae (Lott and Anderson 2011), has been noted rare (Natural History Museum 2018a). Interestingly, the latter species is listed as an

**Table 2:** Summary of the Coleoptera surveys and basic vegetation details on the different roof heights over the study period

| | Roof height (m) | | | | | Statistical analysis |
|---|---|---|---|---|---|---|
| | 2.5 | 5.0 | 7.5 | 10.0 | 12.5 | |
| Total Coleoptera abundance* | 171^A | 156^A | 198^A | 152^A | 10^B | Kruskal–Wallis $H = 53.33$ m, $df = 4$, $P < 0.001$; without top roof non-significant |
| FFGs | | | | | | |
| Herbivore | 4/6 | 4/4 | | ½ | 1/1 | Non-significant |
| Predator | 9/83^ab | 8/142^ab | 5/170^b | 9/117^ab | 4/5^a | Abundance: Kruskal–Wallis $H = 15.71$, $df = 4$, $P < 0.05$; no. of species non-significant |
| Detritivore | 1/82 | 2/10 | 2/28 | 1/33 | 1/4 | Non-significant |
| Coleoptera species richness* | 14^A | 14^A | 7^AB | 11^A | 6^B | Kruskal–Wallis $H = 51.45$, $df = 4$, $P < 0.001$; without top roof: $H = 7.62$, $df = 3$, $P < 0.05$ |
| Coleoptera biodiversity index (H') | 1.45^AB | 0.98^C | 0.80^C | 1.10^BC | 1.61^A | Kruskal–Wallis $H = 11.3512$, $df = 4$, $P < 0.05$, without top roof: non-significant |
| Mean forb family richness ± SD | 5 ± 1 | 6 ± 2 | 7 ± 1 | 5 ± 2 | 7 ± 1 | Non-significant |
| Mean percent forb cover* ± SD | 64.14^A ± 14.05 | 58.86^A ± 22.72 | 56.86^A ± 15.79 | 65.57^A ± 24.36 | 36.10^B ± 9.19 | ANOVA $F = 13.42$, $df = 4$, $P < 0.001$; without top roof: non-significant |
| Mean percent grass cover ± SD | 33.36 ± 11.43 | 28.86 ± 19.11 | 33.00 ± 12.42 | 31.93 ± 21.87 | 42.20 ± 14.02 | Non-significant |

*Significant difference between roof heights indicated by different letters (Tukey post hoc $P < 0.01$).

introduced species in the USA (Newton, 1987), and more recently in Canada (Brunke 2016) indicating a good adaptation ability to changing environments.

The results also showed a general decrease of Coleoptera species abundance with increasing roof height. However, in the studied extensive green roofs, no clear trend was observed for Coleoptera richness overall in relation to increasing roof height, even though the number of species recorded was lowest for 7.5- and 12.5-m high roofs. Interestingly, at 7.5 m, the highest beetle abundance was recorded (due to the dominance of *Q. levicollis*), indicating that some species may be influenced more by roof height, with dispersal abilities (both active and passive) potentially playing a role. While specific studies assessing beetle diversity and abundance in relation to roof height are lacking, a study by MacIvor (2015) showed increasing building heights reduces the nesting success of bee and wasps. Other studies, supporting the IBT, have shown that green roofs act as 'island in the sky' (Berthon et al. 2015) where invertebrate diversity is mainly influenced by immigration limitations and resource provisioning (Blank et al. 2017). We could show that beetle diversity and abundance was positively correlated by percentage forb cover, however, the PCA results indicated one of the driving factor were the lower forb cover on the highest roof. Therefore, the influencing factor of beetle communities could to be resource availability rather than colonisation success. This could have been further influenced by the heterogeneity of the 12.5-m roof, which dictated the different sampling regime, however, sampling effort was adjusted according to the methodology proposed by Gabrych, Kotze, and Lehvävirta (2016). Interestingly following the IBT, the prediction for the highest roof (also being the largest) would result in higher abundance, whereas the opposite was the case. This implies that dispersal ability appears to be the main factor determining colonisation success of green roofs rather than size (Madre et al. 2013; Braaker et al. 2014) with an observed decrease in invertebrate colonisation with increasing roof height (Madre et al. 2013). For example, an Australian study showed a trend of decreasing abundance with height but not a change in invertebrate richness (Berthon et al., 2015). They proposed that invertebrates capable of dispersing to low rooftops will also be able to colonise higher roofs, but the lower roofs are favoured due to lower energy expenditure required to reach them (Berthon et al. 2015).

Factors such as connectivity of green roofs to surrounding equivalent areas can impact diversity and abundance (Braaker et al. 2014). While building height can strongly influence low mobility species such as Carabids (Kyrö et al. 2018), mobile species recorded on green roofs can partially mirror invertebrate communities at ground level (Mayrand and Clergeau 2018) and are affected by urban matrices in which they reside. Recent studies indicate that functional diversity on green roofs remain similar (Braaker et al. 2014, 2017), and biodiversity differences are mainly explained by influences such as harsher microclimates and lower resource availability (Mayrand and Clergeau 2018). In this study, beetle abundance and diversity were similar on the lower roofs but significantly different than the highest roof (which did have low-trapping rates). Most species were only present in very low numbers. However, a few species were present on all roofs (see Table 1) in very high numbers, implying that only the species suited to the actual microhabitat will establish themselves.

Beetle diversity and abundance along an urbanization gradient has been correlated to body size with larger species having a lower dispersal ability, resulting in decrease of larger beetle species with increased urban disturbance due to their requirement
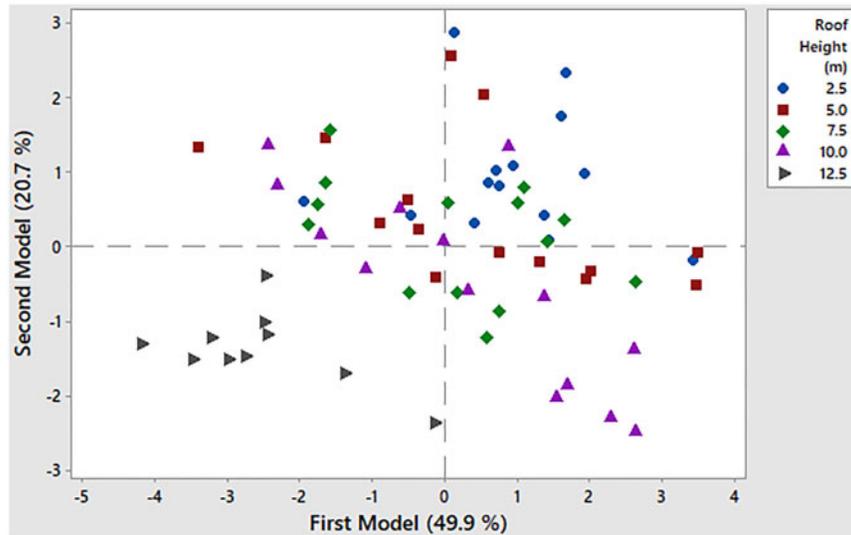
**Figure 2:** A scatterplot of beetle species richness and vegetation cover grouped by roof height explored in the PCA explained 70.6% of the variation within the study.

of stable resources (Jones and Leather 2012). Gardener (2016) found significant smaller Coleoptera species on rooftops compared with sites at ground level, suggesting that dispersal can be via mediated transport or by flying. Sadler et al. (2006) propose that phenotypes with strong dispersal abilities would need to be well adapted to active flight: for example, possessing long wings in relation to their body size. While this study did not specifically analyse morphological traits related to dispersal, the majority of identified Coleoptera species were small or medium size, which may have favoured more passive dispersal. In Sadler et al.'s (2006) study, Carabidae species were assessed along a rural to urban gradient, showing not only did species richness and diversity decrease with increasing urbanisation, but there was also an observed decrease in species with shorter wings. This is in-line with a later study of Carabids on green roofs undertaken by Petremand et al. (2018), which documented a distinct lack of short-winged species present. However, Gardener's (2016) study could not demonstrate that wing morphology trait was significantly different between rooftops and ground level showing more research is needed in this area. Our results show that the recorded beetle species generally appear to be better adapted to increased mobility (similarly observed by Sadler et al. 2006 and Gomez and Van Dyck 2011), indicating that potentially species less well adapted to dispersal were underrepresented in our roof surveys. As arthropod diversity on green roofs are influenced by connectivity and plant species richness (Braaker et al. 2017), this highlights the need of increased connectivity between roofs and ground-level habitats to increase the ecological value of green roofs.

Coleoptera abundance varied greatly between species with the majority of specie being represented in numbers smaller than five, but the studied roofs overall seem to provide suitable habitats for fairly diverse native beetle communities (although at small populations), many of which are typically found to inhabit more traditional grassland habitats (MacIvor and Lundholm 2011; Petremand et al. 2018), a widely present habitat around the study site. The high abundance of the detritivore *M. concinnum*, however, is harder to explain, as this species is better known to inhabit grasslands that have livestock due to the presence of their dung. However, its main dispersal activity is from August to October and as a

typically polarotactic Hydrophillidae, it may have been attracted to the roofs due to the large area of glass covering the building. Other studies have shown that polarizing artificial surfaces (such as large glass facades) can act as polarized ecological traps for positive polarotscytic insects (Schwind 1991; Malik et al. 2008).

Vegetation cover was influenced by building height, with forb cover decreasing with increasing roof height, but grass cover showing no clear correlation. Generally, plant communities on green roofs are influenced by factors such as substrate depth, maintenance, building height and green roof age (Madre et al. 2014) with plant establishment and persistence driven by the abiotic conditions (Mayrand and Clergeau 2018). Although the forb family richness was not correlated to beetle diversity and abundance, the percentage vegetation cover did influence beetle communities. Most green roof studies have linked total living vegetation cover and structural variation to arthropod diversity (Schindler et al. 2011; Petremand et al. 2018) with beetle abundance, for example, being mainly influenced by vegetation cover (Kyrö et al. 2018). However, any influence of vegetation diversity and vegetation cover will also need to consider the FFGs (i.e. what the species feed on) to understand the structuring community patterns. Haddad et al. (2009) had shown an interesting correlation between high plant diversity and arthropod herbivores diversity, with Ksiazek-Mikenas et al. (2018) postulating that greater plant diversity leads to more prey for the predatory beetle species to feed on. In our study, predators were the largest FFG compared with the detritivores and herbivores (present in much lower numbers), which would explain why vegetation cover influences abundance and diversity but not forb family richness. Generally, high levels of vegetation cover are positively correlated to size of ground predator populations (Haddad et al. 2009) and predation rates (Hertzog et al. 2017). The much smaller sample size of detritivores and particularly herbivores in the current study, however, does not allow for detecting clear patterns, as apart from six species (all predators), 73% of species typically only had one or two representatives in the samples. Studies on green roofs generally are more biased towards species, such as predatory beetles (Ksiazek-Mikenas et al., 2018) or pollinators (Colla, Willis, and Packer 2009).

In conclusion, this study has confirmed that green roofs support a diverse community of soil-dwelling beetles including some nationally rare or scarce species and that height of the roof can be an influencing factor. This highlights the importance of studies on vertical and horizontal connectivity between green roof, suggesting the surrounding natural habitats can increase the general ecological value of urban green spaces.

## Supplementary data

Supplementary data are available at *JUECOL* online.

## Acknowledgments

## References

Banting, D. et al. (2005) *Report on the environmental benefits and costs of green Roof Technology for the City of Toronto*, MPRA (Online) <https://mpra.ub.uni-muenchen.de/70526/> Last accessed 8 June 2020.

Berthon, K. et al. (2015) 'Confirmed at last: green roofs add invertebrate diversity'. *State of Australian Cities Conference 2015*. Sydney, Australia: Macquarie University.

Blank, L. et al. (2017) 'Horizontal and Vertical Island Biogeography of Arthropods on Green Roofs: A Review', *Urban Ecosystems*, **20**: 911–7.

Braaker, S. et al. (2014) 'Habitat Connectivity Shapes Urban Arthropod Communities: The Key Role of Green Roofs', *Ecology*, **95**: 1010–21.

Braaker, S. et al. (2017) 'Habitat Connectivity and Local Conditions Shape Taxonomic and Functional Diversity of Arthropods on Green Roofs', *Journal of Animal Ecology*, **86**: 521–31.

Brunke, A. J. (2016) 'First Detection of the Adventive Large Rove Beetle *Ocypus Nitens* (Schrank) in Canada and an Update of Its Nearctic Distribution Using Data Generated by the Public', *Biodiversity Data Journal*, **4**: e11012.

Coleoptera.org.uk. (2018) *UK Beetle Recording* (Online) <http://www.coleoptera.org.uk/> Last accessed 8 June 2020.

Colla, S. R., Willis, E., and Packer, L. (2009) 'Can Green Roofs Provide Habitat for Urban Bees (Hymenoptera: Apidae)?' *Cities and the Environment (Environment)*, **2**: 1–12.

Cook, W. M. et al. (2002) 'Island Theory, Matrix Effects and Species Richness Patterns in Habitat Fragments', *Ecology Letters*, **5**: 619–23.

Cook-Patton, S. C., and Bauerle, T. L. (2012) 'Potential Benefits of Plant Diversity on Vegetated Roofs: A Literature Review', *Journal of Environmental Management*, **106**: 85–92.

Donovan, T. M. et al. (1997) 'Variation in Local-Scale Edge Effects: Mechanisms and Landscape Context', *Ecology Ecological Society of America*, **78**: 2064–75.

Dunnett, N., Nagase, A., and Hallam, A. (2008) 'The Dynamics of Planted and Colonising Species on a Green Roof Over Six Growing Seasons 2001–2006: Influence of Substrate Depth', *Urban Ecosystems*, **11**: 373–84.

Dvorak, B., and Volder, A. (2010) 'Green Roof Vegetation for North American Ecoregions: A Literature Review', *Landscape and Urban Planning*, **96**: 197–213.

Ewers, R. M., and Didham, R. K. (2008) 'Pervasive Impact of Large-Scale Edge Effects on a Beetle Community', *Proceedings of the National Academy of Sciences USA*, **105**: 5426–9.

Gabrych, M., Kotze, D. J., and Lehvävirta, S. (2016) 'Substrate Depth and Roof Age Strongly Affect Plant Abundances on Sedum-Moss and Meadow Green Roofs in Helsinki', *Ecological Engineering*, **86**: 95–104.

Gardener, M. (2016) 'Comparison of Body Size and Wing Type in Beetles Found on Green Roofs and Adjacent Ground Sites in Portland, Oregon', University Honors Thesis Paper 332. DOI: 10.15760/honors.332.

Getter, K. L. et al. (2009) 'Carbon Sequestration Potential of Extensive Green Roofs', *Environmental Science & Technology*, **43**: 7564–70.

Gomez, G. S. M. Y., and Van Dyck, H. (2011) 'Ecotypic Differentiation between Urban and Rural Populations of the Grasshopper *Chorthippus Brunneus* Relative to Climate and Habitat Fragmentation', *Oecologia*, **169**: 125–33.

Google. (2018) *Google Maps* (Online). <https://www.google.co.uk/maps/@50.7621617,0.159765,1592m/data=! 3m1! 1e3? hl=en> Last accessed 8 June 2020.

Haddad, M. N. et al. (2009) 'Plant-Species Loss Decreases Arthropod Diversity and Shifts Trophic Structure', *Ecology Letters*, **12**: 1029–39.

Hertzog, L. R. et al. (2017) 'Plant Diversity Increases Predation by Ground-Dwelling Invertebrate Predators', *Ecosphere*, **8**: e01990. doi.org/10.1002/ecs2.1990.

Joimel, S. et al. (2018) 'Are Collembola "Flying" onto Green Roofs?' *Ecological Engineering*, **111**: 117–24.

Jones, E. L., and Leather, S. R. (2012) 'Invertebrates in Urban Areas: A Review', *European Journal of Entomology*, **109**: 463–78.

Kalmar, A., and Currie, D. J. (2006) 'A Global Model of Island Biogeography', *Global Ecology and Biogeography*, **15**: 72–81.

Ksiazek-Mikenas, K. et al. (2018) 'If You Build It, Will They Come? Plant and Arthropod Diversity on Urban Green Roofs over Time', *Urban Naturalist*, **1**: 52–72.

Kyrö, K. et al. (2018) 'Local Habitat Characteristics Have a Stronger Effect than the Surrounding Urban Landscape on Beetle Communities on Green Roofs', *Urban Forestry & Urban Greening*, **29**: 122–30.

Lott, D. A., and Anderson, R. (2011). *The Staphylinidae (Rove Beetles) of Britain and Ireland. Parts 7 & 8: Oxyporinae, Steninae, Euaesthetinae, Pseudopsinae, Paederinae, Staphylininae*. London: Royal Entomological Society.

Macivor, J. S. (2015) 'Building Height Matters: Nesting Activity of Bees and Waps on Vegetated Roofs', *Israel Journal of Ecology and Evolution* **62**: 88–96.

Macivor, J. S., and Lundholm, J. (2011) 'Insect Species Composition and Diversity on Intensive Green Roofs and Adjacent Level-Ground Habitats', *Urban Ecosystems*, **14**: 225–41.

Madre, F. et al. (2013) 'A Comparison of 3 Types of Green Roof as Habitats for Arthropods', *Ecological Engineering*, **57**: 109–17.

Madre, F. et al. (2014) 'Green Roofs as Habitats for Wild Plant Species in Urban Landscapes: First Insights from a Large-Scale Sampling', *Landscape and Urban Planning* , **122**: 100–7.

Malik, P. et al. (2008) 'Imaging Polarimetry of Glass Buildings: Why Do Vertical Glass Surfaces Attract Polarotactic Insects?' *Applied Optics*, **47**: 4361–74.

Matteson, K. C., and Langellotto, G. A. (2010) 'Determinates of Inner City Butterfly and Bee Species Richness', *Urban Ecosystems*, **13**: 333–47.

Mayrand, F., and Clergeau, P. (2018) 'Green Roofs and Green Walls for Biodiversity Conservation: A Contribution to Urban Connectivity', *Sustainability*, **10**: 985.

Met Office UK. (2018) *Regional Values—Annual 2017* (Online). @metoffice. <https://www.metoffice.gov.uk/climate/uk/summaries/2017/annual/regional-values> Last accessed 8 June 2020.

Minitab Inc. (2018). *Minitab* (Online). <http://www.minitab.com/en-us/> Last accessed 8 June 2020.

Mullen, J. D., Lamsal, M., and Colson, G. (2013) 'Green Roof Adoption in Atlanta, Georgia: The Effects of Building Characteristics and Subsidies on Net Private, Public, and Social Benefits', *Environmental Science & Technology*, **47**: 10824–31.

Natural History Museum. (2018a) *Ocypus (Matidus) nitens (Schrank, 1781)—Natural History Museum* (Online). <http://www.nhm.ac.uk/our-science/data/uk-species/species/ocypus_(matidus)_nitens.html> Last accessed 8 June 2020.

——. (2018b) *Protapion filirostre (Kirby, 1808)—Natural History Museum* (Online). <http://www.nhm.ac.uk/our-science/data/uk-species/species/protapion_filirostre.html> Last accessed 8 June 2020.

Newton, A. F. J. (1987) 'Four Staphylinus (Sensu Lato) Species New to North America, with Notes on Other Introduced Species (Coleoptera: Staphylinidae)', *The Coleopterists Bulletin*, **41**: 381–4.

Oberndorfer, E. et al. (2007) 'Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services', *BioScience*, **57**: 823–33.

Organic Roofs Ltd. (2018) *Award-Winning Green Roof Experts for New Builds and Retrofits* (Online). <http://www.organicroofs.co.uk/> Last accessed 8 June 2020.

Petremand, G. et al. (2018) 'Ground Beetle (Coleoptera: Carabidae) Communities on Green Roofs in Switzerland: Synthesis and Perspectives', *Urban Ecosystems*, **21**: 119–32.

Ruzicka, V. (1995) 'The Spreading of *Ostearius Melanopgius* (Araneae: Linyphiidae) through Central Europe', *European Journal of Entomology*, **92**: 723–6.

Sadler, J. P. et al. (2006) 'Investigating Environmental Variation and Landscape Characteristics of an Urban–Rural Gradient Using Woodland Carabid Assemblages', *Journal of Biogeography*, **33**: 1126–38.

Schindler, B. Y. et al. (2011) 'Factors Influencing Arthropod Diversity on Green Roofs', *Cities and the Environment (Environment)*, **4**: 1–22.

Schmidt, M. H. et al. (2006) 'Capture Efficiency and Preservation Attributes of Different Fluids in Pitfall Traps', *Journal of Arachnology*, **34**: 159–62.

Schwind, R. (1991) 'Polarization Vision in Water Insects and Insects Living on a Moist Substrate', *Journal of Comparative Physiology A*, **169**: 531–40.

Thuring, C., and Grant, G. (2016) 'The Biodiversity of Temperate Extensive Green Roofs—A Review of Research and Practice', *Israel Journal of Ecology and Evolution*, **62**: 44–57.

Timeanddate.com. (2018) *Weather in August 2017 in Brighton, England, United Kingdom* (Online). <https://www.timeanddate.com/weather/uk/brighton/historic?  month=8&year=2017> Last accessed 8 June 2020.

Waite, S. (2000) *Statistical Ecology in Practice: A Guide to Analysing Environmental and Ecological Field Data*. Harlow: Prentice Hall.

Woodcock, B. A., and Pywell, R. F. (2010) 'Effects of Vegetation Structure and Floristic Diversity on Detritivore, Herbivore and Predatory Invertebrates within Calcareous Grasslands', *Biodiversity and Conservation*, **19**: 81–95.

Zhang, X. et al. (2012) 'Barriers to Implement Extensive Green Roof Systems: A Hong Kong Study', *Renewable and Sustainable Energy Reviews*, **16**: 314–9.