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Research paper

Soil microarthropod community dynamics in extensive green roofs

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ABSTRACT

Green roofs are of increasing interest to ecologists, engineers and architects, as cities grow and aim to become more sustainable. They could be exploited to improve urban biodiversity and ecosystem services, yet almost nothing is known about them from a soil community ecology perspective, despite how critical soil food webs are to ecosystem functioning. This paper provides the first comprehensive study incorporating the annual cycle of green roof soil microarthropods.

Microarthropod communities were monitored over 14 months on two extensive green roofs. Abiotic factors, including substrate moisture, were recorded, as were biotic factors such as plant and mycorrhizal colonisation. Microarthropod interactions with these variables were then examined.

Microarthropod diversity was low overall, with a few dominant species peaking seasonally. On occasion, total abundance was comparable to other early successional soils. The majority of species present were drought tolerant collembola and xerophillic mites, suggesting that moisture levels on green roofs are a major limiting factor for soil microarthropods.

Our results suggest that the microarthropod community present in extensive green roof soils is impoverished, limiting the success of above-ground flora and fauna and ultimately the success of the roof as an urban habitat. We conclude that green roof building guidelines should incorporate soil communities in their design and should aim to be heterogeneous at the roof and landscape level, for the purpose of supporting soil biodiversity and creating sustainable habitats.

1. Introduction

Green roofs, i.e. intentionally vegetated roofs, are attracting the attention of ecologists as a novel urban habitat (Oberndorfer et al., 2007). They were developed to provide a range of environmental and economic benefits, from improving the energy efficiency of buildings (Jaffal et al., 2012) to carbon sequestration (Getter et al., 2009). They encompass a range of designs, from deep 'intensive' roofs to shallow (often less than 80 mm) 'extensive' roofs. The majority of UK green roofs are extensive, with a crushed red brick substrate and hardy plants of the genus *Sedum* (Grant, 2006). They are designed to be cost effective and low maintenance, but are a challenging environment for non-drought adapted plants (Dunnett and Kingsbury, 2004). Despite their harsh conditions, green roofs support rare insect communities (Kadas, 2006), birds (Fernandez-Canero and Gonzalez-Redondo, 2010) and local plant taxa (Molineux, 2010; Monterusso et al., 2005) and associated pollinators (Kadas, 2006). To date, little work has been done on below-ground communities, despite abundant evidence to suggest that these are inextricably linked to above-ground processes (Wardle et al., 2004).

Subterranean microarthropods regulate decomposition of organic matter, aid nutrient cycling and shape soil food webs (Moore et al., 1988). They also significantly affect plant (Ingham et al., 1985) and fungal (Finlay, 1985) growth and can assist movement of fungal spores through soil (Lilleskov and Bruns, 2005). Microarthropods are, therefore, a valuable asset, providing multiple ecosystem services. Despite their importance, they have received remarkably little attention in green roof research and design.

Mites and collembola are prevalent soil microarthropods in the majority of ground-level soils (Vreeken-Buijs et al., 1998) and are known to occur in green roof substrates. Two short-term studies, Schrader and Böning (2006) and Schindler et al. (2011) found collembola on green roofs, the latter finding Coleoptera, Hymenoptera and Chilopoda additionally, in low abundances. One longer study, that of Davies et al. (2010) reported that mites and collembola accounted for 80% of their roof emergence trap counts. To date, only these three studies have examined green roof soil invertebrates.

Unquestionably, two of the most important factors affecting plant growth on green roofs are the availability of soil organic matter and water (Nagase and Dunnett, 2011). In other field soils, many

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invertebrates (collembola in particular) are known to be limited by the availability of moisture (Verhoef and van Selm, 1983). Furthermore, arthropod species richness on roofs is known to be correlated with vegetation cover (Schindler et al., 2011). We therefore hypothesised that soil microarthropod abundance in green roofs would be related to plant cover and moisture availability. It is also well established that in plant communities there are complex interactions between soil invertebrates and soil microbes, principally arbuscular mycorrhizal (AM) fungi (Gange and Brown, 2002). To date, no study has searched for the presence of AM fungi in the roots of green roof plants. The predominant genus planted, *Sedum*, is known to form arbuscular mycorrhizal associations (Busch and Lelley, 1997), but as the plants are generally supplied by the horticultural industry as plugs or modular units, grown either indoors or outdoors, opportunities for mycorrhizal colonisation vary. Thus, our second hypothesis was that arbuscular mycorrhizal presence in green roof substrates would be low, due to a lack of inoculum and invertebrates to disperse it (Gormsen et al., 2004).

Cook-Patton and Bauerle (2012) suggest that a fuller exploration of animal–plant interactions needs to be performed on green roofs, combined with studying ways of enhancing diversity. The overall aim of our work is to do exactly this, but prior to any manipulative experiment, it is essential to characterise the existing community. Thus, the overarching aim of this paper is to characterise the green roof soil community and to understand the reasons for the occurrence (or not) of certain constituents. We present the first study to examine changes over an annual cycle of microarthropods in extensive green roof soils and determine what organisms constitute the green roof community and what challenges they face.

2. Materials and methods

2.1. Field sites

Two green roofs in the grounds of Royal Holloway, University of London, were used in this study (Roof A and Roof B). Both were built in April 2004 (so were 6–7 years old at the time of sampling) and were plug planted with *Sedum album*, *S. acre*, *S. spurium*, *S. kamtschaticum* and *S. rupestre*, in proportions of approximately 3.5:3.5:1:1:1, respectively. The substrate is 80% crushed brick and 20% organic matter (commercial compost) and is approximately 75 mm deep. These roofs are built to a homogenous industry standard, with equal depth and mix of substrate and planting at regular intervals. The roofs are within 40 m of one another and are 12 m high. Roof A is 1960 m^2 in area and B is approximately 2240 m^2. No fertilisation, supplementary watering or removal of naturally colonising plants has ever occurred.

2.2. Sampling

We adopted the method of stratified random sampling for soil invertebrates. Each roof was divided into 12 6 m × 12 m strata. On each sampling occasion, in each stratum, a 1 m^2 sample area was placed at random and two samples were taken from this with an 85 mm diameter soil corer, inserted down to the roof lining (75 mm). This method was chosen to overcome problems associated with aggregated soil invertebrate distributions (Ettema and Wardle, 2002), and resulted in a sample of 851.2 cm^3 at each sampling point. Larger amounts could not be removed for fear of permanently damaging the roof structure. Samples were taken at monthly intervals from March 2010 to April 2011 inclusive.

Samples were weighed to determine wet weight and microarthropods were extracted with Berlese Tullgren funnels for five days (MacFadyen, 1953) at approximately 18 °C. In March 2011, samples were separated into a moss and substrate layer and extracted separately to determine if invertebrates showed spatial separation. Dry weight was obtained from samples after extraction to determine the percentage water content of the substrate.

Invertebrates were stored in 70% ethanol until sorted to species/family level (collembola, commonest mites) or morphospecies (rarer mites, insect larvae) and counted using a dissecting microscope at 100×. Identification was carried out using a compound microscope at 400×.

Collembola were identified using Hopkin (2007). Mites were identified using Strandtmann (1971), Strandtmann and Davies (1972), Walter and Proctor (2001) and Krantz and Walter (2009).

2.3. Biotic factors

2.3.1. Arbuscular mycorrhizal fungi

AM fungal counts were obtained alongside invertebrate sampling in October 2010 by removing one portion of root from one individual of *S. kamtschaticum* in each plot. This plant was chosen because it was present in most plots. The procedure was only performed once, so as to limit the impact on the fragile roof community.

Visualisation of mycorrhizas in the roots was performed after clearing in 10% KOH with a modified ink staining method of Vierheilig et al. (1998), using commercial ink with 1% HCl. Percent root length colonised was obtained with the cross-hair eyepiece method of McGonigle et al. (1990). Presence of hyphae, vesicles and arbuscules were recorded at 200× magnification.

2.3.2. Plant cover and diversity

Plant cover and plant diversity estimates were obtained in April, June, July and November 2010 and April 2011 in the same plots used for invertebrate analysis. Individuals were counted and identified to species where possible. Additionally, vegetation cover was estimated by eye with the aid of a quadrat split into 1% fractions.

2.4. Abiotic factors

Daily and monthly average temperature readings were obtained from a weather station within Royal Holloway Earth Sciences department, situated on a roof approximately 300 m from our study site. Average rainfall for South-East England was obtained from Met Office records (Met Office, 2011).

2.5. Statistical analysis

All statistical tests were performed in SPSS 19.0. Normality tests were performed on whole data sets and data were transformed if necessary by $ln + 1$ or square root.

Differences between total microarthropod abundance over time were tested using a two-factor, repeated measures ANOVA, employing time and roof as main effects, and were also performed for collembola and mites separately. Months were separated with Tukey's HSD post hoc tests.

Relationships between organisms and abiotic and biotic factors were examined using linear and curvilinear regressions. Mites, collembola and total microarthropod abundance were the dependent factors and plant cover, plant diversity, mycorrhiza, temperature and substrate water content were the independent factors.

Diversity was measured using the Shannon Wiener Index and was calculated in four variations: all roof organisms, mite morphospecies, collembolan species and all organisms not belonging to mites or collembola. Data examining differences in mite and