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Green roof soil organisms: Anthropogenic assemblages or natural communities?

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ABSTRACT

Green roofs provide a range of ecosystem services, from stormwater retention to thermal insulation. They can also provide habitat for biodiversity, remediating land lost in development. However, few extensive green roofs are designed with this benefit in mind and, as such, biodiversity often does not reach its full potential. In particular, the soil ecology of green roofs is poorly understood, despite soil microorganisms having a large impact on nutrient cycling and thus plant diversity. In particular, whilst there are studies describing the soil microarthropods and microbial communities present on green roofs, little is known about how these species arrive there. This paper aims to determine how soil microarthropods and microbes colonise green roofs and which species survive post-construction, to inform green roof technosol design and to understand if remediation of impoverished green roof soils is possible. To do this, we conducted a preliminary study by analysing green roof construction materials (substrates and *Sedum* plugs) for microarthropods, bacteria and fungi before constructing a new green roof. We then monitored survival and independent colonisation over eleven months.

Whilst green roof substrates were a poor source of colonisation, *Sedum* plugs showed potential as a vehicle for colonisation by microbes and, especially, by soil microarthropods. However, the majority of the species present within *Sedum* plugs were not adapted to the harsh conditions of the green roof, resulting in high mortality. Two ubiquitist species, the Collembola species complex *Parisotoma notabilis* and a mite of the family Scutoverticidae survived in high abundance after the eleven month sample period, and the functional role of these species on a green roof should be investigated. Some species colonised independently during the study, highlighting that microarthropods and microbes in green roofs consist of a mix of anthropogenic assemblages and natural communities. Mycorrhizal fungi were extremely successful, independently colonising almost all *Sedum* plants by the end of the study. However, the absence of arbuscules suggests that this colonisation may not have a benefit to plant growth in this instance.

Demonstrating that the succession of soil organisms is influenced by the communities present in construction materials has implications for substrate design, demonstrating that soil organisms may be inoculated onto green roofs to provide functioning technosols. In addition, the independent colonisation of mycorrhiza in this study stimulates discussion about the role of commercially applied mycorrhizal fungi in green roof construction.

1. Introduction

Green roofs are one of many anthropogenic habitats that could contribute to urban biodiversity by supporting local fauna and flora. Many green roofs are built following an ‘extensive’ design of shallow substrates planted with succulents such as *Sedum* spp. These are designed to benefit buildings from an engineering perspective by, for example, reducing stormwater runoff (VanWoert et al., 2005) or insulating buildings from seasonal temperature fluctuations (Jaffal et al., 2012) as well as improving the aesthetics of the roof. These extensive green roofs do support floral and faunal diversity, but often few features are designed specifically for this objective. As a result, biodiversity is often limited (Williams et al., 2014), overlooking the fact that many organisms directly influence, and can improve, engineering properties, providing ecosystem services (Blouin et al., 2013; de Vries et al., 2013). Below-ground biodiversity is particularly important in this regard, because soil properties and thus function are known to be altered by soil communities (Lavelle et al., 2006).

The ability of a habitat to support biodiversity relies on the colonisation ability and subsequent survival of the organisms colonising.

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Whilst there are now numerous studies describing aspects of green roof ecology at different stages of development (see: Williams et al., 2014), little research has been focussed on the initial stages of green roof construction or the 'virgin' green roof state, a key element of baseline data needed to understand colonisation and successional processes. It is thought that green roof substrates are virtually inert pre-construction, due to the practise of firing substrates to remove seed banks and a lack of opportunity for natural colonisation thereafter (Emilsson, 2008). But personal observations by the authors note that often substrates are then stored outside, and within *Sedum* nurseries plants are typically grown outdoors or in non-sterile glasshouses, affording two opportunities for pre-construction colonisation of materials by microarthropods.

Many soil microarthropods are relatively immobile, particularly in terms of active transport (Wallwork, 1970), and may not be able to colonise green roofs by their own means post-build, especially considering that these roofs are not usually connected to ground level soils. Braaker et al. (2014) found that for above-ground insects, the relative inaccessibility of green roofs means that only the most mobile species are able to colonise them, suggesting that green roof communities are often driven by organism dispersal ability rather than suitability of the habitat. This could have a number of negative consequences, including green roofs acting as a sink habitat for species, either when mobility changes (e.g. when offspring are born, see: Baumann, 2006) or when environmental conditions change due to season or weather (e.g. during drought, see: Rumble and Gange, 2013), resulting in a loss of biodiversity. In addition, a collection of species colonising an environment based on their mobility, rather than on adaptations to their environment could mean that sustainable communities form slowly, or not at all, hampered by environmental conditions. Rumble and Gange (2013) investigated this within green roof substrates, finding that below-ground biodiversity was not sustainable, due to a lack of resilience in the community to drought. Studies on ground-level soils suggest that even without the challenges green roofs present to less-mobile species, microarthropod colonisation into virgin soils can take 10–20 years. This could represent more than a fifth of a green roofs overall life span (Porsche and Köhler, 2003), so mechanisms to speed this process up or biologically enhance roof technosols could be an important factor in ensuring green roofs provide maximum functionality and ecosystem service provision.

In order to produce green roofs with sustainable, diverse, soil communities it is, therefore, important to understand how species colonise green roofs and how this may be facilitated. There are two key stages in a green roof's development when soil organisms may colonise a green roof. The first is pre-build, within construction materials, which to our knowledge has not been investigated. The second is post-build via natural colonisation, for example by passive methods such as phoresy and aerial dispersal. The latter have not been investigated for green roofs, but are well-established as dispersal methods for other habitats (Flø and Hågvar, 2013)

As extensive green roofs are designed to be low maintenance after construction, it has been suggested that the design of pre-build construction materials is key, with several papers aiming to develop green roof substrates that support sustainable plant communities from the onset (Molineux et al., 2009; Odonõ No et al., 2014). In addition, we suggest that the design of green roof components should take soil organisms into consideration, as this is potentially a key element in ensuring later sustainable development of substrates and plant communities (Wardle et al., 2004). As technosols, green roof substrates can, in theory, be designed and tailored to support desired species communities. This could benefit plant growth as well as support higher faunal trophic levels by supplying prey, improving overall green roof biodiversity. Understanding whether there is an incumbent soil community within construction materials could inform this technosol design, allowing the creation of biologically active technosols or technosols that facilitate colonisation and survival. Rumble and Gange (2013) suggest that at least some colonisation of arthropods occurs post-build, but the contribution of these species compared to those arriving in construction materials is not yet known. Understanding how soil microorganisms colonise and proliferate on green roofs could determine if healthy soil could be installed on already existing green roofs for remediation purposes, to facilitate colonisation and potentially provide refugia in times of environmental change. So little is known about how species colonise green roofs, that a preliminary study was undertaken to address these questions and to highlight areas of future research.

The study had two primary aims. The first was to determine if current green roof building materials, i.e. *Sedum* plugs (in their residual soil) and substrate, contain soil microorganisms and microbes before a green roof is constructed. If so, these materials could act as the only source of less mobile, but functionally important, species, thereby addressing a research priority area highlighted by Braaker et al. (2014). The second aim of the study was to determine whether species within green roof building materials then go on to make up the communities found in more mature green roofs. It was hypothesized that in a green roof substrate, where there is probably little incumbent community, the foundation community will have an important impact on the later development of the roof. In addition to these main aims, this paper builds on the work of Wanner and Dunger (2002), developing our understanding of soil community development in virgin soils.

2. Materials and methods

2.1. Experimental site

In June 2011, a new green roof was constructed on a roof within the Royal Holloway grounds (London, UK; N 51.25350, W 0.33469) in the South East of England. The roof was constructed in a modular design using trays (for layout, see Supplementary Material 1). Five of these trays (replicates) were used in the current preliminary study, all other trays were part of a larger study (Rumble, 2013). Trays were of dimension 0.52 m by 0.42 m by 0.10 m and were installed at approximately 20 m from ground level, with 0.30 m between each tray. Holes were drilled in each tray to allow water to drain freely and each tray was lined with a filter sheet (ZinCo SF, ZinCo GmbH, Nürtigen, Germany) to prevent leaching of particulate matter. An extensive substrate mix (Shire Green Roof Substrates, Southwater, Kent, UK), consisting of crushed red brick with 10% organic matter (rough compost), was added to each tray to a depth of 0.08 m. This depth is within the range commonly used on extensive green roofs (FLL, 2008) and has been used in previous studies (Molineux et al., 2015), making comparison between studies viable. The bricks that this substrate is made from are obtained from the county of Cambridgeshire, UK, where they are fired during the brickmaking process. Bricks that are not of a suitable standard are crushed and stored outside in 1 tonne bags, creating the potential for seeds and microarthropods to colonise prior to green roof construction. This is standard practise for green roof substrates and as this experiment is designed to replicate what would happen on a real green roof, no modifications (such as autoclaving) were applied to the substrate. Mixing and packing of the substrate was supervised by the authors. Five samples of substrate each of 166 cm^3 were then checked for the presence of microarthropods and a microbial community before being installed.

Trays were planted with nine *Sedum* plugs each, three of *S. album* (Linnaeus, 1753), three of *S. spurium* (Marschall von Bieberstein, 1808) and three of *S. reflexum* (Linnaeus, 1753). These had been grown in a greenhouse by an industry supplier (*Sedum* Green Roof Ltd, Wiltshire, UK). After consultation with several green roof manufacturers (*Sedum* Green Roof Ltd, Wiltshire, UK; Shire Green Roof Substrates, Kent, UK; SkyGarden, Gloucestershire, UK) about the density at which plugs are normally planted, a distance of 0.1 m between each plant was used (the quotes given varied between 0.1 and 0.2 m). These plugs were planted uniformly, but the order in which they were planted was random. No attempt was made to remove the soil the plugs arrived in, again to