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Research paper

Investigation of weed phenology in an establishing semi-extensive green roof

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ABSTRACT

Although weeding is one of the most time consuming tasks in green roof maintenance, there have been few studies of weed phenology and it is not clear how planting design affects weed colonisation on green roofs. This study investigated weeds including self-sowing planted species during the establishment period in a semi-extensive green roof in Rotherham, UK. This green roof was installed in the summer of 2005, and 54 plant species were planted in 10 cm (areas with gravel mulch) and 20 cm (areas without mulch) of the substrate. The planting density was 18–22 plants/m^2. Thirty-two quadrats (50 × 50 cm) were set up through the combinations of plant species diversity (high and low), planting density (high and low), four aspect and covering 2.5 cm of gravel mulch (with and without). Drip irrigation was installed for supplementary watering in dry seasons. All weeds and self-sowing in each quadrat were not removed. The remainder of the roof was weeded six times in this period. Nine weed species were found on the green roof. They were all native species and could have value of biodiversity. High planting density reduced weeds effectively whereas plant diversity did not affect weed colonisation significantly. Moreover, the use of gravel mulch significantly reduced the number of weeds. Knowing phenology of expected weeds allows targeting maintenance to remove them before they set seeds. 29 species planted on this green roof were self-sowing, *Allium schoenoprasum*, *Campanula rotundifolia*, *Festuca* spp. and *Petrorhagia saxifraga* showed a very high number of seedlings.

1. Introduction

Recently, the use of green roofs has received considerable attention and the number of papers related to green roofs is increasing rapidly. At present, the environmental benefits of green roofs seem to be most frequently studied (Berndtsson, 2010; Sailor and Hagos, 2011; Tonietto et al., 2011). Other examples of research topics are the adaptation of plants to the green roof environment (Butler and Orians, 2011; MacIvor and Lundholm, 2011; Rowe et al., 2012), substrate composition for green roofs (Emilsson, 2008; Nagase and Dunnett, 2011; Molineux et al., 2009.) and social aspects of green roofs (Francis and Lorimer, 2011; Kosareo and Ries, 2007). However, there has been little research on green roof maintenance. Green roof maintenance tends to rely on people's experience, and information on green roof maintenance is mainly obtained from books (Dunnett and Kingsbury, 2008; Weiler and Scholz-Barth, 2009; Snodgrass and McIntyre, 2010). Lack of scientific evidence on green roof maintenance may result in inappropriate plant selection and planting design and lead to a high maintenance cost. It has been reported that the increased maintenance cost could be a barrier to the implementation of green roofs (Zhang et al., 2012) and reduction of the maintenance cost may be an important initiative for installing green roofs. In some countries, such as Germany, Switzerland, the United States of America and Japan, governments encourage the installation of green roofs through policy, direct and indirect regulation, and financial incentives, and funding of demonstration or research projects (Carter and Fowler, 2008). However, they tend to be limited to the encouragement of new green roof construction and not green roof maintenance. Moreover, maintenance may be a continuing concern for green roof owners because the maintenance cost may not be guaranteed for a long period in many cases.

Different types of green roofs may have different maintenance requirement. Usually, a set of simple annual tasks such as plant protection, checking drainage and weeding is carried out for extensive and semi-extensive green roofs which are light-weight green roof systems in which mainly herbaceous plants are used (Dunnett and Kingsbury, 2008). Intensive green roofs, which have a thicker

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substrate and various types of plant species, require maintenance operations such as the weeding of undesirable plants, fertilisation, infilling bare spots (with cuttings, plugs or seeds), replacing eroded substrate, pruning vegetation back from building structures and cleaning plant debris from roof drains (Getter and Rowe, 2006). However, it is important to note that the requirement of maintenance may depend on the planting design intent. For example, lawn cover extensive roofs may require high maintenance to keep tidy and aesthetic. On the contrary, naturalistic intensive green roofs may allow weed colonisation to get more diversity benefits such as like a green roof in Ministry of land, infrastructure transportation and tourism in Japan.

Weeding is one of the most important and time-consuming maintenance tasks for any type of green roof. In this paper, weeds are defined as spontaneously colonising plants without the grower's intention. Weeds may grow aggressively, compete for nutrients and water and often shade out desirable plants (Weiler and Scholz-Barth, 2009). Weeds can be brought in with the growing medium, with the wind, by birds or through the shoes, clothing and tools of people installing or maintaining the roof (Snodgrass and McIntyre, 2010). Weeds are also brought onto roofs with the plants, and as contaminants in any seed-mixes used. However, height above the ground in green roofs may exclude heavier weed seeds and some herbivores and dispersers. Weeding is important for garden type of green roofs for healthy growth of planted plants and for aesthetic. However, extensive green roofs, particularly those of the meadow type, may allow plant colonisation to have a fully covered vegetation layer. It is required to remove vigorous weeds such as willow, birch and buddleia regularly (Grant, 2006). These vigorous weeds tend to compete with desired plants for nutrients, water, sunlight, and other resources (Allaby, 2006). Their roots can also damage roof components such as the waterproofing membrane (Luckett, 2009).

Weed control can be more efficient if urban ecosystems are understood. Although some studies have reported plant colonisation in green roofs (Dunnett et al., 2007; Köhler, 2006; Köhler and Poll, 2010), there has been little research on the efficacy of using planting design to reduce weeds on green roofs. Seed establishment may be influenced by space, light, nutrient and moisture availability. Three methods are typically used to reduce weeding in urban landscapes with the methods being (1) exclude light at ground surface using sufficient height and density of plants, self-mulching plants or mulch (Hitchmough, 1994), (2) Use high plant diversity (Cook-Patton and Bauerle, 2012; Lundholm et al., 2010; Nagase and Dunnett, 2010, 2012), (3) remove parent plants before seed is physiologically capable of germination. Many previous ecological studies have suggested that resident biodiversity is an important determinant of invasion success, arguing that high diversity increases the competitive environment of communities and makes invasion more difficult (Funk et al., 2008; Levine, 2000; Naeem et al., 2000; Zimdahl, 2004).

Some plant species, commonly planted for green roofs, could be self-sowing; they disperse seeds freely and the seeds germinate quickly. In this paper, self-sowing is defined as seed dispersion from planted species. For example *Allium* spp. which was planted initially self-sow well and this is one of the most dominant species on the extensive green roof installed in 1985 in Berlin (Köhler and Poll, 2010). Self-sowing planted species can be valuable or problematic, depending on the situation (Hitchmough, 2004). In meadow planting, self-sowing may be recommended to be planted to fill gap, however, if the other plants are displaced, it could present a problem. Plant establishment from vigorous self-sowing seeds can be minimised by using species that do not produce viable seed in the region and cutting before the seed is physiologically capable of germination (Hitchmough, 1995). Several studies have been conducted to identify the plant species that are self-sown in Britain on the ground (Clement and Foster, 1994; Hitchmough and Woudstra, 1999). However, it is necessary to study self-sowing plants on green roofs because the microclimate on a green roof tends different from that on the ground (e.g. drought, extreme temperature, high light intensity and high wind speed).

Fig. 1. Overview of green roof.

This study investigated weeds, including self-sowing planted species, in a semi-extensive green roof, case study in Rotherham, UK. Our first goal was to understand the dynamic changes in the weeds and self-sowing plants on the green roof over a year. We aimed to suggest appropriate maintenance season and frequency, to reduce maintenance costs and to estimate maintenance costs more accurately and to enable more careful selection of self-sowing plants. Our second goal was to identify which factors (plant species diversity, plant density, mulch, substrate depth) in the planting design may affect weed colonisation. This provides useful information because the planting design tends to influence weeds colonisation significantly after the installation of green roofs. If planting design influences weed composition, then appropriate planting design could reduce maintenance costs. Plant species diversity, plant density and mulching were studied to test this hypothesis.

2. Methods

This experiment was conducted between February and November 2006 on the fourth storey of a commercial building; Moorgate Crofts Business Centre in Rotherham, North England (Latitude: 53.433°, Longitude: −1.356°). An area of 415 m^2 of accessible green roof was constructed on the roof (770 m^2) in the summer of 2005. There was additional building on the third floor, and the building was surrounded by the green roof. A picture and floor plan of the green roof are shown in Figs. 1 and 2, respectively.

The green roof consisted of a vapour control barrier (Hi-Ten Universal vapour barrier), 9 cm of insulation (Alumasc BGT polyurethane insulation), a waterproofing membrane (Derbigum), a root barrier (Preventol B2), a geotextile made of polypropylene with fleece backing for green roof drainage (SSM45), a drainage layer (Floradrain FD 40), a filter sheet (SF) and a substrate (Zinco heather and lavender substrate: ≤15% of granules that were <0.063 mm in diameter, salt content ≤2.5%, total porosity 64%, pH 7.8, dry weight 940 kg/m^3, saturated weight 1360 kg/m^3, maximum water capacity 42%, air content at maximum water capacity 22%, water permeability ≥0.064 cm/s). The substrate analysis was