Ecological Engineering 82 (2015) 301–310

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Effects of varying organic matter content on the development of green roof vegetation: A six year experiment

Adam J. Bates[a,*], Jon P. Sadler[b], Richard B. Greswell[b], Rae Mackay[c]

[a] Biosciences, School of Science & Technology, Nottingham Trent University, Clifton, Nottingham NG11 8NS, UK
[b] Geography, Earth & Environmental Sciences, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[c] School of Engineering and Information Technology, Federation University Australia, Gippsland Campus, Victoria 3800, Australia

ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form 2 April 2015
Accepted 28 April 2015
Available online 7 June 2015

Keywords:
Brown roof
Development mitigation
Drought disturbance
Productivity diversity
Recycled aggregate
Succession

ABSTRACT

Green roofs can potentially be used to tackle a variety of environmental problems, and can be used as development mitigation for the loss of ground-based habitats. Brown (biodiversity) roofs are a type of green roof designed to imitate brownfield habitat, but the best way of engineering these habitats requires more research. We tested the effects of altering organic matter content on the development of vegetation assemblages of experimental brown (biodiversity) roof mesocosms. Three mulch treatments were tested: (1) sandy loam, where 10 mm of sandy loam mulch (about 3% organic matter by dry weight) was added to 100 mm of recycled aggregate; (2) compost, where the mulch also contained some garden compost (about 6% organic matter by dry weight); and (3) no mulch, where no mulch was added. Mesocosms were seeded with a wildflower mix that included some *Sedum acre*, and vegetation development was investigated over a six-year period. Species richness, assemblage character, number of plants able to seed, and above-ground plant biomass were measured. Drought disturbance was an important control on plant assemblages in all mulch treatments, but there were significant treatment response interactions. The more productive compost treatment was associated with larger plant coverage and diversity before the occurrence of a sequence of drought disturbances, but was more strongly negatively affected by the disturbances than the two less productive treatments. We suggest that this was due to the over-production of plant biomass in the more productive treatment, which made the plants more vulnerable to the effects of drought disturbance, leading to a kind of 'boom-bust' assemblage dynamic. The 'ideal' amount of added organic matter for these green roof systems was very low, but other types of green roof that have a larger water holding capacity, and/or more drought resistant plant floras, will likely require more organic matter or fertiliser. Nonetheless, nutrient-supported productivity in green roof systems should be kept low in order to avoid boom-bust plant assemblage dynamics. Research into the best way of engineering green roof habitats should take place over a long enough multi-year time period to include the effects of temporally infrequent disturbances.

1. Introduction

Green roofs are associated with a wide range of potential environmental and societal benefits including building insulation and cooling, improved roof materials longevity, improved well-being, air pollution removal, reduced storm-water runoff, urban cooling, and habitat provision (Bengtsson, 2005; Brenneisen, 2006; Mentens et al., 2006; Oberndorfer et al., 2007; Yang et al., 2008; Castleton et al., 2010; Francis and Lorimer, 2011; Rowe, 2011; Rumble and Gange, 2013; Li et al., 2014; Loder, 2014). Extensive green roofs use relatively thin (<20 cm) growth substrates, and do not usually require the substantial roof reinforcement and maintenance input often associated with intensive green roofs (Oberndorfer et al., 2007). Therefore, extensive green roofs could be installed on new-builds or retrofitted to existing buildings across wide areas, potentially contributing to the alleviation of a range of environmental problems (Dunnett and Kingsbury, 2004; Getter and Rowe, 2006). The approaches and materials used to construct an extensive green roof will however strongly influence its environmental benefits (Simmons et al., 2008; Bates et al., 2009; Rowe, 2011). So, for example, designing a roof to try and maximise its potential biodiversity benefit might trade-off against its ability to delay and store storm water (Bates et al., 2009).

* Corresponding author. Tel.: +44 115 8483126.
E-mail addresses: adam.bates@ntu.ac.uk (A.J. Bates), j.p.sadler@bham.ac.uk (J.P. Sadler), r.b.greswell@bham.ac.uk (R.B. Greswell), rae.mackay@federation.edu.au (R. Mackay).

http://dx.doi.org/10.1016/j.ecoleng.2015.04.102
0925-8574/

This research focuses on a type of extensive green roof designed mainly for habitat creation, which are often called brown or biodiversity roofs (Gedge, 2003; Grant, 2006; Bates et al., 2013, 2015; Ishimatsu and Ito, 2013). Brown roofs are designed to replicate brownfield habitats, which are also known as derelict, post-industrial, or wasteland sites. Because of the need for new development and their perceived low visual appeal, brownfield sites are often lost to development (Harrison and Davies, 2002; Thornton and Nathanail, 2005; Dallimer et al., 2011; Sadler et al., 2011; Hofmann et al., 2012). However brownfield habitats can be diverse and valuable wildlife habitats (Gilbert, 1989; Small, et al., 2003; Woodward et al., 2003), and are now often considered habitats worthy of conservation (Harrison and Davies, 2002; Donovan et al., 2005). The construction of brown roofs attempts to partially mitigate the loss of brownfield habitat on the ground by creating brownfield habitats on roofs (Gedge, 2003; Grant, 2006; Sadler et al., 2011). Brown roofs can be associated with rare species and diverse wildlife assemblages (Brenneisen, 2006; Kadas, 2006; Francis and Lorimer, 2011), but more research is required to properly understand which design approaches and construction materials best support biodiversity. Vegetation takes time to establish on green roofs, and many vegetation characteristics vary from season to season due to periods of water shortage and successional processes, so medium and long-term investigations of green roofs will likely generate more robust findings than short-term ones (Köhler, 2006; Dunnett et al., 2008; Köhler and Poll, 2010; Nagase and Dunnett, 2010; Rowe et al., 2012; Bates et al., 2013, 2015; Ishimatsu and Ito, 2013; Lundholm et al., 2014; Thuring and Dunnett, 2014).

Like other types of green roofs, plant growth on brown roofs is strongly controlled by characteristics of the growth substrate such as depth, porosity, water retention, organic matter content, nutrient availability, and soil microbe assemblages (Dunnett and Kingsbury, 2004; Nagase and Dunnett, 2011; Olly et al., 2011; Bates et al., 2013, 2015; Graceson et al., 2014b; Molineux et al., 2014). Well-designed brown roofs share many of the substrate characteristics of brownfield habitat, such as containing areas of bare ground, diverse substrate types and depths, and replication of brownfield substrate characteristics (Brenneisen, 2006; Kadas, 2006; Bates et al., 2009; Madre et al., 2014). Brown roof substrates will therefore often be made up of recycled demolition materials or industrial waste aggregates and include large clasts, which can limit water holding capacity, making them vulnerable to drought disturbance (Kadas, 2006; Molineux et al., 2009; Bates et al., 2013, 2015).

Some theories predict that species diversity has a humped relationship with productivity, is highest at low to intermediate levels of productivity, and that this varies with disturbance regime (Grime, 1973; Huston, 1979; Michalet et al., 2006). However, a wide variety of productivity – diversity relationships have been predicted and detected, and there is also particular support for a positive monotonic relationship with productivity (Abrams, 1995; Mittelbach et al., 2001; Gillman and Wright, 2006; Adler et al., 2011). The main controls of plant productivity on green roofs are likely to be water availability, and nutrient availability from fertiliser or organic matter. During long periods of water shortage, substantial plant mortality can result, and a low productivity due to a lack of water can become a drought disturbance. We believe that the interplay of productivity and disturbance in both brown and green roof systems may well control plant assemblage dynamics. Responses to productivity and disturbance are species specific, and consideration of general life history strategies of plants, such as the competitive stress-tolerant ruderal strategies of Grime (1977) in green roof research (Lundholm et al., 2014) have proved fruitful.

This document describes the effects over a six-year (medium-term) period, of the experimental addition of two types of mulch on the diversity, character and amount of brown roof vegetation. This experiment aimed to assess the relative suitability of the two organic matter treatments for the growth of brownfield-like, wildflower vegetation on green roof mesocosms. Specifically, our objectives were to test the effect of organic matter content, time and weather conditions on the: species richness of the forb assemblage, characteristics of that assemblage, ability of plant species to complete their life-cycle (i.e. to seed), structure of the habitat (e.g. coverage of bare ground and moss), and distribution of above-ground plant biomass in that assemblage.

2. Materials and methods

2.1. Study roof test array

The study site was at The University of Birmingham, UK (52″27′01.54″N, 1″55′43.41″W), which has a temperate maritime climate. The green roof test array was installed on a flat 5-storey building roof and completed in May 2007. The edge of the roof had a solid safety parapet of about 1.5 m height, but due to the need to distribute weight through the building support columns, the green roof mesocosms were elevated about 1m above the roof and so were more directly exposed to wind and air circulation above and below the mesocosms (Fig. 1). This meant that the study mesocosms would likely have different temperature and evapo-transpiration regimes than if the mesocosms had been sited on the roof surface. However, doing the same experiment on a roof without a solid safety parapet, or on a roof of a different height might produce similar differences in microclimate, and the between-treatment findings should remain robust.

Each mesocosm was separated by at least a 50 cm air gap, meaning that plants were only able to spread propagules between replicates via wind or bird movement. Mesocosms were distributed using a stratified–randomised approach. Each column in Fig. 1 represented a strata, and the upper and lower half of the rows represented a strata. Positions of treatments/controls were allocated randomly, providing no more than three of each treatment/control were distributed in each strata. This approach equalised, as far as possible, the effects of unwanted environmental variation (e.g. difference in exposure to wind, and potential bias due to sampling order), but still allowed randomisation within strata.

2.2. Study mesocosms

The study mesocosms were designed to replicate real extensive green roofs, with drainage and filter layers underlying the different growth media treatments (Fig. 2). The mesocosm containers were built from 2.44×1.22 m plywood sheets with 47 mm wide by 150 mm deep timber sides, which were water-proofed and root-protected using polyester reinforced PVC. The 'egg-box' drainage board that covered the floor of the mesocosm container had fines filters at the top and bottom, and fines were prevented from flowing around the edge of this board with the installation of an IKO filter fleece around the edge. The mesocosms were on a 2° slope and drained in one corner with a 50 mm diameter domestic bath plug-hole.

Recycled crushed demolition aggregate (40 mm down) was added to approximately 100 mm depth (approximately 110 mm in the control, see below). This aggregate was a material produced from the demolition of buildings that had been stripped of glass, paint and other contaminants, with further treatment to remove silts and clays. The material can be highly variable, but in this case was mainly concrete, pebbles, brick, ceramics, and sand. Tests of