Landscape and Urban Planning 130 (2014) 125–133

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Species interactions in green roof vegetation suggest complementary planting mixtures

Amy Heim*, Jeremy Lundholm

Biology Department, Saint Mary's University, 923 Robie St., Halifax, NS B3H 3C3, Canada

HIGHLIGHTS

- Tested ability of 3 species to facilitate a forb species on a green roof.
- We compared the growth of the target forb with and without neighbours.
- Forb coexisted with lichen and moss neighbours; these reduced substrate temperatures.
- The bunchgrass reduced the growth of the target forb.
- Species diversity may improve resilience and performance of green roof systems.

ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form 9 July 2014
Accepted 14 July 2014

Keywords:
Coexistence
Moss
Lichen
Competition
Facilitation
Extensive green roofs

ABSTRACT

Facilitation between species could be used to increase the number of plant species that can survive on an extensive green roof. Green roofs are associated with high substrate temperatures and water loss which can lead to plant death. Therefore, species that are known to cool substrate temperatures and reduce water loss may be able to act as facilitators. Three drought tolerant, mat-forming species native to Nova Scotia were tested. Species included *Cladonia* spp. (lichen), *Polytrichum commune* (acrocarpous moss), and *Danthonia spicata* (bunchgrass). The target species was the forb *Solidago bicolor*. Additional neighbour treatments included an artificial plant, conspecific neighbours (*S. bicolor* surrounded by 8 *S. bicolor*), and a no-neighbour control. This study was conducted over a two year period in green roof modules. Overall, none of the neighbour treatments appeared to facilitate the growth of *S. bicolor* species. However, the *S. bicolor* in both the moss and lichen treatments had similar growth measurements to the control, likely due to a mulching effect, an indication that these species can successfully co-exist. Additionally, the substrate temperature in the lichen and moss treatments was significantly cooler than the control. The bunchgrass treatment had a net competitive interaction with *S. bicolor*. However since no *S. bicolor* died in this treatment the smaller stature of the *S. bicolor* in these treatments may improve drought tolerance. Overall, the incorporation of functional diversity, especially varied growth forms, increases the diversity of green roofs potentially improving the resilience and performance of green roof systems over the long term.

1. Introduction

Over the past 10 years, the use of green roofs for environmental and ornamental purposes has become prominent in North America. This trend can be attributed to the green roof's ability to mitigate the effects of urbanization, including higher ambient temperatures, air pollution and storm water runoff. Because the modern green roof industry is relatively young, having originated in Germany at the turn of the 20th century (DeNardo, Jarett, Manbeck, & Beattie, 2005; Oberndorfer et al., 2007; Thuring, Berghage, & Beattie, 2010), and has received little attention from ecologists until recently, there are still unanswered questions about the role of vegetation on green roofs. This is particularly true in North America, which has only recently begun to develop living architecture (Oberndorfer et al., 2007). The way a green roof is constructed affects the potential benefits that the roof has to offer (Olly, Bates, Sadler, & Mackay, 2011; Simmons, Gardiner, Windhager, & Tinsley, 2008). For example, a roof with a deeper substrate and a shallow slope can hold more moisture and nutrients than a roof with a shallow substrate and a steeper slope (Getter, Rowe, & Andresen, 2007; Olly et al., 2011). Additionally, taller species with higher water demands, such

* Corresponding author. Tel.: +1 585 749 0890.
E-mail addresses: heim.amy.e@gmail.com (A. Heim), jeremy.lundholm@smu.ca (J. Lundholm).

http://dx.doi.org/10.1016/j.landurbplan.2014.07.007

as graminoids, can be more effective at reducing storm water runoff compared to shorter species with conservative water use such as *Sedum* (MacIvor & Lundholm, 2011; Nagase & Dunnett, 2012). There are two main types of green roofs. Intensive green roofs have substrate layers deeper than 20 cm and extensive green roofs which have substrate layers less than 20 cm. Due to weight restrictions, many consumers are interested in extensive green roofs (Carter & Butler, 2008; Castleton, Stovin, Beck, & Davison, 2010; Olly et al., 2011). However, the shallow substrate depths limit the number of species that can survive and the majority of extensive green roofs are planted solely with species of *Sedum* (MacIvor & Lundholm, 2011; Nagase & Dunnett, 2010).

The lack of diversity on green roofs can be partially attributed to the harsh conditions on the rooftop, which include drought, extreme temperatures and high winds (Oberndorfer et al., 2007). The species that can subsist in this type of environment tend to have particular characteristics that have evolved to improve their survival (Nagase & Dunnett, 2010). These characteristics include a low, compact or matted growth form with evergreen, succulent or tough and twiggy foliage. The leaves tend to be small, flat, waxy, dense and/or hairy (Nagase & Dunnett, 2010; Oberndorfer et al., 2007), reflecting adaptations to dry environments (Orians & Solbrig, 1977). The plant species used on extensive green roofs should be found naturally occurring in habitats that reflect the extreme conditions of the roof, such as rocky outcrops and costal barrens (Farrell, Szota, Williams, & Arndt, 2013; MacIvor & Lundholm, 2011; Van Mechelen, Dutoit, & Hermy, 2014). In Nova Scotia several native species that are found growing on the coastal barrens have been tested on extensive green roofs, including forbs (*Solidago bicolor*, *Campanula rotundifolia* and *Sibbaldiopsis tridentata*), Creeping shrubs (*Empetrum nigrum*, *Vaccinium angustifolium* and *Vaccinium marcocarpon*) and graminoids (*Danthonia spicata*, *Deschampsia flexuosa*, and *Festuca rubra*) (Heim et al., 2014; MacIvor & Lundholm, 2011).

In natural ecosystems species diversity has been associated with increased ecosystem services (Nagase & Dunnett, 2010), therefore diverse plant species mixtures on green roofs could be beneficial to the overall system. For example, graminoids such as *Carex* spp. have been shown to be some of the best performers at reducing substrate temperatures and storm water runoff compared to species of *Sedum* and forbs (MacIvor & Lundholm, 2011; Nagase & Dunnett, 2012; Wolf & Lundholm, 2008). Forb species suitable to the green roof environment can provide foraging resources for pollinators (Tonietto, Fant, Ascher, Ellis, & Larkin, 2011). Additionally, the extreme drought tolerance of certain *Sedum* and moss species may allow substrate cooling and water capture to continue even when other less drought tolerant species have died back (Anderson, Lambrinos, & Schroll, 2010; Heim et al., 2014). Since species diversity is associated with an increase in the aesthetic appeal of the roof (Lee, Williams, Sargent, Farrell, & Williams, 2014; Nagase & Dunnett, 2010), combining different plant types in one system would allow the consumer to take advantage of each species' individual traits while enhancing the aesthetic value of the roof.

While green roofs are commonly planted with multiple species, studies of plant mixtures on green roofs over time show that diversity often declines from the originally planted mixture (Dunnett, Nagase, & Hallam, 2008; Kohler, 2006; Lundholm, MacIvor, MacDougall, & Ranalli, 2010; Rowe, Getter, & Durhman, 2012). Individual species may exhibit poor survival in the green roof environment due to competition with dominant species or low tolerance of stressful conditions. *Sedum* species tend to dominate green roof plant communities when substrate depths are below 10 cm. At increased depths, the surrounding vegetation creates shade that is unfavourable to *Sedum* (Dunnett & Kingsbury, 2004; Heim & Lundholm, 2014a; Oberndorfer et al., 2007), thus competition for limiting resources can reduce species on green roofs. While diversity in green roof plant communities is desirable in many cases, the coexistence of many species, even over relatively short periods, is not assured.

Facilitation between plant species is also commonly detected in many vegetation types. Interspecific facilitation can be defined as a net positive association between plant species such that components of individual fitness, survival, growth or recruitment are higher when a neighbouring plant is present and lower when the neighbour is absent (Callaway & Walker, 1997; Zhang & Shao, 2013). Since dominant plant species can ameliorate microclimate or other drivers of plant survival, less tolerant species can have a better chance of surviving in harsh conditions when growing close to a facilitator (Soliveres et al., 2011). Interspecific facilitation can result from alterations to many habitat properties, both abiotic and biotic: shading, cooler substrate temperatures, greater resource availability, increased humidity, greater water retention and protection from predators (García-Cervigón, Gazol, Sanz, Camarero, & Olano, 2013; Rixen & Mulder, 2005; Soliveres et al., 2011; Zhang & Shao, 2013). However, plants that facilitate each other can also act as competitors. The general framework predicts that plants will have net positive interactions (driven by facilitation) during unfavourable conditions and net negative interactions (due to competition) during favourable conditions (Callaway & Walker, 1997; García-Cervigón et al., 2013). Interspecific competition can also indirectly facilitate plant growth in arid conditions in that plants influenced by competition tend to be smaller, making them potentially more resistant to drought (Armas, Ordiales, & Pugnaire, 2004; Butler & Orians, 2011).

The utility of interspecific facilitation on an extensive green roof has been demonstrated by Butler and Orians (2011), who surrounded the forb species *Agastache rupestris* and *Asclepias verticillata* with species of *Sedum*. Overall, they found that during favourable conditions competition was present and during times of drought the growth of the two forbs increased relative to the conspecific controls with no *Sedum*. This facilitative effect may have been due to decreased substrate temperature and greater water retention under the *Sedum* plants (Butler & Orians, 2011; Wolf & Lundholm, 2008). It is possible that other drought tolerant species that share the same matted growth form as *Sedum* could act as facilitators to forbs. For example, both greenhouse (Wolf & Lundholm, 2008) and rooftop (Lundholm et al., 2010; MacIvor & Lundholm, 2011) experiments have shown that *D. spicata*, a bunchgrass native to Nova Scotia with a matted growth form, demonstrates low water usage and can retain more water in the substrate than substrate-only controls. This stored water could facilitate the survival of less drought tolerant species. Lichens and mosses may play a similar role and both life forms are commonly found growing amongst creeping shrubs and forbs on the coastal barrens of Nova Scotia (Porter, 2013). Mosses in particular are known to facilitate the growth of vascular plants in other rock barren ecosystems (Sand-Jensen & Hammer, 2012), and their water-holding capacity is much higher than that of vascular plants (Anderson et al., 2010). Rooftop experiments have also demonstrated that *Cladonia* lichens can result in significantly cooler substrate temperature and lose significantly less water than substrate-only controls (Heim & Lundholm, 2014b). When grown together, both of these qualities could potentially facilitate the survival and/or growth of neighbouring vascular plants. The objective of this study was to determine if bunchgrass, moss and/or lichens could improve the survival and growth of a forb species.

2. Methods

We used a roof on the five-story Atrium building at Saint Mary's University in Halifax, Nova Scotia, Canada (44°39′ N, 63°35′ W). The experiment was separated into two blocks. Block one was