



Short communication

# Phenological complementarity in plant growth and reproduction in a green roof ecosystem



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## ABSTRACT

Green roofs are often planted with multiple species to improve aesthetics and other ecosystem services. If diverse species mixtures contain species with phenological differences in growth and reproduction, this could enhance ecosystem functioning by increasing the duration over which a valuable process operates. Phenological complementarity describes a species mixture where plant growth or reproduction is more evenly spread over time among species than predicted by chance. Here we report general phenological patterns of growth and reproduction from the third year of a four-year modular green roof experiment involving 13 species from five life form groups, planted in mixtures and monocultures. The relationships between phenological complementarity in canopy density (a surrogate for aboveground biomass) in species mixtures and thermal and hydrological functions were determined for the fourth year of the study.

Timing of peak growth occurred from May to July, differing greatly among species. Flowering times also differed among species and occurred from May to October. Six species showed variation in phenology depending on whether they were planted in monocultures or species mixtures, suggesting competitive or facilitative interactions with other species. Phenological complementarity in canopy density was observed in four of the species mixture treatments, with mixtures of species from the same life form tending to have the highest complementarity values. Phenological complementarity was weakly negatively correlated with the temporal coefficient of variation in stormwater capture, indicating the potential for greater process stability over time in complementary mixtures.

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## 1. Introduction

Biodiversity can improve the provisioning of ecosystem services (Cook-Patton and Bauerle, 2012; Isbell et al., 2011). On a green roof these ecosystem services may include increased faunal diversity, stormwater retention, thermal stability, pollution mitigation and visual appeal (Cook-Patton and Bauerle 2012; Forest et al., 2011; Lee et al., 2014). Green roofs are often planted with multiple species, and this may increase the performance of many functions simultaneously (Lundholm, 2015), although initially planted species may not persist over time due to competition or climatic fluctuations (Lundholm et al., 2014). Species that differ in the timing of resource uptake (phenological complementarity (PC)) may be able to more easily coexist as competitive pressure for limited resources may

be lower than if species have high resource use simultaneously (Gotelli and Graves, 1996; Gulmon et al., 1983; Monson et al., 1983; Tilman et al., 1997). For example, in desert annual communities differences between species in the timing of resource acquisition can allow species with low and high water use efficiency to co-exist (Huxman et al., 2008), resulting in temporally separated peak growth (Fargione and Tilman, 2005; Fowler and Antonovics, 1981; Kamiyama et al., 2014; Mathias and Chesson, 2013). In contrast, if resource availability is restricted in time, due to a short growing season or availability of pollinators, then coexisting species may show phenological convergence (Dante et al., 2013; Ghazoul 2006; Mahdi et al., 1989). In order to promote co-existence and higher species diversity, species exhibiting PC could be implemented into green roof designs.

Plant communities containing species that differ in the timing of their peak growth may also enhance ecosystem services (Qin et al., 2003; Stevens and Carson, 2001). For example, species that flower at different times might improve the aesthetic appeal of a green roof and provide resources for pollinators throughout the growing

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season (Cook-Patton and Bauerle, 2012). Additionally, plant species that differ in the timing of their active growth may enhance overall ecosystem service provision if the combination of complementary species results in a longer period with metabolically active vegetation. Past work has suggested that water uptake from green roof plant species may be temporally complementary, since the individual species with the greatest water uptake rate changes over time as soils dry after a rain event (Wolf and Lundholm, 2008), but this has not been tested in species mixtures. Grasses and forbs can be more effective than succulents at reducing substrate temperature and stormwater runoff on green roofs (Lundholm et al., 2010; MacIvor and Lundholm, 2011; Nagase and Dunnett, 2012). However, in harsh conditions both grasses and forbs may become dormant earlier than succulent species. If both are used in a green roof system then during favorable times the forbs and grasses should provide strong ecosystem services and during unfavorable conditions the succulents should allow some level of ecosystem services to continue (Lundholm et al., 2014).

The goals of this study were to characterize phenological differences between species on a green roof and to determine if greater PC in aboveground biomass in plant species mixtures can improve plant growth within a species and the overall ecosystem services provided.

## 2. Materials and methods

This study was conducted between June 2007 and August 2010 at Saint Mary's green roof testing facility (44°39'N, 63°35'W), in Halifax, Nova Scotia, Canada. The study was conducted in free draining modules (36 cm by 36 cm) (Botanicals Nursery LLC, Wayland, MA, USA) which contained a weed barrier, (Quest Plastics Ltd., Mississauga, ON, Canada), a water-retention layer (Huesker Inc., Charlotte, NC, USA), an Enkamat layer (Colbond Inc., Enka, NC, USA) and 6 cm of substrate (Sopraflor X, Soprema Inc., Drummondville, QC, Canada). The system has been described in previous publications (e.g. Lundholm et al., 2014; Lundholm, 2015).

Three species from five life form groups were originally planted in this experiment: *Danthonia spicata*, *Deschampsia flexuosa*, *Poa compressa* (graminoids); *Minuartia groenlandica*, *Sagina procumbens*, *Spergularia rubra* (creeping forbs); *Empetrum nigrum*, *Gaultheria procumbens*, *Vaccinium vitis-idaea* (dwarf shrubs); *Rhodiola rosea*, *Sedum acre*, *Sedum spurium* (succulents); *Campanula rotundifolia*, *Plantago maritima*, *Solidago bicolor* (tall forbs). However, none of the *M. groenlandica* and *S. rubra* survived past the first growing season and so these species were excluded from the analysis.

At the beginning of the study each module was planted with 21 individual plants in four rows of four plants (on 9 cm centers) and five plants on 7 cm centers in a central row (Lundholm et al., 2010). Treatments consisted of monocultures of each species (3 replicates, 21 individuals per module), life form groups (5 replicates, 7 individuals of each of the 3 species per module), each combination of three life form groups (5 replicates), all five life form groups (20 replicates) and a substrate only control (10 replicates). For the three and five life form treatments, each species was added once, alternating life forms, with the life-form and species pattern being randomly chosen without replacement, until each species to be included was added once, after which the same pattern was repeated to fill the rest of the planting locations within the module until 21 plants total were included. Thus, the number of individuals planted from each species varied initially within a level of life-form diversity (Lundholm et al., 2010). The modules were organized into five blocks three to four modules wide and up to 20 modules long; modules were rotated randomly within blocks six times within each growing season. Irrigation was only provided

to these modules, for establishment, prior to June 2007 (3–6 times per week).

### 2.1. Phenological patterns

Between May and October 2009 individual plants (from separate modules) per species were randomly selected from both monocultures ( $n=3$ ) and mixtures ( $n=3$ ) (Appendix A). In order to characterize general phenological patterns among species, measurements on these target plants were recorded every two weeks with data collected for plant growth and the presence of flowers/fruit. For growth, three shoots or leaves were selected per plant except *P. maritima* and *P. compressa* where data were recorded for the whole plant. Each plant/leaf/shoot selected was marked at a fixed point by tying 5–8 cm of Fenwick Profile braided backing (Pure Fishing Inc., Spirit Lake, IA, USA) at the base of the shoot. The length from the fixed mark to the tip of the marked shoot was then measured. For *S. bicolor*, *P. maritima* and *S. procumbens*, the mark was set at the base of the basal rosette of leaves and the growth of the longest leaf was recorded instead of the shoot. In order to maintain sample size new plants/shoots were chosen to replace those missing, damaged or dead (when this occurred the growth rate was reset for the new plant). Shoot growth rate was calculated between May 6 and October 21, 2009 at two week intervals using the following formula (Harper 1977):  $Shoot\ Growth\ Rate = \{ \ln(Time2) - \ln(Time1) \} / \# \text{ of days}$ .

### 2.2. Temperature, water capture and canopy density

Canopy density was collected in August 2007 and in May, June, July and August 2010. Canopy density measurements taken in August 2007 and 2010 were used to calculate the canopy growth rate of each species over the entire experiment (calculated with the same formula as shoot growth rate). The canopy density measurements taken in 2010 were used to calculate an index of PC in species mixtures for the 2010 growing season. Canopy density was collected through the point interception method using a three-dimensional pin frame (36 cm<sup>3</sup>) containing 16 equally spaced rods (Floyd and Anderson 1987). Each time a pin hit the living aboveground biomass of a plant it was recorded for that species. Indicators of ecosystem services were calculated for the 2010 growing season. Stormwater capture was determined for each module by weighing the module, then adding 1.3 L of water, then re-weighing after 10 min. An index of water loss was calculated by re-weighing the modules 24 and 48 h after the initial addition of water (Lundholm 2015). This analysis was conducted once in June and once in August 2010, on sunny days within 1 hour of solar noon. Water loss and capture values were converted to indices of the relative contribution of the vegetation to each function by dividing the values by the average values from the substrate-only controls collected on the same days.

Substrate temperature was measured by inserting a temperature probe (Taylor 9878 Slim-Line Pocket Thermometer probe (Commercial Solutions Inc., Edmonton, AB, Canada)) 1 cm below the soil surface within 1 h of solar noon on a sunny day. This was done in May (air temperature: 17° C–19° C) and July (air temperature: 27° C–29° C) 2010. Substrate temperature values from vegetated treatments were converted to an index of substrate temperature difference caused by the vegetation by dividing the values by the average values taken from substrate-only controls collected on the same days (Lundholm 2015). The air temperature data were gathered from a weather station adjacent to the green roof modules.

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