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An assessment of pollen limitation on Chicago green roofs

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HIGHLIGHTS

- We evaluated pollen limitation of nine native plant species on green roofs and ground-level sites through seed set studies and surveyed their associated pollinator communities.
- The percent of the maximum seed set on green roofs was significantly higher than that of nearby ground-level sites.
- Plants on green roofs were not pollen limited.
- Bee abundance on green roofs was lower than on the ground and bees found on green roofs had smaller overall body size.
- These results demonstrate that the ability of native plant species to produce seed is not hindered by being on a green roof, despite the lower number of pollinators.

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ABSTRACT

With increasing urbanization and creation of novel habitat types, green roofs can provide habitable space for many species. To date, most research on green roofs has focused on minimizing environmental impacts of buildings and little is known about the ecological services they may provide. Previous research has found a deficiency of pollinating bees on green roofs, which could result in pollen limitation, poor seed production and reproductive failure of many plant species requiring bee pollination. This study aims to determine whether pollination services on modern green roofs are sufficient for these novel habitats to function sustainably. Nine native Illinois prairie plant species and their pollinator communities were studied on green roofs and ground-level locations in the Chicago area. Pan traps were used to assess pollinator communities and supplemental pollination treatments were used to evaluate pollen limitation. All species showed significantly reduced seed set when pollinators were excluded but few significant differences were observed between supplemental and open pollination treatments. Seed set differed by habitat type in that green roofs had a higher overall mean percent maximum seed set compared to ground-level sites. Our results support previous studies, showing lower numbers and diversity of bees on green roofs compared to the ground level. Together, these data suggest that although green roofs contain a smaller and less diverse community of pollinators, the insects that are present provide sufficient pollinator services for many native plants. This study therefore supports the use of biotically pollinated native forbs in future green roof design.

1. Introduction

As the global human population increases, urban landscapes are growing both in size and number, with over half of the current global population living in cities (UN-Habitat, 2010). Virtually all of the world's projected population increase over the next 30 years is expected to occur in urban areas (UN-Habitat, 2010). As this pattern continues, changes in habitat structure and function caused by habitat degradation, loss, and fragmentation will likely reduce the survival and reproductive ability of many plant communities (Aguilar, Ashworth, Galetto, & Aizen, 2006) as well as the species they support (Savard, Clergeau, & Mennechez, 2000; Winfree, Aguilar, Vazquez, LeBuhn, & Aizen, 2009).

Urban environments are particularly susceptible to the recently documented declines in pollinator diversity and richness (Potts et al., 2010). Increased fragmentation and infrastructure common to urban landscapes affect plant reproductive success due to changes in pollinator movement, diversity, and density (McIntyre & Hostetler, 2001; Tommasi, Miro, Higo, & Winston, 2004; Winfree et al., 2009). For example, isolated or fragmented patches are less accessible to pollinators than larger areas and require them to

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alter their foraging behavior to maximize floral resources (Andrieu, Dornier, Rouifed, Schatz, & Cheptou, 2009; Goverde, Schweizer, Baur, & Erhardt, 2002; Hadley & Betts, 2009). Plant species flowering in these urban patches may receive fewer successful pollinating visits resulting in pollen limitation; a reduction in plant reproductive success due to the deposition of low quality or a reduced quantity of pollen (Aguilar et al., 2006; Aizen & Harder, 2007). Further, smaller fragments in or near urban areas are often dominated by *Apis mellifera* (introduced European honey bee) and are characterized by a decrease in native (Aizen & Feinsinger, 1994; Gonzalez-Varo, Arroyo, & Aparicio, 2009), oligolectic, or pollen collecting specialists (Cane, Minckley, Kervin, Roulston, & Williams, 2006; Steffan-Dewenter, Klein, Gaebele, Alfert, & Tscharntke, 2006) and ground-nesting bee species (Cane et al., 2006). Visitation by non-specialist species and other ineffective pollinators experienced by plant species in urban environments can lead to decreased reproductive success (Cheptou & Avendano, 2006; Segal, Sapir, & Carmel, 2006; Liu & Koptur, 2003). If pollinator decline in highly disturbed urban landscapes continues (Winfree et al., 2009), pollen limitation could become increasingly common in fragmented urban plant populations (Knight et al., 2005). However, the complete array of community-wide effects of pollen limitation and long-term consequences are not completely well documented (Ashman et al., 2004; Steffan-Dewenter et al., 2006) and few empirical studies to date have demonstrated that perturbations in the pollinator community result in increased pollen limitation and reduced fitness in offspring (Cosacov, Nattero, & Cocucci, 2008; Gomez, Abdelaziz, Lorite, Munoz-Pajares, & Perfectti, 2010).

In contrast to the wake of urban expansion and the resulting fragmented habitat, the number of internationally reported green roof projects has increased from 93 in 2000 to over 1300 in 2012 (Greenroofs.com, 2012). Green roof installation on new and retrofitted buildings in North America has increased as a result of policies and technology standards employed by cities and municipalities that encourage their use (Carter & Fowler, 2008). Known environmental benefits include reduction in stormwater runoff (Carter & Butler, 2008; Dunnett, Nagase, Booth, & Grime, 2008; Oberndorfer et al., 2007), mitigation of the urban heat-island effect due to an increase in evapotranspiration (Getter & Rowe, 2006), pollution abatement (Rowe, 2011), and reduction in energy use by buildings for heating and cooling (Carter & Butler, 2008; Oberndorfer et al., 2007; Spala et al., 2008).

Despite the progress that has increased our understanding of how green roofs function, little research has focused on the ecosystem processes green roofs foster and how they compare to those in natural areas. Additionally, ecosystem functions, including the ability of these novel habitats to support communities of native plants and pollinators, have yet to be investigated in detail.

Native plants are increasingly being incorporated into green roof design and though they are often assumed to support native wildlife, few studies have shown that pollinating insects and birds use this available habitat (Baumann, 2006; Brenneisen, 2006; Colla, Willis, & Packer, 2009; Fernandez-Canero & Gonzalez-Redondo, 2010; Kadas, 2006; MacIvor & Lundholm, 2011; Tonietto, Fant, Ascher, Ellis, & Larkin, 2011). Furthermore, few published studies compare the abundance and diversity of pollinators on green roofs to nearby or similar habitats at the ground-level. Two recent investigations found marginal to no significant differences between pollinating species on green roofs and ground level (Colla et al., 2009; MacIvor & Lundholm, 2011). In Chicago, however, lower abundance and diversity of bees has been found on green roofs compared to nearby parks and natural areas (Tonietto et al., 2011). If the pollinator communities on green roofs are composed of fewer individuals and are less diverse, reductions in pollinator visitation and increases in pollen limitation could result in reduced seed set and reproductive success of plants on green roofs. The relationship between pollinator abundance and plant reproductive success has not previously been investigated in these urban habitats.

This study examines potential deficiencies in plant–pollinator interactions on green roofs in the Chicago area. We tested the following hypotheses focused on pollination on green roofs with pollen limitation and seed set studies: (1) plants on green roofs are pollen limited, and (2) seed set is lower in green roof plants than in nearby gardens or natural areas due to a reduction in pollinator diversity and abundance on green roofs.

2. Materials and methods

2.1. Site locations and characteristics

Chicago, IL, USA and its surrounding suburbs were chosen for the location of this study, as there are currently over 500 green roofs completed or in the process of being built in this area (Kamin, 2010). Experiments were conducted at four green roof locations and four ground level locations (Table 1); green roofs varied in size, distance from ground-level, time since establishment, sun exposure, irrigation regimes, and number of plant species. Three of the ground and green roof locations selected were paired, with ground sites adjacent to the buildings upon which the green roofs were located. All ground locations were landscaped with horticultural species and prairie species native to Illinois. The ground locations each contained a minimum of six of the species that were also found on the green roofs.

2.2. Species selection

Nine species were selected for analysis in the pollen limitation study: *Allium cernuum* Roth (nodding onion), *Amorpha canescens* Pursh (lead plant), *Aquilegia canadensis* L. (red columbine), *Baptisia alba* (L) Vent. (also known as *Baptisia leucantha* (L.) Vent. or wild white indigo), *Baptisia australis* (L.) R. Br. (blue wild indigo), *Dalea purpurea* Vent. (purple prairie clover), *Monarda fistulosa* L. (wild bergamot/bee balm), *Penstemon digitalis* Nutt. Ex. Sims (foxglove penstemon), and *Zizia aurea* (L.) W.D.J. Koch (golden Alexander). Species were chosen based on the following criteria: present at a minimum of three study sites, native to Illinois, animal-pollinated flowers, and production of seeds large enough to be contained within pollinator/seed predator exclusion bags. All species are perennials, reproduce by seed, and are primarily pollinated by bees (Cane, 2006; Cruden, Hermanutz, & Shuttleworth, 1984; Davis & Hendrix, 2008; Dieringer & Cabrera, 2002; Eckert & Schaefer, 1998; Haddock & Chaplin, 1982; Zorn-Arnold & Howe, 2007). Species were only used if there were more than ten individuals present at each site so as not to disrupt future persistence of the population by over-collection of fruits and seeds. The green roof at the Center for Green Technology lacked large populations of our selected species and therefore was not included in the pollen limitation experiment.

2.3. Autogamy

To determine the rate of spontaneous autogamy (self-fertilization), six individuals per species were haphazardly chosen at each location and a pollinator exclusion bag (Delnet® Pollinator Bags, Delstar Technologies, Inc.; 0.5 mm diameter pore size) was placed over a single flower bud or buds on a single inflorescence per plant. All pollinator exclusion bags were cut and sewn to the appropriate size based on flower/inflorescence length and secured with wire. Bags were left on the plant for the duration of the flowering period to exclude pollinators and seed predators. The proportion of the seed set attributable to autogamy was calculated for each location and species by dividing the average seed set of the closed