Abundance and diversity of pollinators on green roofs are affected by environmental factors

Tingfeng Wu

1 Shanghai Institute of Technology, Shanghai, 201418, China

E-mail: 1617350635@qq.com

Abstract. Bees provide a variety of ecological services for urban ecosystems, while green roofs can also be of high value to bees through providing habitats and foraging sites. In this study, four hypotheses about impacts on abundance and diversity of pollinators were proposed from the roof and the surrounding environment. The evidences revealed that the height of the building affected the diversity of some bee species; increasing proportions of surrounding green space helped to increase abundance of bees and wasps; the colonies of bees were significantly affected by habitat connectivity, a frequent movement of bees and other mobile insects between roofs and ground guaranteed pollination of plants; plentiful plants combination was better than a single species in roof ecosystem services, and native forbs were beneficial for pollinations and foraging of pollinators; using fine substrate on green roofs may have a greater ecological value than common soil.

1. Introduction

Green roofs are covered with single or multiple plant species that most plants are first planted into a set of artificial substrate, later some wild plants[1] are transported to roofs by chance to share substrate with earlier plants. In a constructed ecosystem that mixtures of plant life-forms can strengthen green roofs performance[2], complex vegetation structure can enhance arthropod diversity[3]. Green roofs have a greater diversity of species than traditional roofs[4], they provide potential habitats for urban biodiversity conservation, and a large number of Invertebrates (arthropod, mollusc) and Chordates (reptile, birds) researches support this viewpoint[5-7]. Common species found on green roofs like spiders, beetles, bees, butterflies and so on, there are 236 species of Apidae alone in the world (151 in Europe, 72 in North America and 2 in Asia), eleven species have been recorded in Europe and North America[8]. Invertebrates on green roofs have many ecological benefits such as ‘substrate stabilization’, ‘pollination’, ‘pest control’, and ‘enhanced food web’[9], researching pollination on roofs in particular have gradually increased in recent years (Figure 1).

Pollinators play an important role in urban ecosystems and provide a wide range of benefits to whole society, including food security, farmers and beekeeping, social and cultural values, and maintaining broader biodiversity and ecosystem stability[10]. The world's 87 major food crops depend on animal pollination including fruit, vegetable or seed production, in addition 28 crops do not rely upon animal pollination[11], some are likely to be wind-borne plants. In agricultural and wild land settings, bees provide pollination services for major crops and angiosperms, with an estimated 85% of angiosperms relying on bee pollinators[12]. Obviously, maintaining pollinator service is crucial to livelihood of urban populations, furthermore, it is even more important to protect pollinators. Unfortunately, quite a few researches have reported a descending trend in pollinators worldwide, potential factors including land-use intensification, habitat loss and fragmentation, the spread of alien...
species, agrochemicals, climate change and the interactions between them[13-14]. This descending trend may be due to negative responses to climate and land-use change by pollinators’ dispersal, reproduction, habitat use and diet-related functional characteristics[15].

The natural conditions on green roofs are more serious than ground (stronger solar radiation, faster air flow, thinner substrate, less connectivity, and more extreme weather), it can't be compared directly with desert ecosystem. Because of their geographical isolation, there are differences in climatic conditions such as annual average rainfall and maximum temperature. The similarity of site climate and environment should be taken into account in comparative research of green roofs, it should be compared with the same city or neighbouring cities, otherwise compared to the changing before and after construction on the roof. Warm and dry habitat types on roof attract large numbers of xero-thermophilic species[3][8], they may be settled or migratory pollinators who visit a short time during flowering. In order to create specifically green roof that benefits pollinators (mainly bees), it is necessary to study the effects of environmental factors on abundance and diversity of pollinators.

Figure 1. An intensive green roof, which has been established over 4 years, is on the third floor of a university building.

2. Pollinators are affected by surrounding environment

Hypothesis 1: Affected by height of the building and surrounding green space

Native bees live on green roofs with lower abundance and diversity than reference habitats of tallgrass prairie natural areas and traditional city-park green spaces[16]. Wild bee colonies on green roofs are less abundant and less diverse than ground habitats, but share species with all habitat types[17-18]. There are about 30,000 species wild bees throughout the world, except for honeybee (Apis mellifera), all bees are used as "wild bees”[19]. The wild bees on roofs are both native and exotic, and many investigations show that the diversity of native bees is greater than that of exotic bees[20-22]. However, the number of individuals does not have such a relationship, which is relevant to bees' ability of survival and reproduction under the stress of special roof habitat. Our research found differential abundance of some species on green roofs (two extensive roofs) and ground sites (a woodlot, a lawn and two untended grassy areas), but to a lesser extent between two extensive roofs[20]. This indicates that the difference between two types of habitats has a great impact on species distribution, and the height of the building may affect some species that are highly mobile and fly. A researcher monitored cavity-nesting bees and wasps that breed in human-made trap nests on 21 vegetated and non-vegetated roofs over three years, found that increasing height of the building resulted in decreasing numbers of bees and wasps using in trap nests, indicated that height of the building affected bees and wasps' diversity on vegetated roofs[23].

As height of the building increases, the distance for bees flying from ground to roof increased (vertical flight is the shortest distance without wind), and the expansion of surrounding green space that facilitates bee proximity of the shortest distance and promotes bees to roof nesting and foraging.
By collecting and observing bees at six city parks, six green roofs, and six prairies, for all habitats there were positive trend between bee species richness and proportion of natural area in surrounding landscape, which was significant only at prairies[16]. Another research shown that increasing proportions of surrounding green space (within a 600m radius) contributed to an increase in colonization of bees and wasps in trap nests on the roof, but the correlation was not significant[23]. In general, considering the difficulty of pollinators reaching roofs that greening should be carried out on roofs of low-rise or middle-rise with a certain area. Such roofs may be more conducive to bees to take advantage of positive effects of wind than high-rise, which future is still worth studying (Figure 2).

**Hypothesis 2: Affected by connectivity between roofs**

The proportion of roofs covered with plants in cities is small, and the isolation between green roofs leads to reduced connectivity of landscape structures, which greatly limits the ability of animals to move, disperse and settle. Especially for spiders, beetles, snails, etc., which are large quantities and non-flying, their range of motion is limited to the maximum distance that can be reached by roof surface and vertical movement. The communities of arthropod populations with high migration rates such as bees are also significantly affected by habitat connectivity, bees and other mobile insects often move between green roofs and ground, which guarantees pollination of plants[24]. On green roofs, connectivity strongly increased the functional diversity of bees[25]. High dispersion costs in highly fragmented habitats reduce the incentive for animals to migrate between roof plaques, some species will be exhausted by trying to settle in new habitats and may even die on the way[26]. Usually the biogeography theory would predict that if habitat islands like green roofs are less isolated, they would have higher diversity[27-28]. Consequently, it is necessary to highlight the mobility characteristic of animal survivors on roofs.

**Hypothesis 3: Affected by the environment on roof**

**Hypothesis 3: Affected by the plant diversity and native forbs**

By collecting bees on six green roofs (two green roofs were dominated by plants native to Illinois, and the other four were *Sedum* plants), the largest number of bee species and individuals collected was the green roof which planted native prairie species as well had the highest plant diversity[16]. Also in Illinois, another research found that present insects provided sufficient pollination services for many native plants (nine were actually tested)[18], sufficiently demonstrated the advantages of native forbs. A researcher investigated bee species and visit counts on 25 vegetated roofs, on average *Sedum* roofs attracted only half the number of bee species compared with planted with multiple forms of vegetation (herbaceous roofs), and the number of visit counts on *Sedum* roofs were only one fifth than herbaceous roofs[19]. The reasons may be that the *Sedum* plants have shorter bloom time, providing a short period of flower resources available throughout the year and not attracting bees at other times. During the blooming of *Sedum*, the pollen load of bees increased in 1~3 days, and declined at the end of blooming period, indicated the brevity of flower resources[21]. With the reduction of *Sedum* as forage availability, the abundance of bees has also decreased. After that, wildflowers have replaced *Sedum* as an excellent substitute for bees. The rich wildflowers have even attracted more bee species during

![Figure 2. Pollinators on roofs are affected by a variety of factors.](image-url)
flowering[29]. Doubtlessly, *Sedum* plants provide sufficient pollen supplements for bees as one of the most suitable species on the roof in summer. Even on intensive green roofs, it is also conceivable to design different species to enhance appreciation of wild (Figure 3). In summary, plentiful plants combination is better than a single species in roof ecosystem services, and native forbs are beneficial for pollinations and foraging of pollinators.

Figure 3. Five plants that bloom in summer (*Achillea millefolium*, *Hypericum monogynum*, *Ligustrum sinense*, *Tulbaghia violacea* and *Abelia×grandiflora*), which may be used as a reference for roof greening materials in Shanghai.

*Hypothesis 4*: Bee nesting is affected by characteristics of substrate

Through the summary of a large number of researches, revealed that the percentage of cavity-nesting bees on roofs is higher than that on nearby ground[8], but there are also plenty of ground-nesting species. Most bees captured by insect nets and pan traps are ground nesting types[16]. The characteristics of substrate usually become key to bee nesting, such as substrate thickness, composition and particle size. Mixing different materials in different proportions will directly affect softness and permeability of substrate. Through investigated a microhabitat on the most biodiverse green roof, 79 kinds of beetles and 40 kinds of spiders were found, and their ability to adapt the substrate appeared to be a factor in successful colonization[31]. A research found that a finer and deeper substrate had a positive effect on abundance of *Halictus subauratus* and eusocial species, yet *Halictus subauratus* were social species that primarily nesting on ground[29]. There are few researches on effects of substrate characteristics on bee nesting on green roofs, but we know that fine substrate may have a greater ecological value than common soil.

4. Conclusion

Some of the bees come from the ground and some live on the roof or around, they are attracted by sun and the resources of flowers. This type of environment approximately wild makes them more relaxed in collecting pollen. In this paper, the environmental factors affecting abundance and diversity of pollinators on green roofs are discussed comprehensively from the height of the building, the proportion of surrounding green space, plant diversity and native forbs, connectivity and substrate, so that providing a meaningful reference for the future improvement of roof pollination system. It is recommended that landscape architects can adopt ecologist's advice when creating a pleasant garden, while taking into account the ecological designing of insects and arthropods, it can be effectively avoided that the roof becomes ecological trap by the arrangement of specific plants, substrate and structures.

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