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Research paper

Thirty years unmanaged green roofs: Ecological research and design implications

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HIGHLIGHTS

- 30 years study of unmanaged simple-intensive green roofs in Temperate climate.
- 120 Phytosociological relevés allowed an accurate assessment of vegetation dynamics.
- 32 species traits were used to investigate green roof ecosystem property variations.
- Spontaneous stress-tolerant and ruderal species out-competed most of the sown species.
- Unplanned plant colonisation should be accepted to develop resilient green roofs.

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ABSTRACT

The variations in species composition and assemblage of unmanaged simple-intensive green roofs in Hannover, Germany, were investigated over a thirty year period, in order to assess the persistence of the initial seed mixture and to evaluate floristic changes. The roofs were greened in 1985 with soil-based turf rolls sown with a mixture of five grasses (*Festuca rubra*, *Festuca ovina*, *Agrostis capillaris*, *Lolium perenne* and *Poa pratensis*). Three sets of 120 phytosociological relevés, sampled in 1987, 1999 and 2014, have been compared to assess: (1) nestedness vs spatial turnover, (2) functional diversity and (3) the importance of vegetation dynamics on green roof performance and design. Results demonstrated that from 1987 to 1999 the species diversity increased and the species turnover prevailed over nestedness, due to the progressive niche occupation by new species. In contrast, from 1999 to 2014 species diversity remained steady, suggesting that nestedness prevailed over species turnover. The main driver of the observed functional changes was a shift towards relatively more thermoxeric conditions. In terms of plant life strategies, the competitive species sown on the roof gradually gave way to stress-tolerant and ruderal species, along with a progressive increase in species with shortdistance seed dispersal strategies. It is concluded that: (a) to create resilient green roofs, spontaneous colonisation should be accepted and considered as a design factor; and (b) regional plant communities could serve as a model for seed recruitment and installations.

1. Introduction

Urban sustainability is one of the urgent challenges of the 21st century (Wu, 2014), since more than 50% of the world's population live in urban areas, and this figure is estimated to reach 66% by 2050 (UNDESA, 2014). Continuously spreading cities and the growth of intensive agriculture are the major causes of habitat loss and fragmentation worldwide (Grimm et al., 2008). However urban green spaces can play a key role in biodiversity conservation (Goddard, Dougill, & Benton, 2010) and enhance urban ecosystem resilience (Colding, 2007). In particular, green roofs can partially compensate for the loss of green areas by replacing impervious surfaces, contributing to an increase in urban biodiversity (Brenneisen, 2003, 2006). In fact, by replicating specific habitat features and conditions, these artificial biotopes can host native flora and fauna in

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relatively undisturbed stands where plants, insects and birds can become established (Köhler, 2006; Kadas, 2006; Baumann, 2006).

The first known study on the biotic colonisation of green roofs dates back to 1940, when Kreh (1945) listed the plant species colonising some tar-paper-gravel roofs in Stuttgart, Germany. This roofing technique was developed at the beginning of 19th century in Silesia and consisted of a combination of tar and four layers of paper covered by a mixture of gravel and sand (Köhler and Poll, 2010). In Kreh's study (1945), species were categorised according to the following functional group: bryophytes, CAM (Crassulacean Acid Metabolism) species and therophytes, substrate depth preferences (5–20 cm), pollination and dispersal strategies.

Modern green roofs can be classified as intensive, extensive and simple-intensive (German guidelines; FLL, 2008). Extensive green roofs consist of a shallow substrate ranging from 6 to 15 cm, planted or sown with drought tolerant plant species, and require low maintenance; intensive green roofs consist of a >20 cm thick substrate (normally top-soil), planted with woody and/or herbaceous species, and generally require irrigation and high maintenance; and simple-intensive green roofs can be seen as an intermediate roof type, consisting of 15–20 cm thick substrate (including top-soil), hosting perennial grasses and tall herbaceous species, and requiring medium maintenance.

Several studies of spontaneously colonised tar-paper-gravel, simple-intensive as well as extensive green roofs in central Europe, have described the recurrent plant communities thriving on different depths and kinds of substrate (Darius and Drepper, 1984; Thommen, 1986; Borchardt, 1994). These studies found that on 5–8 cm gravel roofs, stress tolerant species (*Sedo-Scleranthetea*) are enhanced while greater depths favoured ruderal species (*Artemisietea vulgaris* and/or *Stellarietea mediae*) and competitive species (*Molinio-Arrhenatheretea* and *Festuco Brometea*) (Bornkamm, 1961; Bossler & Suszka, 1988). Moreover, humus accumulation, nutrient supply and water holding capacity were identified as the main environmental drivers for plant establishment and community dynamics over time.

Recently, plant functional traits including Grime's CSR strategies (Grime, 1974, 2001) and life forms, have been used to predict green roof ecosystem services and identify suitable plant species (Nagase and Dunnett, 2010; Lundholm, MacIvor, MacDougall, & Ranalli, 2010; Van Mechelen, Dutoit, Kattge, & Hermy, 2014).

Despite the importance of long-term data in providing adequate planning recommendations (Rowe, Getter, & Durhman, 2012), only few studies have examined green roof dynamics for more than a decade (Krüger, 1999; Köhler, 2006; Köhler and Poll, 2010). Köhler & Poll (2010) assessed the effects of growing media on the vegetation quality and species richness of roofs in Berlin over a time span ranging from 13 to 48 years. Krüger (1999, 2001) instead focused on the changes in species composition over 12 years on the roofs of an eco-settlement in Hannover previously investigated by Ackermann and Vahle (1987).

The present study revisited the research site investigated by Ackermann and Vahle (1987) and Krüger (1999, 2001) to examine the composition of the plant community over a thirty year period. Where the main goal of previous studies was the phytosociological description of the vegetation, with the recognition of different facies (characterized by the dominance of a given species) and typologies, the current study focuses on whole roof communities.

We hypothesised that species composition and assemblage on unmanaged green roofs would have changed over the course of thirty years. Specific aims were: (1) to assess if such changes were due to nestedness (species loss) or to turnover (species replacement), (2) to determine changes in species and functional diversity over time and (3) to assess the importance of vegetation dynamics on green roof performance and design.

2. Materials and methods

2.1. Study area

The study area consisted of 15 simple-intensive green roofs of the Waldorf School in the eco-settlement "Laher Wiesen" in Hannover (Germany, 52°22′N, 9°43′E; 55 m a.s.l.), built between 1983 and 1985 on land formerly cultivated for rye, 9 km away from the city centre. The area lies north of the city park Eilenriede, near Laher Wald, at the southern edge of the Bothfeld district. Along the northern side, the eco-settlement is adjacent to farmland, whereas the other sides neighbour the city conurbation.

The local climate, according to the Köppen-Geiger classification, is warm-temperate, fully humid (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). The roofs of the eco-settlement were designed by Boockhoof & Rentrop architects and by the landscape architect Gustav Störzer on the basis of the Grassdach-System-Minke roofing technique (Fig. 1) (Minke and Witter, 1983; Minke 2000). This technology was conceived for sloped roofs (5–25°) and consists of a wooden structure sealed with a root resistant, waterproof PVC membrane and a mixture of local topsoil and light aggregates overlapped by a readymade turf carpet (Rollrasen). The investigated roofs had an inclination of 25°, and were elevated 4–7 m from the ground. Although differences in exposure and shade cast by trees could have locally influenced the roof vegetation, the effect of these variables were not investigated in the current study since we were interested in temporal changes in species composition, rather than in spatial variation. The substrate consisted of a mixture of topsoil/expanded clay (liapor) in a 1:1 ratio, 8 cm thick, plus another 8 cm in a 2:1 ratio. The turf rolls were prepared next to the settlement on plastic films to prevent root penetration into the ground. Ten centimetres of topsoil was sown with commercial seeds of *Festuca rubra* (50%), *Festuca ovina* (25%); *Agrostis capillaris* (5%); *Lolium perenne* (5%); *Poa pratensis* (15%) and installed on the roofs after 6 months. Our investigation focussed on the roofs of the Waldorf School (Fig. 2), since they were left to the natural succession, in contrast to the rest of the settlement, where turfs were periodically irrigated, fertilised and mown as was originally intended (Krüger, 1999, 2001). Since their installation, the roofs of the Waldorf School have been surveyed twice: in 1987 (Ackermann and Vahle, 1987) and in 1999 (Krüger, 1999), allowing the presented long-term vegetation study and a realistic performance assessment.

2.2. Vegetation data

A database of 138 species × 120 phytosociological relevés was created using TURBOVEG software (Hennekens and Schaminée, 2001), 33 of which were sampled between July and November 1987 (Ackermann and Vahle, 1987), 23 between May and June 1999 (Krüger, 1999), 64 between June and July 2014. In all cases, plot size ranged from 1 to 4 m^2. All relevés were sampled following the phytosociological method of the Zürich-Montpellier School (Braun-Blanquet, 1964). In addition to the species list and their respective cover values, each relevé included the following attributes: exposure, slope, total cover of grass and cryptogramic layer. Taxonomical nomenclature was standardised using The Plant List (http://www.theplantlist.org/, accessed in November 2014). All the relevés were georeferenced via the Google Maps interface of the TURBOVEG software and then exported in Quantum GIS vers. 1.8.0-Lisboa (Fig. 2).

2.3. Species traits

In order to analyse the vegetation data, 32 plant species traits were considered, grouped into the following categorical ($_c$) or ordinal ($_o$) functional units: (1_c) chorology, (2_c) life form, (3_c)