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Plant trait analysis delivers an extensive list of potential green roof species for Mediterranean France

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ABSTRACT

Green roofs are increasingly popular in urban areas of NW Europe and North America. However, greening roofs still needs incentives particularly in countries with a Mediterranean climate. Although green roof benefits such as cooling capacity and storm water retention would be even more pronounced in this challenging climate with hot and dry summers, vegetation stress on extensive green roofs will be enhanced, causing low performance if the same species as in the temperate regions of NW Europe and North America are used. In order to support further development and application of green roofs in the Mediterranean climate, new insights on suitable native species is an essential step. Using the habitat template concept, specifically taking into account drought adaptation and self-regulation, we developed a screening procedure using both functional plant traits and utilitarian aspects. Plant traits of two species lists (one resulting from an extensive vegetation study and another one covering the successful plant species of extensive green roofs in NW Europe) were analyzed. The results were incorporated into a hierarchical multi-criteria screening tool. This tool can encourage further experimental trials and inspire and guide the green roof industry toward the most appropriate species for extensive green roof design. As an example, the key was illustrated on a subset of plant species from Mediterranean southern France, which identified 34 newly potential green roof species. Interestingly, 35% of these species were annuals, a promising life form that has until now rarely been considered for extensive green roofs.

1. Introduction

The life-quality-improving value of green roofs in densely populated urban areas arouses the public interest for these novel urban ecosystems (Perring et al., 2013). Green roofs have the potential to mitigate urban temperatures to more comfortable levels through higher albedo and evapotranspiration from vegetation and substrate (cf. Oberndorfer et al., 2007). The evapotranspiration, together with water storage in the substrate, also leads to more effective storm water management. Additionally, green roof vegetation offers habitats and food sources that support a range of local invertebrate (Madre et al., 2013) and bird communities, therefore increasing biodiversity value (Madre et al., 2014; Oberndorfer et al., 2007). Other benefits include noise reduction, esthetic and psychological value, a longer roof membrane longevity and substitution for lost space on ground level (Cook-Patton and Bauerle, 2012; Oberndorfer et al., 2007). In an era of climate change, where more intense rainfall events and extended dry periods are predicted, the buffering capacity of green roofs will increase their importance even further (Vanuytrecht et al., 2014).

During the last decades, research and application of green roofs have shown a remarkable rise in NW Europe and North American countries (e.g. Dvorak and Volder, 2010). However, knowhow and proper incentives are to some extent still lacking in a large part of the world (Dvorak and Volder, 2010; Fioretti et al., 2010; Williams et al., 2010). This is for instance the case in countries with a Mediterranean climate, where the beneficial effects of green roofs would be similar or even more pronounced (Alexandri and Jones, 2008; Fioretti et al., 2010). Unfortunately, environmental conditions on rooftops are very harsh, particularly in the Mediterranean during summer, and it is necessary to have a better understanding

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of drought-tolerant vegetation that could survive and thrive in this challenging climate (Benvenuti and Bacci, 2010; Van Mechelen et al., 2014; Vanuytrecht et al., 2014).

Until recently, research exploring the suitability of various plant taxa has been limited. Succulent plants are generally considered the most appropriate plants to apply on extensive green roofs, due to their shallow root systems, (facultative) crassulacean acid metabolism (CAM) and hence efficient water use and tolerance to extreme conditions of drought (Benvenuti and Bacci, 2010; Durhman et al., 2006). Butler and Orians (2011) highlighted the potential of succulents by indicating that *Sedum* species can facilitate the performance of neighboring plants, the so called 'nursery effect', by reducing soil temperature during dry weather conditions, thereby decreasing abiotic stress for other life forms. While the green roof industries rely mainly on the use of succulent and some other 'tried-and-true' plants (i.e. plants tested and found capable for use on green roofs), often applied in low species numbers or limited to only one life form, a range of unexplored herbaceous perennial and annual plants exists with the necessary drought adaptations (Dvorak and Volder, 2010; Nagase and Dunnett, 2010; Van Mechelen et al., 2014). The use of different life forms has been shown to provide better ecosystem functioning and resistance to environmental stress, mainly due to niche complementarity and facilitation (Lundholm et al., 2010). Furthermore, highly diverse green roofs have a higher survival probability and are more esthetically pleasing even under dry conditions (Nagase and Dunnett, 2010).

In order to find potential species for urban greening projects (including green roofs and green walls), the 'habitat template hypothesis' (Lundholm, 2006) is a highly interesting concept. In the case of extensive green roofs, this hypothesis suggests that natural habitats with similar characteristics as those on this green roof type, thus scree slopes, limestone pavements and calcareous grasslands on very shallow and nutrient poor soils, can inspire green roof design. Therefore, studying the native plant species composition in these habitats is useful. As a biodiversity hotspot, representing over 10% of the world's flora (Lavergne et al., 2006) and a lot of extreme habitats, the Mediterranean area offers a potentially interesting species pool for green roof application (cf. Van Mechelen et al., 2014). With the habitat template hypothesis in mind, we described semi-natural vegetation in southern France in a previous study, and identified an elaborate list of species which do have some potential for use on extensive green roofs (Van Mechelen et al., 2014). Drawing attention to potential species is a starting point, but implementation of these species can still prove to be impossible, as there are also other factors besides drought adaptation to account for. For example, traits like plant size, growth potential, flowering duration, pollinator attractiveness and esthetic value are factors that also need to be considered (cf. Benvenuti and Bacci, 2010). Detailed information on plant traits can offer insights into the typical characteristics of green roof plants and therefore guide us to the most useful species for green roof application (cf. Lundholm et al., 2010). Because species selection can be a complex process when a wide range of criteria are involved (Reubens et al., 2011), the development of a decision support tool is a welcome instrument to assist green roof developers toward an appropriate choice of native plants in green roof projects.

The objective of this study is to provide an overview of plant traits that are crucial for survival of plants on green roofs in areas where dry periods are prominent, in particular in the Mediterranean climate. The focus is on green roofs of the extensive type as these are widely applicable and their low-maintenance supports self-regulation which is an essential feature of these versatile systems. The most important plant traits will be incorporated in an easy to handle screening tool and it will be applied on a species list of a vegetation survey in Mediterranean southern France.

2. Material and methods

2.1. Species lists

For the analysis and case study, a matrix of plant species and corresponding traits was assembled. The species lists included a set of green roof species (FGR), commonly used or spontaneously occurring on extensive green roofs in NW Europe, and a Mediterranean plant species list (FMED) from a previous study of an extensive vegetation survey in southern France (Van Mechelen et al., 2014). As drought tolerance and self-regulation are always important on all extensive green roof systems, FGR is used as a reference data set.

For FGR, seven sources were used. These included five key literature sources of internationally recognized green roof specialists or scientists (Bornkamm, 1961; Köhler, 1993; Kolb and Schwarz, 1999; Krupka, 1992; Snodgrass and Snodgrass, 2006) and two species lists of international Green Roof Companies (Optigreen Limited, 2012; ZinCo Gmbh, 2012).The number of times a species is noted in these sources is considered a proxy to its frequency of use on extensive green roofs (FREQ), which will be used to analyze the relation between frequency and plant traits. As plant traits were only available at the species-level, FGR comprised 483 species, after exclusion of subspecies, varieties and hybrids. By this we assume that plant traits of infraspecific taxa are the same as for the species.

FMED comprised the species of (sub) Mediterranean France observed in 2011 during an elaborate vegetation survey of open habitats on calcareous, shallow stony soils (for a full habitat description we refer to Van Mechelen et al. (2014)). These extreme habitat conditions are assumed representative for the conditions on extensive green roofs. Additionally we added four literature data sources describing similar habitats (Loisel, 1976; Molinier and Tallon, 1949; Rieux et al., 1977; Van den Berghen, 1963). The vegetation in these literature sources was described as Mediterranean matorral (also called *garrigue*), typical for thermophylous limestone pavements of southern France, with high species richness and a mosaic of different biological types. Both our vegetation descriptions and the literature data together accounted for 633 species, from which 131 species also occurred in FGR. Plant nomenclature follows The Plant List (2010).

2.2. Trait selection procedure

The approach was based on both functional traits and utilitarian aspects, as actual species selection for extensive green roofs will depend on both. Drought adaptation and self-regulation (e.g. regeneration strategy, presence of a seed bank, plant longevity) were considered key factors for survival and overall success on extensive green roofs, which also holds for more arid environments (Getter and Rowe, 2008; Vinson and Zheng, 2013). Relevant trait "groups", all related to drought adaptation and/or self-regulation, were identified through an extensive literature research. For the selection of utilitarian aspects, a similar approach was used, in which four green roof publications were consulted. For a summary of the literature used, we refer to Appendix A. Next, the TRY Initiative (Kattge et al., 2011; list of contributed authors in Appendix B), a global archive of plant traits, was screened for plant traits related to the trait "groups"identified by the literature survey. A total of 67 traits (53 functional traits and 14 utilitarian aspects) were assembled for the 985 unique plant species. All species for which no information was available were omitted as they do not contribute to the analysis. This reduced the dataset to 696 plant species (316 of