6R: A Look at Resilient Vegetation and Growing Media

A plant sociological approach for *extensive green roofs* in Mediterranean areas

Chiara Catalano[1], Riccardo Guarino[2] , Stephan Brenneisen[3]

1, Università degli Studi di Palermo, Dipartimento SAF, phd student - Tecnologie per la sostenibilità e il risanamento ambientale.

2, Università degli Studi di Palermo, Dipartimento STEBICEF, Sezione botanica.

3, Zürcher Hochschule für Angewandte Wissenschaften, Institut für Umwelt und Natürliche Ressourcen.

Abstract

Extensive Green roofs can be an important mean for environmental mitigation if designed according to the principles of restoration ecology. Moreover, if optimally executed, properly managed and of sufficient extension, they could be assimilated to meta-populations of natural habitats, worth to be included in the biodiversity monitoring networks. The best example supporting this hypothesis is the *Lake water plant Moos* in Wollishofen (Zurich, Switzerland) where, on three 100 years old units of extensive green roofs, occur most of the typical flora of *Mesobromion*, including high density of some endangered orchid species. With this work, we propose a methodology approach for green roofs in Mediterranean areas, based on a practical plant sociology understanding of EU Directive 92/43: a recognition of Natura 2000 habitat that could be imitated on roofs in terms of characteristic species and substrates. Our results lead to three category groups: those linked to sandy substrates (*psammophilous vegetation*), to gravely-pebbly substrates (*glareicolous vegetation*) and to xeromorfic soils (*garrigues* and *dry grasslands*). According to the last theories and practical application for grasslands restoration, we suggest a method applied and studied in Switzerland for green roofs, based on diaspore hay transfer from a donor meadow, in order to obtain the highest plant species richness and diversity.

Keywords : Extensive green roofs, plant sociology, habitat replication, biodiversity assessment, Natura 2000, hay transfer.

Introduction

The Mediterranean climate is characterized by dry, sunny summers and mild, rainy winters which are imposing to the vegetation two critical periods: summer drought and winter cold that, above 500 m, can be rather intense. (Mitrakos, 1980). The environmental conditions on the roofs are even more critical, because of the shallow substrates, daily temperature fluctuations and intense evaporation, with an increased tendency to dehydration. Moreover, green roofs are exposed to all features of the urban ecosystems, such as heat island effect, pollution and particulate, nitrogen and nutrients upload from human activities (Bettez & Groffman, 2013), including the abundance of sinanthropic and invasive neophytes.

In this work we present a methodological approach for greening roofs in Mediterranean regions, basing on the mutual relationship between vegetation and pedo-micro-climatic conditions, studied by the plant sociological science to describe the natural vegetation in terms of species assemblages, spatial and ecological range, endogenous variability and dynamics (Braun-Blanquet, 1964). We believe that getting inspired by the plant communities existing in nature, may be a fundamental mean in the functional design of the green roof system. The approach of restoration ecology will give new perspectives regarding the spatial importance and impact, beside the traditional gardening approach of establishing vegetation on extensive green roofs which often includes the use of non-native plant species, often invasive, that may cause problems threatening native ecosystems. In fact, variables such as size, substrate depth, type and composition, micro-habitats patchwork and species diversity and interaction (e*ndogenous variability*) together with micro-climate influence, local disturbing factors and/or proximity to natural habitats (*exogenous variability*), can affect species richness, composition and succession in this built environment (Kadas, 2002; Gedge, 2002; Brenneisen, 2003; Dunnett 2006; Bass & Currie 2010).

An astonishing example of what kind of plant communities can establish - showing the potential conservation value of extensive green roofs - is the Lake Water Plant *Moos* in Wollishofen (Zurich, Switzerland)(Brenneisen 2006, Landolt 2001). Landolt (2001) found 175 plant species, including nine orchids species and many other species that are endangered or rare in the eastern Swiss Plateau. Most impressive are the ca. 30’000 individuals of *Anacamptis morio* a species otherwise extinct in the surroundings of Zurich (Schnurrenberger & Spühler 2010). Moreover, the vegetation on Lake water plant Moos reflect the species richness of agricultural land at the beginning of the 20th century.

Besides of being widely used to describe the natural vegetation throughout Europe, the Braun-Blanquet's plant sociological approach has been used to analyze and describe the spontaneous vegetation that colonized some roofs in the historical centers of many central European towns, with particular reference to those built at the beginning of 1900 (Sukopp et al. 1990, 1995; Thommen 1988). Typically, those roofs adopted a sandy-gravel layer as a protection for the waterproof membrane, that enhanced the vegetation to permanently establish, due also to the accumulation of dung and nitrates over time (seagull colonies and city pollution). These phytosociological investigations highlighted an abundant vegetation ascribed to the class *Sedo-Sclerantetea* , whose chief species are featuring several habitat types targeted in the EU Directive 92/43 for the conservation of the most relevant European biotopes (Natura 2000 framework). In particular, the habitat codes 2330, 8230 and 8240 have many similarities with the natural vegetation colonizing the central European ancient roofs. This demonstrates that a well designed extensive green roof, besides of enhancing the aesthetical value and environmental performance of a building, could also play an active role against habitat loss, being a potentially undisturbed areas where also endangered species could find their habitat or, at least, a stepping stone within the urban environment. For instance, the rare *Sideritis montana* has its only stands within the Region of Friuli Venezia Giulia in the town of Trieste, on the gravelly roofs of the Liberty-style buildings (Martini et al. 2004).

According to the results of these investigations, we identified some habitats mentioned in the EU Directive 92/43/EEC that could be potentially imitated on roofs in terms of characteristic species and substrates (natural top soil, sandy gravel and loamy sand substrates) in Mediterranean basin. Besides of the theoretical interest of our experimental design, it may represent an useful approach for the promotion and proper use of eco-building techniques.

Methodology

Habitat selection

Basing on the available plant sociological literature, a first screening was done on all habitats belonging to the Natura 2000 programme known for the Mediterranean region. A reference list of the consulted literature is available at the following website: http://vnr.unipg.it/habitat/index.jsp.

In order to select the most suitable habitats for extensive green roofs, the following criteria were considered: species composition, vegetation structure, ecological conditions and distribution range. Basing on the Raunkier's classification of plant growth forms (Box, 1987), preference was reserved to the vegetation types linked to habitats characterized by the prevalence of pioneer, drought tolerant therophytes, hemicryptophytes and small chamaephytes, dwelling poorly developed soils and eroded slopes.

Habitats having a species poor and scattered vegetation were excluded, as well as those characterized by a limited distribution range in the Mediterranean Region. The remaining habitats were grouped into three categories: those linked to sandy substrates (psammophilous vegetation), to gravely-pebbly substrates (glareicolous vegetation) and to xeromorfic soils (garrigues and dry grasslands).

Biodiversity assessment

Even if the approach to biodiversity assessment on extensive green roofs is classically based on the evaluation of species richness (Coffman & Waite, 2011) included non-native species (Hui & Chan, 2011) or presence-absence of Red List animal species (Brenneisen *l.c.*), we esteem that the similarity, and therefore the compatibility, with natural biotopes should be focused on the vegetation cover, coherently with the current trends in ecological research. In particular, a plot-based approach lets to evaluate a number of additional parameters which are much more informative than a mere species check-list (Box & Fujiwara, 2011), basing on the assumption that a given fauna can always be associated to well defined vegetation units. Indeed, it has been widely demonstrated in ecological research, that the occurrence of motile organisms in a given site, does not necessarily imply their stable presence, which instead is related to the attitude of the system vegetation-soil, to fulfil the behavioural traits of the inhabiting fauna.

A highly standardized method widely used for the biodiversity assessment and monitoring of herbaceo-chamaephytic natural vegetation was proposed by Dengler (2009) and it is based on a nested-plot sampling sized 0.0001 m^2, 0.001 m^2, 0.01 m^2, 0.1 m^2, 1 m^2, 10 m^2, 100 m^2. All areas below 100 m^2 are replicated twice within the largest plot. Besides of the species list in incremental surfaces, the following parameters are recorded in every 10 m^2 plot: percentage cover value of all occurring plant species; structural data (height and cover of vegetation layers); GPS coordinates (latitude, longitude, altitude); relief (inclination, aspect, relief position, microtopography); land use; soil depth, stone cover, litter and a mixed soil sample for the analysis of basic chemico-physical parameters (C_{org}, nutrients, pH, carbonate, conductivity, loss on ignition, soil texture).

By using replicated smaller subplots, the approach does not only provide mean richness values, but also information on their variability, such as diversity indices, accounting for the varying performance of different species. Another parameter that can be easily obtained is the characterization of the species-area relationship and its variation over time, if the sampling is replicated yearly. Further, the frequency distributions of species at different spatial scales provide meaningful diversity information (Allers & Dengler, 2007) and the sampling approach with several replicates of all smaller plot sizes distributed within the largest plot allows a sound assessment of spatial heterogeneity of floristic, structural and abiotic parameters (Dengler, *l.c.*).

The Dengler's approach can be easily applied to the biodiversity assessment on green roofs, to analyze the similarity ratio with comparable vegetation types in natural biotopes and its eventual variability over time.

Results

According to our screening, the list of Natura 2000 sites that could be imitated on Mediterranean roofs, in terms of characteristic species and substrates (loamy-sandy substrates, sandy gravel and natural top soil) is reported below, with short references to the construction techniques. Further details on such issue are reported in the discussion paragraph. In the following comments, bioclimatic units refer to Rivas-Martínez (1994,1996); plant sociological units refer to the European syntaxonomical checklist (Rodwell et al., 2002).

1. *Psammophilous vegetation (Habitats 2210 Crucianellion maritimae, 2230 Malcolmietalia dune grasslands, 2240 Brachypodietalia dune grasslands with annuals, 2260 Cisto-Lavanduletalia dune sclerophyllous scrubs)*

Coastal dune system are characterized by strong environmental gradients, which determine the coexistence of different vegetation types in relatively small areas (Frederiksen et al., 2006). One of the most outstanding features of these habitats is an high ecological diversity in terms of environmental heterogeneity and variability of species composition (Van der Maarel 2003; Martínez et al. 2004). In dune ecosystems, the most obvious gradient associated with vegetation diversity is related to primary succession with the earliest stages along the shoreline and more developed vegetation types landwards (Acosta et al. 2007; Doody 2008). This shoreline–inland gradient is influenced by a set of ecological factors such as wind, waves, salt concentration, dryness and grain size of sand (Boyce 1954; Rozema et al. 1985; Hesp 1991) resulting in characteristic zonation of species assemblages and vegetation types (Barbour 1992; Davy & Figueroa, 1993).

This allow a great versatility to design green roofs with sandy substrate, that, according to granulometry and see side distance, could recreate combinations of both annual and perennial species. In fact, different condition can be recreated by varying the substrate thickness with reference to habitats 2210 and 2260 for higher depths (10 - 16 cm) and habitats 2220 and 2230 for lower ones (6-10 cm). Moreover, the vegetation of the latter habitats is dominated by annual plants and therefore is suitable to be mowed in order to get seed and mulching materials that, due to its fast decomposition, is a good initial biomass source. Instead, to get seeds from characteristic species from habitats 2210 and 2260, which are dominated by hemicryptophites and chamaephytes respectively, manual collection should be preferred. In this case the mulching material could be represented by alfalfa hay (*Medicago sativa L.*), which is mowed in flowering time and therefore doesn't contain seed that could compete with the sowed species, compromising the integrity of the system.

In Mediterranean areas, coastal littoral has been strongly manumitted due to high urbanization rate (*urban sprawl)* and tourist infrastructures. Green roofs (recommended on existing buildings) with the aforesaid communities could contribute to the protection of endangered species and habitats.

2. *Glareicolous vegetation (3250 Constantly flowing Mediterranean rivers with Glaucium flavum, 5320 Low formations of Euphorbia close to cliffs, 8130 Western Mediterranean and thermophilous scree)*

Mixed perennial and annual vegetation, growing on lithoclastic incoherent substrates, where the pedogenetic processes are hampered by a periodical supply of clasts. These habitats are represented by riverbeds and talus slopes covered with pebbles, stones and gravel.
In the Mediterranean region, the vegetation at issue refers mainly to the plant communities ascribed to the class *Scrophulario-Helichrysetea italici* (Brullo et al. 1998). They are dominated by pioneer hemicryptophytes and chamaephytes forming an open patchwork, whose interstitial space is occupied by annual species that dry up at the beginning of the summer drought, leaving behind a rich soil seed bank that ensures their persistence across the dry season.

The ecological gradients associated with vegetation diversity are driven primarily by the elevation, granulometry, chemical properties of the substrata together with water availability and periodical floods.
In particular, the most suitable plant communities for green roofs belong to the following two alliances: *Linarion purpureae* and *Euphorbion rigidae*, the former including the vegetation of scree and talus slopes from the meso- to the oromediterranean bioclimates; the latter the vegetation of gravelly riverbeds in the thermo-mesomediterranean bioclimates. The interstitial annual vegetation belongs to the classes *Tuberarietea guttatae* and *Stipo-Trachynietea distachyae* on acidic or neutral alkaline soils, respectively.

The vegetation units characterizing the habitat 5320 are suitable for application on coastal areas, on roofs slightly influence by the marine areosol, while those of the habitat 8130 can be considered only in mountain areas (supra- and oromediterranean bioclimates).

As in the previous case, there is plenty of possibilities to design highly diverse vegetation covers through the variation of depth and granulometry of the adopted substrata. On wide surfaces these variations will increase the patchiness and the chromatic-textural variance of the roof. The seeds of annual plants can be obtained through the mowing while those of perennial ones have to be collected manually.

3. *Garrigues and dry grasslands (5330 Thermo-Mediterranean and pre-desert scrub, 5420 Sarcopoterium spinosum phryganas, 6220* Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea)*

The considered habitat units include a variety of xerothermophilous garrigues and dry grasslands growing on oligotrophic soils throughout the Mediterranean region, from the thermo- to the supramediterranean bioclimate, from coastal to inland areas within markedly edapho-xeric conditions (Biondi et al, 2012). This vegetation is mainly secondary, linked to degradation processes of woodlands due to the human influence (fire, overgrazing, deforestation). In particular, fire has been traditionally used in the Mediterranean area to create rangelands since prehistorical times. The species diversity in these habitats is constrained within certain limits of predictability by the spatial heterogeneity, periodical disturbance and stochasticity, that is the basis for understanding the coexistence, in the same plots, of annual and perennial species (Guarino, 2006; Guarino & Ilardi, 2009). Typically, the Mediterranean dry grasslands consist of a mosaic, formed by more or less dense tussocks of perennial grasses with interstitial spaces occupied by annual grasses. The density of perennial vs. annual species is greatly influenced, as well, by disturbance and soil compaction: an excessive grazing pressure during the rainy season compacts the soil near the surface, which reduces infiltration, percolation, and water holding capacity, and concentrates roots near the surface (Menke 1989). Soil compaction also impedes root elongation, placing deep rooted species, such as the perennial bunchgrasses, at a disadvantage during seedling establishment. Seeds of annuals germinate faster and earlier and the roots develop faster than those of the seedlings of perennial grasses.

Differences in germination date and early seedling vigour may determine the competitive ability of one functional group (Joffre 1990, Garnier 1992).

As far as perennial plants are concerned, the ratio between grasses and dwarf-shrubs is often influenced by the structure and texture of substrata, with grasses dominating on relatively more nutrient-rich carbonatic or marly soils and dwarf-shrubs on acidic or leached substrata (Guarino et al., 2006). In particular, most of the Mediterranean thermo-xerophilous dwarf-shrubs display several symbioses with fungi and bacteria, in order to increase the efficiency of nutrient-uptake (Kummerow, 1981; Puppi & Tartaglini, 1991)

Due to the strong relationship between human disturbance and the vegetation units at issue, the optimal way to collect seeds material is hay transfer from a donor meadow to the roof combined with manual collection of the seeds of shrub species. Copying the habitat and varying the thickness and the quantity of organic matter of the substrate, the characteristic patchiness of colours and textures of ephemeral and perennial species would be easily recreated.

Discussion

The methodology of hay transfer, as an alternative restoration method, is a technique developed since the last decade, based on the application of fresh mowing from areas with similar habitat conditions, which may be paired to topsoil removal (Kirmer & Mann, 2001; Patzelt et al. 2001; Hölzel & Otte 2003). Moreover, studies showed successful results in terms of plant species richness, number of target plant species and Red List plant species, both in a short- and long-term analysis, for the re-establishment of species rich grasslands (Kiehl & Wagner, 2006).

Applying diaspores with plant material (hay) has the advantage of having large plant specie pools that normally are not commercially available with particular reference to rare species; of serving and maintaining the genetic material; of protecting seeds from extreme micro-climate conditions, specially on bare soils; of being a cheaper practical application in comparison with direct seed sowing. This technique, indeed, has been applied to improve Natura 2000 poor mesophilus species-rich grasslands (Buchwald et al., 2007) and in general to restore grassland biodiversity in combination with the sowing of structuring species (Coiffait-Gombault et al., 2011; Pèter Török et al. 2012).

In Switzerland, the Green Roof team from the Zürcher Hochschule für Angewandte Wissenschaften (ZHAW – University of Applied Science) utilize to execute vegetated surfaces, selected seed-mixture (UFA certified seeds) together with hay from close protected areas and/or from *Lake water plant Moos* in Wollishofen (Zurich). This suggest that alternative seed source could be represented, later on, also by green roofs themselves. In fact, the team is running an experiment on hay transfer from the aforesaid roof in Wollishofen (around 6000 m^2) and from Diegten (around 1000 m^2) considering that the total plant species richness and the number of target plant species are surely affected by mowing time and frequency. As a matter of fact, this latter principle is confirmed by the relatively lower number of species in the *one time mowing source material,* compared with the richness of the donor meadows, due to the early- or late- flowering species (Kiehl & Wagner, *l.c.*). Therefore, one of the aim of the project is to define a replicable method to gain a final greater specie richness results, due to the repeated mowing within one season. To determine the seed quantity/diversity apex and therefore the mowing frequency, that in this specific case was set weekly from July to September 2013, a preliminary vegetation analysis and a floristic list is needed. Successively, according to the theoretical anthesis diagram, is possible to establish the maximum flowering period that involve the higher number of species and consequently the highest diaspora, generally after one month. Evaluating on site the shifting period due to yearly changing climatic conditions, it is possible to define the mowing schedule. Unfortunately the possibility to apply fresh plant clippings is rare and therefore the hay, after harvested, is dried and stored in big bags in a ventilated, covered space. The monitoring of the achieved results will be done through plant sociological relevés that will be compared with the known genetic material source.

The approach of designing and executing green roofs described above, could be compared with plug planting and pre-vegetated solutions. One case that could be used for this scope could be represented by the California Academy of Science, designed by the Italian architect Renzo Piano, in San Francisco (ASLA - American Society of Landscape Architects, 2009). For this roof, has been propagated and planted nearly one-half million native California plants, selected between 25 species, tested on the roof of the older museum before its demolition. Nine evergreen species were chosen according to their drought tolerance and capability to attract local butterflies, birds and insects, some of them endangered: *Fragaria chiloensis*, *Armeria maritima*, *Prunella vulgaris*, and *Sedum spathifolium* (Perennial species); *Eschscholzia californica*, *Lupinus bicolor*, *Lasthenia californica*, *Plantago erecta* and *Layia platyglossa* (Annual species).

Conclusions

The desirable collaboration between vegetation ecologists and planners, when designing a green roof in terms of species richness, seed source and collection, will lead to a comprehensive designing approach counting on some preliminary analysis such as climatic conditions (bio-climatic regions) and vegetation potential, including endangered species and habitats. Moreover, adopting plant-sociological approach to identify species, is reasonable to predict that living roofs without irrigation are also possible in Mediterranean areas due to an increased resiliency of the system. In fact, many Mediterranean species (xerophytes) have developed morpho-functional and physiological adaptations to survive in the arid climatic conditions of the Mediterranean environment: changes that affect the leaves (imbricate or often linear, with a thick, waxy cuticle, silvery colour, sunken stomata), the roots (deep rooting, hairy surface, fast development of young plants, symbiotic relationships), decreased photosynthesis, loss of leaves in response to drought, incident solar radiation and high summer temperatures (Davis & Richardson, 1995). Furthermore, the Mediterranean regions have a unique floristic richness, with over 24,000 species of plants of which 35% are endemic (*hot spots*) and many of them linked to the Mediterranean basin.

As last, but not less important, people should be aware that those roofs will change *color* and *appearance* during the year, following nature cycles, seasonality and respecting the *genus loci*. This has to be considered as an assumption that would need public effort: if roofs of public buildings would be greened following this approach (best practices), imitating and blending with the surrounding, citizens would start to perceive *green* differently and in line with the principle of sustainability to *design with nature.*

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