Chapter 3
A Plant Sociological Procedure for the Ecological Design and Enhancement of Urban Green Infrastructure

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Abstract Urban green infrastructure could represent an important mean for environmental mitigation, if designed according to the principles of restoration ecology. Moreover, if suitably executed, managed and sized, they may be assimilated to meta-populations of natural habitats, deserving to be included in the biodiversity monitoring networks. In this chapter, we combined automatised and expert opinion-based procedures in order to select the vascular plant assemblages to populate different microhabitats (differing in terms of light and moisture) co-occurring on an existing green roof in Zurich (Switzerland). Our results lead to identify three main plant species groups, which prove to be the most suitable for the target roof. These guilds belong to mesoxeric perennial grasslands (*Festuco-Brometea*), nitrophilous ephemeral communities (*Stellarietea mediae*) and drought-tolerant pioneer species linked to nutrient-poor soils (*Koelerio-Corynephoretea*). Some ruderal and stress-tolerant species referred to the class *Artemisietea vulgaris* appear to fit well with local roof characteristics, too. Inspired by plant sociology, this method also considers conservation issues, analysing whether the plants selected through our procedure were characteristic of habitats of conservation interest according to Swiss and European laws and directives. Selecting plant species with different life cycles and

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life traits may lead to higher plant species richness, which in turn may improve the functional complexity and the ecosystem services provided by green roofs and green infrastructure in general.

Keywords Green roofs · Urban biodiversity · Species introduction · Urban meadows · Data mining · Vegetation

3.1 Introduction

The Natura 2000 'Habitats' Directive 92/43/EEC is the backbone of the European ecological network. It mentions 231 habitat types, 71 of which are designated as priority conservation targets (European Commission 1992, 2007). Despite the huge effort for mapping, surveying, monitoring and implementing conservation measures for the Sites of Community Importance belonging to the Natura 2000 network (the large majority of them falling in national parks and nature reserves), less effort was put to develop sound ecological corridors connecting them (Biondi et al. 2012; Jongman et al. 2011).

In the last decade, the European Commission started to promote nature-based solutions to contrast the erosion of biodiversity, habitat fragmentation and degradation, urban sprawl, resources depletion, the spread of invasive species, the reduction of ecosystem services and climate change (Bauduceau et al. 2015). With this regard, the construction and implementation of green infrastructure is a commonly adopted strategy to restore natural ecological processes and to implement the ecological network (Naumann et al. 2011). In landscape and urban planning, green infrastructure is conceived as (Department for Communities and Local Government 2012: 52):

> […] a network of multi-functional green spaces, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefit for local communities.

In urban areas, the concept of green networks was developed already at the beginning of the twentieth century with the idea to implement green belts to connect cities with the surrounding natural ecosystems and to provide recreational services (Jongman et al. 2004). Nowadays, when more than half of the world's population lives in cities and urbanisation is considered to be one of the main causes of habitat and species losses, it is necessary to foster species survival but also their chances to move and disperse within the built environment (Müller and Werner 2010; Planchuelo et al. 2019).

Given these premises, on the one hand, urban greenways and urban green infrastructure are gaining more attention by ecologists because of their species conservation relevance; on the other hand, planners and designers are increasingly willing to *design with nature* so to improve cities' ability to support biodiversity whilst increasing citizens' awareness and wellbeing (Hunter and Hunter 2008). Scientists and educators conveyed the need to interweave urban biodiversity and design with the Convention of Biological Diversity (CBD) by instituting the International Network in Urban Biodiversity and Design (URBIO, previously CONTUREC or Competence Network Urban Ecology), after the conference *Urban Biodiversity and Design: Implementing the CBD in Towns and Cities* held in Erfurt (Germany) in 2008 (Müller and Kamada 2011; Müller and Werner 2010).

Despite the extensive surveys and monitoring effort to describe the ecology of cities, little attention was given to the role that less disturbed spaces like railways, brownfields, city airports and green roofs can play as steppingstones and corridors within the Natura 2000 network. With this regard, Lundholm (2006) introduced the *habitat template approach* (hereafter: HTA) as a basic concept for the design of green roofs and green walls (see Box 3.1). As a matter of fact, the best way to identify the most appropriate habitat template is to become familiar with the vegetation occurring close to the project area. These preliminary field surveys may be supported by identification tools (see Box 3.2).

In southern France, the HTA was used to select a pool of 142 species adapted to grow on green roofs under Mediterranean climate (Van Mechelen et al. 2014). Plant species were obtained from vegetation relevés in open vegetated areas with shallow soils and limestone pavements but also from published phytosociological literature on the selected areas. The results were refined according to specific functional traits (Raunkiær's life forms and Grime's plant strategies – CSR) obtaining a list of several hemicryptophytes (perennial herbs with buds at soil level), few therophytes (annual plants) and geophytes (perennial herbs with underground buds).

Box 3.1 Habitat Template Approach (HTA)

HTA aims at finding habitat analogues (Lundholm and Richardson 2010) to mimic plant species compositions of natural stands assuming the similarity in terms of environmental conditions (both climatic and edaphic) between natural habitats and man-made ones (novel habitats). Thus, this approach can be adopted to create near-natural patterns, in terms of spatial heterogeneity and substrate properties, but also in the selection of plant species for green roofs and walls, e.g. stress-tolerant species typical to habitats subject to environmental stresses comparable to those imposed by urban ecosystems, like summer drought and periodical floods.

As mentioned by Lundholm (2006), the same principles of the HTA were applied in Switzerland by Brenneisen (2006) at the beginning of the 2000s. The Swiss prototypes are nowadays a mainstream, at least in Central Europe. These are known as biodiverse green roofs: an intermediate type between the simple intensive and the extensive green roofs (Catalano et al. 2018). These roofs were inspired by the surveys focused on species richness and evenness carried out on German green roofs during the 1990s (Buttschardt 2001; Mann 1998; Riedmiller 1994; Thuring and Dunnett in press) and characterised by a fine-grained patchwork of different, contiguous habitats capable of hosting different biocoenoses.

Box 3.2 Online Interactive Tools

Recently, several tools were launched to help planners and designers to select the appropriate species, among pools of native plants, according to the location (often political/administrative boundaries) and the ecological requirements (e.g. light temperature, pH). For example, Menegoni et al. (in press) developed the Italy Anthosart: an online tool based on the Flora of Italy (Pignatti et al. 2017–2019) providing a suitable species list (with pictures) after applying filters like region (e.g. Sicily or Lombardy), altitude (e.g. 0–300 m a.s.l.), infrastructure to be designed (e.g. extensive green roof or rocky garden), plant growth form (e.g. tree or herb), blooming season, size (e.g. <1 m), flower colour (e.g. red, white), climate and soil parameters (i.e. light, temperature, soil humidity, pH and salinity).

Similarly, Staas and Leishman (2017) launched the project *Which Plant Where* to develop an online tool for Australia to select the right species according to the location, whilst Vogt et al. (2017) developed Citree, a tool focused on the selection of urban trees and shrubs suitable for temperate climates by taking into account not only the site characteristics and the species natural distribution but also the ecosystem services, the management and citizens' need.

In addition, identification keys for phytosociological units are available for some regions (see, for instance, Prunier et al. 2014; Schubert et al. 1995) such as the app *Probabilistic Vegetation Key* freely available at https://play.google.com/store/apps/details?id=com.test.tichy.vegkey&hl=en; it was recently developed for Czech Republic to help users to classify the plant communities observed in the field by means of a probabilistic approach based on species identification. This allows to retrieve information concerning the vegetation structure, ecology and characteristic species combination (Tichý and Chytrý 2019) which might be used to implement the HTA (see Box 3.1).

Similarly, in Italy Caneva et al. (2013) proposed a list of 138 species by merging the national lists of species tested on green roofs and the information derived from vegetation studies concerning the following habitat analogues: (1) rocks and screes, (2) grey dunes, (3) perennial grasslands and (4) anthropogenic habitats. The final species list was obtained by applying filters related to chorology, life forms and ecological traits (namely, Ellenberg indicator values) concerning the Italian vascular plants (Guarino et al. 2010, 2012; Pignatti et al. 2005). Quite surprisingly, the paper by Caneva et al. (2013) excluded annual and biennial species (therophytes and short-lived hemicryptophytes), which represent a distinctive feature of Mediterranean landscapes, especially grasslands (Guarino et al. 2020), and proved to perform well on green roofs (Vannucchi et al. 2018).

Going beyond species lists, Catalano et al. (2013) proposed a plant sociological approach for green roofs. More in detail, they explicitly referred to two ranks of the sociological hierarchic system, i.e. classes and alliances, to create *ad hoc* seed mixtures based on real plant species assemblages occurring in natural habitats. Plant sociology, also known as phytosociology (Braun-Blanquet 1964; Dengler 2017; Guarino et al. 2018), was brought to landscape architecture by J. P. Thijsse and A. J. Van Laren in the Netherlands and by R. Tüxen in Germany in the second half of the twentieth century: these applications represent the first attempts to re-think urban parks and gardens according to species adaptations and natural assemblages (Woudstra 2004).

In this paper, we combined the inductive methodology proposed by Caneva et al. (2013) and the phytosociological approach by Catalano et al. (2013) in order to select the most appropriate plant species assemblage for an existing green roof in Zurich. With this aim, by screening the *Flora Indicativa* database (hereafter FI) (Landolt et al. 2010; Nobis 2010), we checked (1) whether the Landolt ecological indicators (hereinafter EIs), concerning the plants growing on the study roof, could be used to address the species selection; (2) whether this approach could implement the connectivity of some rare and endangered (target) Swiss habitats and could be applied elsewhere in the EU, taking into account the Natura 2000 Network; and, finally, (3) whether a shadow analysis on the roof may help to adjust the species assemblage derived from the automatic selection and to answer the question *where to sow (or plant) what?*

3.2 Materials and Methods

3.2.1 Study Case

The extensive green roof of the Technopark building has an area of about 1700 m^2 and was constructed in 2011 in Zurich (47°23’24.9” N, 8°30’56.9” E). According to Köppen-Geiger climate classification, the local climate is warm temperate, fully humid with warm summer (*Cfb*) (Rubel et al. 2017). The green roof at issue was implemented by adopting some of the main key designing features characterising *biodiverse green roofs*: varying substrate thickness (from 10 to 20 cm) and topography (small mounds and flat zones), sowing native plant species, using local substrate (sandy-gravel) and laying random piles of tree trunks (deadwood) on the roof to support arthropod communities (Fig. 3.1). Unfortunately, a comprehensive list of the sown species was not available. The facility manager reported that the roof was visited randomly for the maintenance of the drainages and the air conditioning machineries (max once or twice a year) but no agronomical maintenance (weeding, watering, fertilising) was carried out.

Fig. 3.1 (Left) Perspective view of the Technopark building roof in Zurich (study case). (Right) Aerial photo of the study case (magenta perimeter). (Photo credit: Chiara Catalano 2013; aerial photo: Bing Map 2012)

3.2.2 Vegetation Survey, Preliminary Ecological Assessment and Shadow Analysis

The green roof was visited in September 2013 to write down a list of the plant species (hereinafter: *master species list*) occurring there. This list was used to adjust and choose the values to query the FI database (see next paragraph): the average values of Landolt EIs related to the plant species found there were adopted as a proxy of the environmental conditions on the green roof, related to moisture (F), soil reaction (R), temperature (T), nutrients (N) and light (L) (Diekmann 2003); the indicators of soil aeration (D) and humus content (H) were considered, too. Species abundance and frequency were not recorded; consequently, rare species had the same weight of abundant ones in the calculations. Raunkiær's life forms and Grime's life strategies were used to better characterise the structural pattern of local plant communities. Phytosociological classes (to which the recorded plant species were ascribed) were used to get clues on the plant communities that could potentially be hosted on the roof.

To identify any possible shaded, half-shaded or fully lit surface, a shadow analysis was performed considering the light conditions at summer solstice (21st June) and at autumn equinox (22nd September). The latter simulation was meant to be considered for the microclimatic planting because it represents an intermediate situation at the end of the summer season. Thus, the hours of shade were considered to decide *where to sow (or plant) what* on the roof, according to the light requirements of the selected communities. The simulation was performed on a 3D Model of the Technopark building realised with SketchUp 2020 (Trimble®) and using the plug-in Shadow Analysis for SketchUp (DeltaCode®). Plant ecological information was derived from the FI Software (Landolt et al. 2010; Nobis 2010). Plant taxonomy, phytosociological nomenclature and the affinity of species with phytosociological ranks follow Landolt et al. (2010).

3.2.3 *Automatic Plant Species Selection*

In order to have replicable results, FI was queried to select the most suitable species and, consequently, to identify the phytosociological units that would match the estimated ecological conditions of the study roof. The whole database included 6472 taxa; discarding species aggregates, the remaining 5614 vascular plants were further processed by applying the following five queries (Figs. 3.2 and 3.3):

1. Conservation status for flora of the eastern Swiss Plateau (MP2), in order to sort out endangered species (i.e. those assigned to the following conservation statuses: VU, EN, CR) and to focus only on the species occurring in the Zurich region
2. Native status and invasiveness level (AE) in order to sort out neophytes (exotic plants naturalised after 1500) and most of the invasive species
3. Life forms (LF) *sensu* Raunkiær
4. Landolt EIs for soil moisture (F), soil reaction (R), soil nutrient content (N), temperature (T) and light (L)

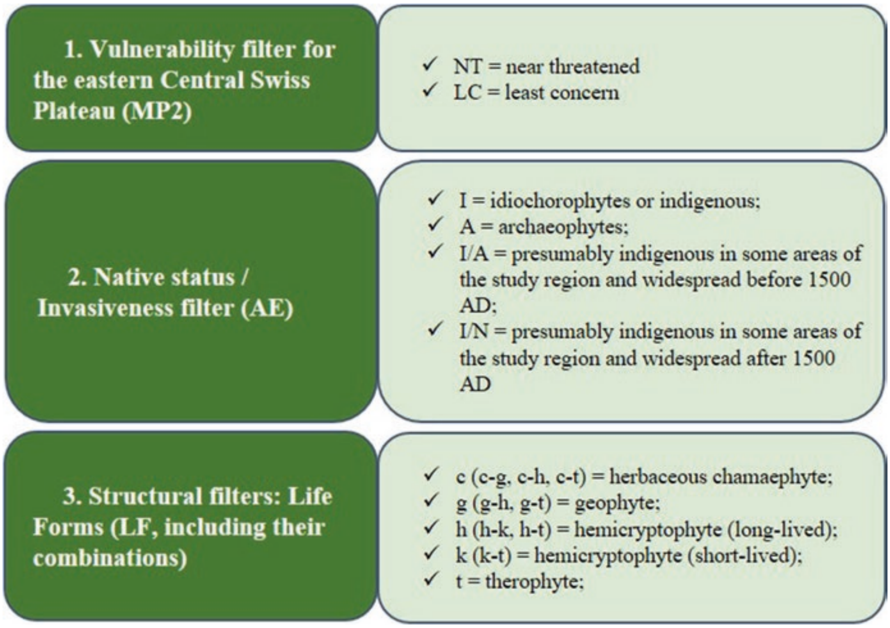


Fig. 3.2 First three steps of the inductive research procedure used to query the Flora Indicativa (FI) Software (Landolt et al. 2010; Nobis 2010). ✓ = queries used for the automatic plant species selection (the other possible choices are not shown)

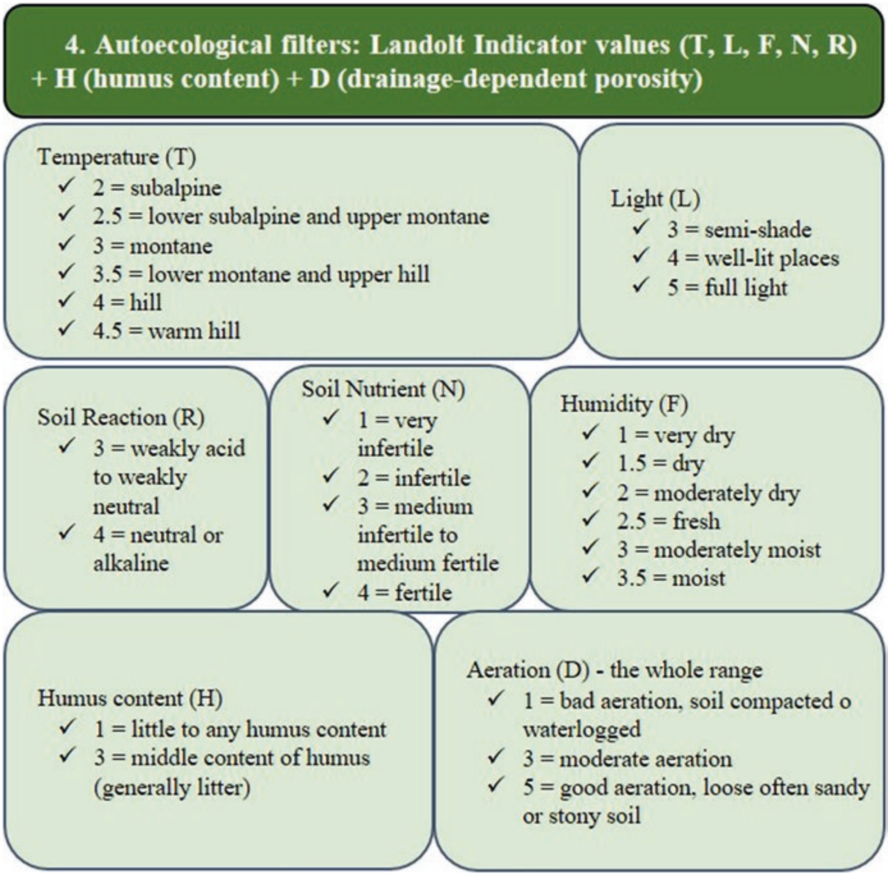


Fig. 3.3 Fourth step of the inductive research procedure used to query the Flora Indicativa Software (Landolt et al. 2010; Nobis 2010): auto-ecological filters encompassing climatic conditions (L and T) and soil conditions (N, R, and F). ✓ = queries used for the automatic plant species selection (the other possible choices are not shown)

5. Indicators of soil aeration (D) and humus content (H)

The values for Landolt EIs as well as those for D and H (queries 4 and 5) were adjusted considering the preliminary vegetation survey (see previous paragraph), i.e. ranging from the minimum and the maximum values of the master species list.

3.2.4 Further Screening and Expert-Based Assessment

The final list issuing from the selection procedure described in the previous paragraph was imported in Excel for Office 365 (Microsoft®). To perform quantitative analysis, we followed a four-step procedure:

1. We discarded (a) the species not recorded in the eastern Swiss Plateau in recent times (Welten and Sutter 1982) and (b) the archaeophytes which only live under cultivation and are not naturalised (infoflora.ch, last accessed: 03.05.2020).
2. The selected species were framed into the phytosociological ranks, i.e. classes (-*etea*), orders (-*etalia*) and alliances (-*ion*) they belong to. We discarded (a) the species not assigned to any phytosociological unit, (b) the classes counting less than three species and (c) the classes whose average value of soil humidity (F) was more than 3 (moderately moist substrates).
3. Expert-based assessment was needed to decide how to handle (a) the classes represented by species which are also ascribed to other classes and (b) the orders and the alliances represented by only one species (c) to obtain the final species list (hereinafter: derived list).

3.2.5 Habitat Connectivity and Microclimatic Design (Where to Sow/Plant What?)

To assess the connectivity of the detected habitats (corresponding to vegetation alliances), we searched for their potential habitat distribution and priority status in Switzerland (Delarze et al. 2015). Additionally, we checked the correspondence of these *syntaxa* with the habitats identified by the 92/43/EEC Directive (http://www.prodromo-vegetazione-italia.org, accessed 19.04.2020). To verify habitat occurrence near the study case at a finer scale, the web-GIS browser of the Canton of Zurich (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020) was consulted, too.

To decide where to sow (or plant) the species issuing from the screening according to the simulated light conditions (shadow analysis), we grouped them according to the following light (L) and soil humidity (F) values:

A. For $L = 4$ and 5 and $1 \leq F \leq 2$ (well-lit, full light areas on dry and very dry substrates)
B. For $L = 4$ and $2.5 \leq F \leq 3.5$ (well-lit areas on fresh to moderately moist substrates)
C. For $L = 3$ and $1.5 \leq F \leq 2.5$ (semi-shade areas on dry to fresh substrates)

3.3 Results

3.3.1 Vegetation Survey and Ecological Assessment of the Green Roof

The 29 *master species* found on the roof during the survey are reported in Table 3.1; most of them were therophytes (t = 13), herbaceous chamaephytes (c = 11) and ruderal strategists (Grime's life strategies *crr*, *crs* and *rrr*). According to the average values of Landolt indicators, the green roof showed the following environmental characteristics: very lit place (L = 4.1), temperature values typical to the deciduous mixed forests of the hill belt (T = 3.8), moderately to fresh soil moisture conditions (M = 2.3), neutral to alkaline soil chemistry (R = 3.6) and medium soil fertility (N = 3.2). At the same time, the species indicated intermediate humus content (H) and moderate aeration (D). Most of the plants belonged to the phytosociological classes *Stellarietea mediae* (nitrophilous therophytic pioneer communities, 15 species), *Koelerio-Corynephoretea* (pioneer communities with therophytes and dwarf succulents typical to well-drained, coarse or sandy substrates, 10 species) and *Festuco-Brometea* (dry grassland and steppe vegetation, 5 species). Other classes were represented by only one species or by species also referred to other classes (Table 3.2), which were considered as a reference for the final species selection and assemblage via expert-based assessment (see next paragraph). It should be noted that some species of wide ecological amplitude can be related to more than one phytosociological class.

3.3.2 Expert-Based Plant Species Selection and Assemblage

The automatic plant species selection gave a total of 283 taxa (*automatic list*) out of the initial 5614 ones, ascribed to 15 phytosociological classes and covering a wide range of habitats (Table 3.2): from open spaces to fringes and open forests (i.e. decreasing light availability), from sandy to sandy-loamy soils (increasing water holding capacity), from oligotrophic to eutrophic soils (rising nutrient content), from anthropogenic ruderal habitats to seminatural grasslands (diminishing disturbance) and from acidic to calcareous soils (pH gradient) (data not shown).

Comparing the phytosociological classes identified by the automatic list with those of the master list (Table 3.2), we decided to keep the classes judged to be compatible with the edaphic conditions of the study roof, i.e. *Festuco-Brometea*, *Stellarietea mediae*, *Koelerio-Corynephoretea* and *Artemisietea vulgaris.*

Within the selected classes, we excluded (i) the segetal annual weeds of the *Stellarietea mediae* that usually grow on base-rich soils in crop fields, vineyards and gardens subject to regular soil tillage (orders *Papaveretalia rhoeadis*, *Centaureetalia cyani, Eragrostietalia* and some species of the *Sisymbrietalia*) and (ii) the ruderal

Table 3.1 Life forms (LF), life strategies (LS) and Landolt ecological indicators (EIs) of the species found on the roof (*master list*) of the Technopark building in Zurich. H humus content, D drainage soil aeration, T temperature, L light, F soil moisture, R soil reaction, N soil nutrients. Species followed by an asterisk * are commonly used in Switzerland for extensive green roofs

						Landolt EIs				
	Taxon	LF	LS	H	D	T	L	F	R	N
1	*Acinos arvensis**	c-t	rrs	1	5	4	4	1	4	1
2	*Arenaria serpyllifolia*	t	rrs	1	5	4	4	2	4	4
3	*Buddleja davidii*	n	ccr	1	3	4.5	4	2	4	3
4	*Chaenorhinum minus*	t	rrs	3	3	4	4	2.5	4	4
5	*Chenopodium album*	t	rrr	3	3	3	4	2	3	4
6	*Conyza canadensis*	t	crr	3	3	4	4	2.5	4	3
7	*Echinochloa crus-galli*	t	crr	3	1	4	4	3.5	3	4
8	*Epilobium ciliatum*	c-h	crr	3	3	5	4	3	3	3
9	*Galinsoga ciliata*	t	crr	3	3	4	4	3	3	4
10	*Gypsophila repens**	c	crs	1	3	2	5	3.5	5	2
11	*Panicum capillare*	t	crr	3	3	4.5	4	2	3	4
12	*Petrorhagia saxifraga**	c	crs	1	5	4.5	4	1.5	4	2
13	*Polygonum aviculare*	t	rrr	3	3	4	4	3.5	3	4
14	*Polygonum persicaria*	t	crr	3	1	3.5	4	3	3	4
15	*Portulaca oleracea*	t	rrr	3	1	4.5	4	2.5	4	4
16	*Prunella grandiflora**	h	crs	3	1	3.5	4	2	4	2
17	*Salix caprea*	n-p	ccc	3	1	3	3	3	3	3
18	*Sedum acre**	c	rss	1	5	3	5	1	3	2
19	*Sedum album**	c	sss	1	5	3	4	1	4	2
20	*Sedum hybridum**	c	css	3	5	4	4	2	4	3
21	*Sedum rupestre**	c	sss	3	3	4.5	4	1.5	3	2
22	*Sedum sexangulare**	c	sss	1	5	3.5	5	1.5	4	3
23	*Sedum spurium**	c	css	3	5	4	4	2	3	3
24	*Setaria viridis*	t	crr	3	3	4	4	2.5	4	4
25	*Solanum nigrum*	t	rrr	3	3	3.5	4	3	4	4
26	*Sonchus oleraceus*	t	crr	3	3	3.5	4	3	4	4
27	*Taraxacum officinale s.l.*	h	crs	3	3	3	4	3	3	4
28	*Thymus pulegioides**	c	css	3	3	3	4	2	3	2
29	*Trifolium repens*	c-h	crs	3	1	3	4	3	3	4
Average				-	-	3.7	4.1	2.3	3.6	3.2
Min				1	1	2	3	1	3	1
Max				3	5	5	5	3.5	5	4

LF: c, herbaceous chamaephyte; h, long-lived hemicryptophyte; n, nanophanerophyte; p, phanerophyte; t, therophyte; KS: ccr, competitive ruderals; ccs, stress-tolerant competitors; crr, competitive ruderals; crs, C-R-S strategists. T: 3, montane; 3.5, lower montane to upper hill; 4, hill; 4.5, warm hill. L: 3, semi-shade; 4, well-lit places; 5, full light. F: 1, very dry; 1.5, dry; 2, moderately dry; 2.5, fresh; 3, moderately moist; 3.5, moist. R: 3, weakly acid to weakly neutral (pH 4.5–7.5); 4, neutral or alkaline (pH 5.5–8.5); 5, alkaline, high pH (pH 6.5>8.5). N: 1, very infertile; 2, infertile; 3, medium infertile to medium fertile; 4, fertile. D: 1, bad aeration, soil compacted o waterlogged; 3, moderate aeration; 5, good aeration, loose often sandy or stony soil. H: 1, little to any humus content; 3, middle content of humus (generally litter); 5, high humus content (generally row humus turf) and nitrophilous herbs and forbs growing on deep soils (alliance *Arction lappae*, order *Onopordetalia acanthii*) referred to the class *Artemisietea vulgaris*.

The above-described procedure allowed to identify the following 10 alliances (habitats) suitable for the study roof: *Mesobromion*, *Xerobromion* and *Stipo-Poion* (*Festuco-Brometea*); *Polygonion avicularis*, *Panico-Setarion* and *Sisymbrion* (*Stellarietea mediae*); *Dauco-Melilotion* and *Onopordion acanthii* (*Artemisietea vulgaris*); *Alysso-Sedion albi* and *Sedo-Scleranthion* (*Koelerio-Corynephoretea*).

3.3.3 Habitat Connectivity

At the scale of biogeographic units, we verified the potential distribution and the vulnerability status of the detected habitats within the eastern Swiss Plateau (Fig. 3.4): five of them resulted to be vulnerable (VU), four near threatened (NT) and one, i.e. *Onopordion acanthii*, endangered (EN). Five of the identified alliances corresponded to the following habitats of the 92/43/EEC Directive: 6110 (*Alysso-Sedion albi*), rupicolous calcareous or basophilic grasslands; 6210 (*Mesobromion* and *Xerobromion*), seminatural dry grasslands and scrubland facies on calcareous substrates; 6240 (*Stipo-Poion*), sub-Pannonian steppic grasslands; and 8230 (*Sedo-Scleranthion*), chasmophytic vegetation of calcareous rocky slopes. Habitats 6110, 6120 and 6240 are of priority interest according to the abovementioned directive. Excluding the habitats not occurring in the eastern Swiss Plateau and/or represented by only one species (*Onopordion acanthii*, *Sedo-Scleranthion*, *Xerobromion* and *Stipo-Poion*), we finally obtained a list of 139 species (derived list).

At the scale of the Zurich urban matrix, according to the cantonal web-GIS open data browsers (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020), the closest habitat type and the most similar to the target green roof are the ruderal communities living along the rails of the Zurich main station (Fig. 3.5). With this regard, many of the selected species belonged to the class *Stellarietea mediae*, characterised by ruderal (*rrr* = 20) and competitive ruderal (*crr* = 16) life strategy (data not shown).

3.3.4 Microclimatic Planting (Where to Sow/Plant What?)

The species of the derived list were grouped according to three combinations of light and moisture, hence suitable for different microenvironmental conditions (Table 3.3):

A. 52 species for well-lit areas on dry and very dry substrates (L = 4 and 5 and $1 \leq F \leq 2$)

Table 3.2 Phytosociological classes (Landolt et al. 2010) obtained by the preliminary survey of the extant flora of the study roof (*master list*, N = 29) and by means of the automatic species selection (*automatic list*, N = 283). The classes are listed first according to the decreasing species number of the master species list and then alphabetically. The species names are reported only for the master list, whilst the humidity values refer only to the automatic species list (F-a)

	Phytosociological classes	N-m	N-a	F-a	Ass.
1	*Stellarietea mediae*: annual, ephemeral, weed ruderal nitrophilous and sub-nitrophilous vegetation found throughout the world except for warm tropical regions	15	78	2.6	✓
	Arenaria serpyllifolia, *Chaenorhinum minus*, *Chenopodium album*, *Conyza canadensis*, *Echinochloa crus-galli*, *Galinsoga ciliata*, *Panicum capillare*, *Polygonum aviculare*, *Polygonum persicaria*, *Portulaca oleracea*, *Setaria viridis*, *Solanum nigrum*, *Sonchus oleraceus*, *Taraxacum officinale* s. l., *Trifolium repens*				
2	*Koelerio-Corynephoretea*: dry grasslands on sandy soils and on rocky outcrops of the temperate to boreal zones of Europe, the North Atlantic islands and Greenland	10	16	1.8	✓
	Acinos arvensis, *Arenaria serpyllifolia**, *Petrorhagia saxifraga*, *Sedum acre*, *Sedum album*, *Sedum rupestre*, *Sedum sexangulare*, *Sedum spurium*[N], *Thymus pulegioides*				
3	*Festuco-Brometea*: dry grassland and steppe vegetation of mostly base- and colloid-rich soils in the sub-Mediterranean, nemoral and hemiboreal zones of Europe	5	64	2.2	✓
	*Arenaria serpyllifolia**, *Petrorhagia saxifraga**, *Prunella grandiflora*, *Sedum acre**, *Thymus pulegioides**				
4	*Asplenietea trichomanis*: chasmophytic vegetation of crevices, rocky ledges and faces of rocky cliffs and walls of Europe, North Africa, Middle East, the Arctic archipelagos and Greenland	3	10	2.6	x
	Gypsophila repens[R], *Sedum album**, *Sedum hybridum*[N]				
5	*Molinio-Arrhenatheretea*: anthropogenic managed pastures, meadows and tall-herb meadow fringes on fertile deep soils at low and mid-altitudes – rarely also high altitudes – of Europe	3	107	2.9	x
	*Polygonum persicaria**, *Taraxacum officinale* s. l.*, *Trifolium repens**				
6	*Artemisietea vulgaris*: perennial (sub)xerophilous ruderal vegetation of the temperate and sub-Mediterranean regions of Europe	2	48	2.9	✓
	Epilobium ciliatum[N], *Taraxacum officinale* s. l.*				
7	*Rhamno-Prunetea*: scrub and mantle vegetation seral or marginal to broad-leaved forests in the nemoral zone and the sub-Mediterranean regions of Europe	2	8	2.6	x
	Buddleja davidii[N], *Salix caprea*[R]				
8	*Elyno-Seslerietea caeruleae*: alpine and subalpine calcicolous swards of the nemoral mountain ranges of Europe	2	22	2.7	x
	Gypsophila repens[R], *Prunella grandiflora**				
9	*Thlaspietea rotundifolii*: vegetation of scree habitats and pebble alluvia of the temperate, boreal and oromediterranean Europe and the Arctic archipelagos	2	11	2.4	x
	Gypsophila repens[R], *Sedum album**				

(continued)

Table 3.2 (continued)

	Phytosociological classes	N-m	N-a	F-a	Ass.
10	*Juncetea trifidi*: acidophilous grasslands in the alpine belt of the nemoral zone of Europe, the Caucasus and in the boreo-arctic and arctic zones of Northern Europe and Greenland	1	7	2.4	x
	*Thymus pulegioides**				
11	*Quercetea pubescentis*: Mixed deciduous oak and conifer open forests of warm regions in the cool-temperate nemoral zone of central and southern Europe and in the supramediterranean belt of the Mediterranean, Asia Minor and Middle East	1	36	2.3	x
	*Prunella grandiflora**				
12	*Agropyretea intermedii-repentis*: not recognised as class in Mucina et al. (2016) (synonym of *Artemisietea vulgaris*, see description above)	-	10	2.4	x
13	*Epilobietea angustifolii*: tall-herb seminatural perennial vegetation on disturbed forest edges, nutrient-rich riparian fringes and in forest clearings in the temperate and boreal zones of Eurasia	-	14	2.9	x
14	*Erico-Pinetea*: relict pine forests and related scrub on calcareous and ultramafic substrates of the Balkans, the Alps, the Carpathians and Crimea	-	16	2.4	x
15	*Trifolio-Geranietea sanguinei*: thermophilous forest fringe and tall-herb vegetation in nutrient-poor sites in the sub-Mediterranean to subboreal zones of Europe and Macaronesia	-	35	2.2	x

N-m species number of the master list, *N-a* species number of the automatic list, *F-a* average value for Landolt EI soil humidity for the species of the automatic list, *Ass.* expert-based assessment. ✓ classes kept according to the Ass., *x* class rejected by the Ass., [R] species not growing in the eastern Swiss Plateau or belonging to a life form not compatible with extensive green roofs (e.g. phanerophyte), * species occurring also in more species-rich classes, [N] neophyte. The ecological description of the classes follows Mucina et al. (2016)

B. 59 species for well-lit areas on fresh to moderately moist substrates (L = 4 and $2.5 \leq F \leq 3.5$)
C. 28 species for semi-shade areas on dry to fresh substrates (L = 3 and $1.5 \leq F \leq 3.5$)

Finally, the shadow analysis showed that during the autumn equinox (22th September), almost the whole roof is shaded at least for 1 h, with a variation from 3 to 6 h closer to the staircase blocks and to 7–9 h close to other elements of the building higher than the roof. According to the solar radiation map, the plant communities of the derived lists that might fit the sun exposure are shown in Fig. 3.6.

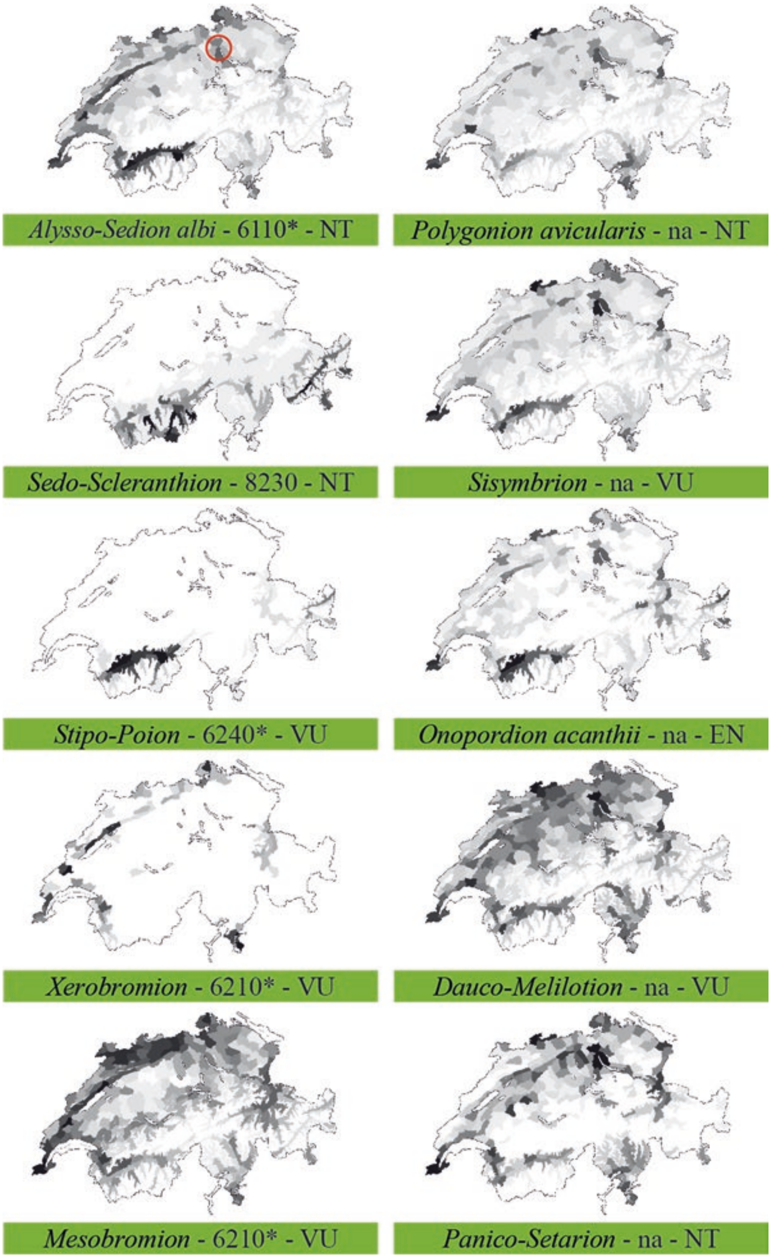


Fig. 3.4 Potential distribution maps and Red List-CH status - as in Delarze et al. (2015) – of the alliances (habitats) obtained combining the automatic screening process and the expert-based assessment. For each map, the legend shows, in order: the alliance name (e.g. *Alysso-Sedion albi*), the correspondence to Natura 2000 habitat code (e.g. 6110*) and the red list status (e.g. VU). The probability of occurrence is expressed by using a scale of greys (from white = 0% to dark grey = 100%); the red circle envelops the Canton of Zurich. The correspondence with the habitats of 92/43 *Habitats* EU Directive was checked in the Italian Vegetation Prodrome (http://www.prodromo-vegetazione-italia.org, last accessed 19.03.20). * priority habitats, na = not applicable. (Maps reprinted with permission from Ott-Verlag, Schweiz)

Fig 3.5 Swisstopo map of Zurich (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020). The cross indicates the Technopark building, the hatched area the nearby ruderal sites (Zurich railway, main station)

3.4 Discussion

3.4.1 Ecological Assessment of the Green Roof

The green roof was surveyed in 2013, i.e. just 2 years after its construction. Not surprisingly, it was characterised by a very poor vegetation cover, except for the mounds and the shaded areas (both between 10 and 20 cm thick) near the access room (Fig. 3.1).

Of the 29 identified plants, 11 were probably brought intentionally, as they usually figure among those adopted for Swiss commercial seed mixtures, whilst the remaining 18 species probably colonised the roof through wind and animal dispersal. Most of them resulted to be ruderal species belonging to the class *Stellarietea mediae* (Table 3.1). Yet, the species that almost certainly derived from direct seeding, i.e. *Acinos arvensis*, *Petrorhagia saxifraga*, *Sedum acre*, *S. album*, *S. rupestre*, *S. sexangulare* and *Thymus pulegioides*, are reported as characteristic to the classes *Koelerio-Corynephoretea* and *Festuco-Brometea*, *Asplenietea trichomanis* (vegetation of crevices, rocky cliffs and walls faces) and *Thlaspietea rotundifolii* (vegetation of screes and pebble alluvia). *Sedum spurium* and *S. hybridum* were probably brought accidentally together with the other *Sedum* spp. sprouts; in fact, these *Sedum* species are commonly used for green roof installations (Zheng and Clark 2013). Most of the species probably sown on the roof were stress-tolerant (*sss*, *crs*, *css*), wind-dispersed and propagating by creeping shoots aboveground (Table 3.1).

A weak point in our study was certainly the small number of species in the master list of the studied roof. One single roof, also without knowing the species composition of the original sowing, could be insufficient to set up and test a novel approach. However, the results obtained from basic data analysis agreed pretty well with those obtained from several phytosociological studies on flat sandy-gravel

Table 3.3 Derived list obtained for (A) well-lit, full light areas on dry and very dry substrates (L = 4 and 5 and $1 \leq F \leq 2$); (B) well-lit on fresh to moderately moist substrates (L = 4 and $2.5 \leq F \leq 3.5$); and (C) semi-shade areas on dry to fresh substrates (L = 3 and $1.5 \leq F \leq 3.5$)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Festuco-Brometea	12	*Festuco-Brometea*	1	*Festuco-Brometea*	8
Brometalia erecti	7	*Brometalia erecti*	1	*Brometalia erecti*	1
Mesobromion	11	*Mesobromion*	12	*Mesobromion*	9
Festuco-Brometea	**31**	***Festuco-Brometea***	**14**	***Festuco-Brometea***	**18**
Achillea millefolium, *Anthyllis carpatica*, *Arabis hirsuta*, *Arenaria serpyllifolia*, *Briza media*, *Bromus erectus*, *Campanula farinosa*, *Campanula rotundifolia*, *Carlina vulgaris*, *Centaurea scabiosa*, *Erigeron acer*, *Festuca guestfalica*, *Hieracium pilosella*, *Hippocrepis comosa*, *Koeleria pyramidata*, *Lactuca serriola*, *Malva moschata*, *Muscari racemosum*, *Ononis spinosa*, *Pimpinella saxifraga*, *Plantago media*, *Poa angustifolia*, *Potentilla neumanniana*, *Prunella grandiflora*, *Ranunculus bulbosus*, *Salvia pratensis*, *Sanguisorba minor*, *Scabiosa columbaria*, *Sedum acre*, *Thlaspi perfoliatum*, *Thymus pulegioides*		*Carex caryophyllea*, *Centaurea jacea*, *Euphorbia verrucosa*, *Galium verum*, *Helictotrichon pubescens*, *Knautia arvensis*, *Leucanthemum ircutianum*, *Lotus corniculatus*, *Ononis procurrens*, *Plantago lanceolata*, *Senecio jacobaea*, *Silene vulgaris*, *Trifolium campestre*, *Trifolium pratense*		*Ajuga genevensis*, *Allium oleraceum*, *Aquilegia vulgaris*, *Brachypodium pinnatum*, *Calamagrostis varia*, *Campanula rapunculus*, *Carex flacca*, *Carex humilis*, *Carex montana*, *Linum catharticum*, *Euphorbia cyparissias*, *Medicago lupulina*, *Origanum vulgare*, *Peucedanum cervaria*, *Sanguisorba muricata*, *Silene nutans*, *Veronica chamaedrys*, *Viola hirta*	
Stellarietea mediae	11	*Stellarietea mediae*	19	*Stellarietea mediae*	8
-	-	-	-	-	-
-	**-**	*Polygonion avicularis*	9	-	-
Panico-Setarion	1	*Panico-Setarion*	2	-	-
Sisymbrion	2	*Sisymbrion*	1	-	-
Stellarietea mediae	**14**	***Stellarietea mediae***	**31**	***Stellarietea mediae***	**8**

(continued)

Table 3.3 (continued)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Achillea millefolium, *Arabidopsis thaliana*, *Arenaria serpyllifolia*, *Capsella bursa-pastoris*, *Chenopodium album*, *Erodium cicutarium*, *Hordeum murinum*, *Lactuca serriola*, *Myosotis arvensis*, *Oxalis corniculata*, *Papaver rhoeas*, *Setaria pumila*, *Sisymbrium officinale*, *Vicia angustifolia*		*Anagallis arvensis*, *Atriplex patula*, *Carum carvi*, *Cerastium glomeratum*, *Chaenorhinum minus*, *Digitaria ischaemum*, *Digitaria sanguinalis*, *Elymus repens*, *Fagopyrum esculentum*, *Geranium pusillum*, *Lamium purpureum*, *Leontodon autumnalis*, *Lolium perenne*, *Malva sylvestris*, *Matricaria chamomilla*, *Plantago major*, *Poa annua*, *Polygonum aviculare*, *Polygonum persicaria*, *Portulaca oleracea*, *Potentilla anserina*, *Potentilla reptans*, *Sagina procumbens*, *Senecio vulgaris*, *Setaria viridis*, *Solanum nigrum*, *Taraxacum officinale* s. l., *Trifolium repens*, *Valerianella locusta*, *Verbena officinalis*, *Veronica serpyllifolia*		*Cirsium arvense, Euphorbia peplus, Euphorbia platyphyllos, Geranium columbinum, Raphanus sativus, Stellaria media, Veronica arvensis, Viola arvensis*	
Koelerio-Corynephoretea	6	*Koelerio-Corynephoretea*	2	-	-
-	-	*Sedo-Scleranthetalia*	1	-	-
Alysso-Sedion albi	3	-	-	-	-
Koelerio-Corynephoretea	**9**	***Koelerio-Corynephoretea***	**2**		
Acinos arvensis, *Arenaria serpyllifolia*, *Bromus tectorum*, *Herniaria glabra*, *Saxifraga tridactylites*, *Sedum acre*, *Sedum album*, *Sedum sexangulare*, *Thlaspi perfoliatum*		*Erophila verna*, *Hypochaeris radicata*, *Trifolium campestre*		-	
Artemisietea vulgaris	**-**	*Artemisietea vulgaris*	7	*Artemisietea vulgaris*	2
Onopordetalia acanthii	4	*Onopordetalia acanthii*	6	*Onopordetalia acanthii*	1
Dauco-Melilotion	1	*Dauco-Melilotion*	2		
Artemisietea vulgaris	**6**	***Artemisietea vulgaris***	**15**	***Artemisietea vulgaris***	**3**

(continued)

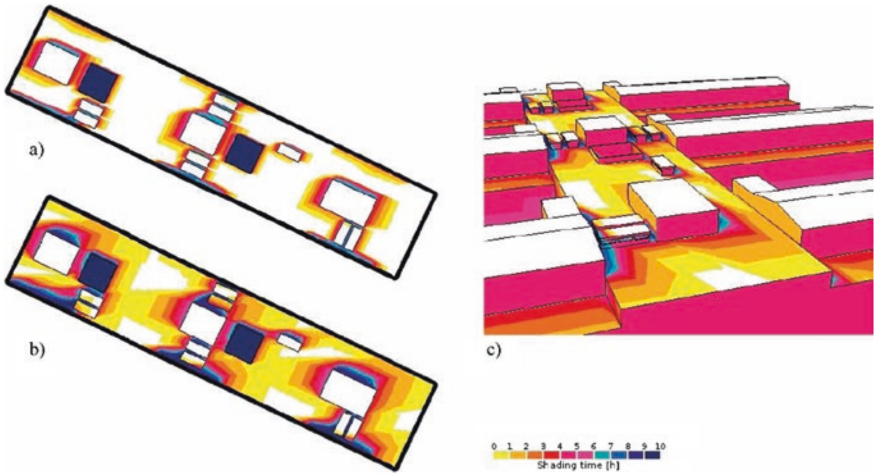
Table 3.3 (continued)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Echium vulgare, *Lactuca serriola*, *Linaria vulgaris*, *Potentilla recta*, *Reseda lutea*		*Cichorium intybus*, *Cirsium vulgare*, *Dactylis glomerata*, *Daucus carota*, *Malva alcea*, *Malva sylvestris*, *Melilotus albus*, *Melilotus officinalis*, *Pastinaca pratensis*, *Picris hieracioides*, *Plantago major*, *Poa annua*, *Senecio erucifolius*, *Silene pratensis*, *Tanacetum vulgare*		*Geranium pyrenaicum*, *Stellaria media*, *Saponaria officinalis*	

Species are grouped per habitat types, phytosociological classes (-*etea*), orders (-*etalia*) and alliances (-*ion*) following Landolt et al. (2010). N = number of species characteristic to the different phytosociological ranks; in bold is indicated the sum of the species characteristic to each class. * = alliances (habitats) not occurring in the study areas but with characteristic species occurring in it.

roofs (Bornkamm 1961; Thommen 1986) and those issuing from long-term monitoring of both flat extensive and sloped simple intensive green roofs (Catalano et al. 2016; Thuring and Dunnett 2019). Basing on literature data, it seems that during the first 2–5 years of biological succession, green roofs with little to no management are first colonised by ruderal plant species dispersed by wind and animals visiting the roofs and only in a more mature stage (after more than 10 years) by stress-tolerant and competitive ones (Martini et al. 2004). In the case of sandy-gravel roofs, the substrate thickness, the shade and the fine earth percentage proved to influence the speed and final result of local vegetation dynamics (Bornkamm 1961; Thommen 1986): from the early ephemeral ruderal assemblages (*Panico-Galinsogetum*, currently framed into the alliance *Panico-Setarion*) to ruderal perennial communities shifting towards *steady* perennial grasslands of nutrient-poor soils (*Alysso-Sedion* and, if the substrate is deep enough, *Festuco-Brometea*) over more than 50 years. In shaded areas, the progressive succession might be faster (about 30 years) and, in the long run (over 45 years), eventually allow the encroachment of pioneer shrubs (*Crataego-Prunetea*).

Several species of *Alysso-Sedion*, whose seeds were intentionally brought on the roof, proved to be able to thrive also at the very early stage (after 2 years). This fact suggests that by carefully selecting the plant species and by creating different ecological niches, it might be possible to foster plant succession processes and diversify species assemblages. This opportunity was confirmed by recent experiences on urban-industrial grasslands. In fact, just 3 years after combining seeding and hay layering, Kövendi-Jakó et al. (2019) observed plant communities whose species composition and richness were similar to that of 30-year-old grasslands.



Shading time (h)	Derived lists	L	N	Phytosociological classes (for the plant species see Tab. 3)
0 - 3	A	4 - 5	52	*Festuco-Brometea* > *Stellarietea mediae* > *Koelerio-Corynephoretea* > *Artemisietea vulgaris*
4 - 6	B	4	59	*Stellarietea mediae* > *Festuco-Brometea* > *Artemisietea vulgaris* > *Koelerio-Corynephoretea*
7 - 9	C	3	28	*Festuco-Brometea* > *Stellarietea mediae* > *Artemisietea vulgaris*

Fig. 3.6 Shadow analysis performed on the Technopark building in Zurich by means of SketchUp Pro 2019 version 19.0.685 (Trimble Inc.®) and the plug in Shadow analysis (DeltaCode®). On the left the shadow analysis for (**a**) the Summer solstice (21st June) and (**b**) the Autumn equinox (22nd September); (**c**) 3D perspective of the shadow simulation for Summer solstice. L Landolt EI for light, N number of species

3.4.2 Plant Species Functional Traits: A Comparison Between the Master and the Derived List

As regards the functional composition of the species included in the master list, the species sown were mostly herbaceous chamaephytes and stress-tolerant strategists, whilst the spontaneous ones were therophytes and ruderal strategists. As for the derived species, they were mostly therophytes (42 species), hemicryptophytes (55 species) and few geophytes (4 species) whilst showing prevailing *crs* (46 species) and ruderal (*crr* and *rrr*, 51 species) life strategies. All these features fit well with the early stages of succession observed in the first studies on spontaneous sandy gravel green roofs (see previous paragraph) and extensive green roofs. Accordingly, recent research recommended to select for extensive green roofs annual and biennial species mixed with succulents, perennial herbs and geophytes (Van Mechelen et al. 2015).

In commercial seed mixtures for green roofs, herbs and grasses are preferred to short-lived plants to obtain more stable communities and higher and more long-lasting plant cover within a shorter time and to be less dependent from the seed germination success of annual species (Caneva et al. 2013). However, even if this choice may offer advantages in the short term, unwanted consequences might occur in the long run, because empty niches will be eventually occupied by unwanted annuals/biennials (often alien, invasive or both). In fact, few years after, the expected *nice* green effect provided by perennial species is overtaken by *messy* ruderals not necessarily considered appealing by customers (Dunnett 2015). However, in the long run, some empty niches could also be occupied by spontaneous vulnerable species, including many orchids, especially in the case of nutrient-poor substrates.

3.4.3 Plant Species Assemblages

Recently, Lundholm and Walker (2018) reviewed the application of the habitat template approach (HTA) 10 years after its definition (Lundholm 2006). The authors concluded that the main limits of HTA were (1) the underestimation of the environmental conditions on green roofs, which are often more extreme than in their habitat analogues and (2) the overestimation of abiotic limiting factors for plants' survival (ignoring the biotic factors). Green roofs are novel ecosystems (artificial habitats) often characterised by additional (both abiotic and biotic) stress if compared with their habitat analogues. In fact, the plants growing on green roofs must adapt not only to the chemical and physical characteristics of artificial substrates and to air pollution, but they must also face herbivores and pathogens typical to urban environment or the absence of specific pollinators, symbiotic/facilitating organisms and substrate micro-organisms (plant microbiota) typical to habitat analogues.

In this chapter, we suggest basing the selection of species for urban infrastructure on plant sociology. Phytosociological associations represent distinct and recurrent species assemblages, selected by distinctive environmental drivers (e.g. edaphic and climatic conditions and disturbance regime); hence, trying to mimic their composition may allow to incorporate also the complex species assemblage rules regulating the plant species co-occurrences in natural habitats. Paying further attention to plant traits (life forms) and physiological requirements (Landolt indicators values) and focusing on the species pool (native to central Swiss Plateau) enabled us to perform a coherent species selection.

A significant percentage of the derived species, as well as many of the plants which spontaneously colonised the study roof, belong to the *Stellarietea mediae*, a class which almost certainly was not represented among the sown species. This result underlines the high colonisation performance of annual pioneer ruderal and/or competitive species on green roofs. Additionally, the plant communities belonging to *Stellarietea mediae* might have high potential for biodiversity conservation in Swiss urban areas; in fact, to this class also belong some phytosociological alliances corresponding to habitats of conservation interest. Among them, one is vulnerable (ruderal communities of *Sisymbrion*), and two result to be near-threatened (communities of trampled sites, framed into *Polygonion avicularis*, and thermophilous summer annuals of *Panico-Setarion*). Interestingly, the spontaneous arrival of species linked to trampled areas (*Polygonion avicularis*) and to generic disturbance (*Sisymbrion*) was probably the direct consequence of the occasional visits by people working on the roof; the same was observed by Bornkamm (1961) in Göttingen on similar sandy-gravel roofs. On the one hand, the ruderal and competitive species belonging to latter class may be able to outcompete some of the neophytes with similar colonisation and survival strategies (e.g. *Buddleja davidii*, *Epilobium ciliatum*, etc.); on the other hand, some of them, like *Cirsium arvense*, behave as noxious weeds; hence, their intentional introduction on green roofs located near crop fields must be avoided (Dierauer et al. 2016).

3.4.4 Habitat Connectivity and Spatial Planning

According to the real and potential habitat distribution in Zurich region (Delarze et al. 2015), most of the habitats identified showed good potential in terms of habitat connectivity (e.g. *Sisymbrion*, *Panico-Setarion*, *Polygonion avicularis*), with the exception of *Sedo-Scleranthion*, *Xerobromion* and *Stipo-Poion* (Fig. 3.4). These habitats came out from the automatic screening procedure because we included near-threatened species in the queries but were eventually discarded on the base of their geographical distribution. Nevertheless, several native species contained in standard seed mixtures are indiscriminately used all over Switzerland even if they grow wild only in certain biogeographic regions and show a narrow distribution range (e.g. *Festuca guestfalica*, *Cytisus nigricans*, *Dianthus sylvestris, Nepeta cataria*). The biogeographic approach, instead, should be more carefully considered by seed producers and green roof designers.

Unfortunately, the GIS portal of the Canton Zurich does not provide any information on the species occurring in the ruderal habitats characterising the rails near Technopark. However, according to literature (Kovář and Lepš 1986), species of *Stellarietea mediae* (e.g. *Atriplex patula*, *Sisymbrium* spp.) and of *Artemisietea vulgaris* (*Verbascum* spp., *Melilotus* spp.) are very common along railways. Hence, green roofs could be used to enhance the populations of these species and may play an important role as steppingstones for the vegetation of the abovementioned syntaxa.

Generally, flat green roofs are fully exposed to sunlight and are subject to intense daily and yearly irradiation; however, shading from building structural elements (e.g. parapets, roof hatches, skylight walls, ventilation supplies, solar panels), surrounding buildings, nearby trees and other features (e.g. deadwood piles and shading structures) designed on purpose may improve the microclimatic conditions on green roofs. Moreover, in a study run in Stuttgart region (southern Germany), plant species growing on conventional extensive flat roofs did not show maximal values of L (light) as it was expected (Thuring and Dunnett in press). In general, the spatial heterogeneity, also in terms of substrate thickness variation, influences plant growth, their cover, their survival and their living together (Bates et al. 2013; Brown and Lundholm 2015; Buckland-Nicks et al. 2016; Gedge and Kadas 2005; Heim and Lundholm 2014; Köhler 2006; Walker and Lundholm 2017). For this reason, the best *modus operandi* is to avoid the use of only one seed mixture for the whole roof but to adopt different mixtures according to varying light/shade and moisture (substrate thickness) conditions (see Fig. 3.6).

3.4.5 Limits of the Method and A Posteriori Remark

The method proposed here could be strengthened through the application to a representative number of different types of flat roofs, so to obtain general species lists for individual cities or even regions, which could represent a good starting point for selecting the habitat templates and related phytosociological units basing on a larger number of ecological indicators.

The most important limit of sorting seed mixtures based on phytosociological units is that many wild species are not available in the market and that their germination rate in controlled experiments is still unknown (Nagase and Tashiro-Ishii 2018). Nevertheless, transferring vascular plants (but also lichens and mosses) with racked material from a sandy dry grassland hosting *Koelerio-Corynephoretea* communities proved to be a very promising technique to establish local wild species otherwise difficult to find in the market (Schröder and Kiehl 2020).

During the vegetation survey aimed at compiling the master species list, we neglected to group the species according to homogeneous habitats and taking into account the existing gradient of light (from well-lit to shaded places), substrate thickness (from shallower to thicker areas) and disturbance (from more to less visited and trampled areas). As a result, the range we applied to sort the species was extremely broad. Instead, when considering the plant species as bioindicators, it would be recommended to use a phytosociological approach, thus making distinct surveying on different habitat patches (when existing).

The present study suggests that the indicators related to soil aeration (D) and humus content (H) are good limiting factors to consider for species screening. By contrast, the rating scale proposed by FI (three values for H and five for D) resulted to be too rough. Further research should address plant-soil relationships and amend the existing plant trait databases. This will allow a more effective species screening based on plant traits and tailored to the type of substrate used. Also, flower colour and the blooming time (season, months, duration) should be considered to fulfil aesthetic issues relevant to designers and people acceptance (see also Menegoni et al. in press) but also to support pollinators.

The expert-based assessment needed to decide which species to leave or to discard from the species list obtained through the automatic selection procedure may be supported by statistically robust datasets issuing from real vegetation surveys carried out in the surroundings. These data, stored in databases like EVA (Chytrý et al. 2016), could help to point out the highest fidelity of each selected species to one preferred vegetation unit/class (Bruelheide et al. 2020).

3.5 Conclusions

This work aimed at identifying a standard, site-specific and replicable procedure to support the selection of the most suitable species and assemblages for green infrastructure. Our selection procedure was inspired by plant sociology: a branch of vegetation science describing extant habitat types by recording and classifying plant species co-occurrences on standard plots. The phytosociological classification proved to be a helpful guidance to tailor plant species mixtures for green infrastructure by mimicking nature. As a matter of fact, plants do coexist because they fulfil similar or complementary requirements (e.g. avoiding the same predators, resisting to the same stress factors, responding to the same disturbances, benefitting of shared facilitation mechanisms, exploiting the same resources, enjoying the same symbiotic organisms, etc.). Moreover, we wanted to overcome both the aesthetic predominance in choosing the plant species (Cameron and Blanuša 2016) and the temptation to use ready-made seed mixtures which are not always place-specific (Prasse et al. 2010).

Further research should test plant communities instead of single species, because species in monoculture might not be able to survive in certain environments. This purpose is related to the concept of niche complementarity: more co-occurring species sharing the same resources are more resilient and can offer a wider array of ecosystem services than uniform monocultures (Lundholm et al. 2010; Tran et al. 2019). The creation of patchy environments hosting many small niches could be a planning strategy not only to increase green roof biodiversity but also to create rescue zones for the species populating green roofs during exceptionally dry seasons. These islands, where the initial planting and sowing might be more successful already in the first year, can serve also as pools of diversity and effective seed banks for the spontaneous cyclic colonisation of other neighbouring niches on the same roof.

Seed mixtures should contain either widespread pioneer annual species, able to colonise roofs at the very early stages of succession (1 to 5 years), or target species able to prevail on the roofs during the following stages, when the edaphic conditions will be more favourable (5–10 years and more than 10 years). This *uncoupled-timing* sowing approach might guarantee a higher ecosystem resilience and require a lower maintenance (but not a lower monitoring) effort over the whole lifetime of a living roof that might reach even one century of glorious survival (Bornkamm 1961; Kreh 1945; Landolt 2001). However, according to the seed longevity of the target species, under severe conditions, it might be necessary to sow the roof more than once. In other cases, when higher budget is available, combining the sowing of annuals and biennials with the planting of propagules of vegetative-dispersing species and perennials should be encouraged.

In the specific case of acting on existing green roofs, the site analysis plays a crucial role to choose the appropriate plants and/or seed mixture. Besides the shadow analysis, both the roof topography and the main wind intensity/direction should be considered to know *where to sow (or plant) what*: the first as a proxy of the soil moisture and the second to boost the colonisation on the roof by species dispersed by wind gusts. The minimum substrate thickness is a major challenge and focus for future applied research: a huge amount of experiences showed that 5-cm-thick substrates only allow the survival of few stress-tolerant species. If we want a higher number of species to establish and spread on the roofs, forming more steady and resilient communities, we should better design roofs and choose more suitable substrates. If the roofs must connect habitats, then we must build them accordingly.

The analysis and the comparison of distribution maps, databases, regulations and risk assessments at different scales (regional, national or international) showed some incongruences. For instance, some neglected vegetation units may correspond (or not) to priority habitats according to the Swiss law; some species of least concern in Europe may be critically endangered in the eastern Swiss Plateau; and some habitats which are very common and not threatened in Canton Zurich may be severely menaced on the international scale or *vice versa*. Also, this work highlighted the need of creating interactive tools (such as online platforms or plug-ins) based on freely accessible databases containing detailed information on species and habitat distribution and adopting a standardised nomenclature for plant names, habitat types, growth and life forms and ecological and biogeographical traits.

In conclusion, the ecologically informed design approach presented in this work represents only a starting point, and it would need the cooperation of vegetation ecologists, horticulturalists and designers to be developed, eventually creating new opportunities for professional figures, able to adopt and implement this approach in dialogue with several specialists.

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