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1.3 Plant Performance and Biodiversity

GREEN ROOFS FOR BIODIVERSITY: RECONCILING AESTHETICS WITH ECOLOGY

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Abstract

The promotion of green roofs for their wider value for biodiversity has received great attention recently. Indeed, in a number of European cities, the main driver for implementation of green roofs is their habitat value, particularly where development on the ground is destroying or threatening protected or rare wildlife sites. A particular approach has developed that has lead to certain types of green roof being referred to as 'biodiversity roofs', and a set of rules has emerged (closely related to concepts of restoration ecology) that typify an approach that is good for biodiversity. This paper reviews some of these rules or assumptions, using the latest scientific evidence, and evaluates their direct application to the green roof context. Specific aspects covered include: the use of native plant species only (assumed to be better fitted than non-natives to regional climates, and to support a wider range of other life than non-native plants); the use of locally-characteristic plant communities (assumed to provide local distinctiveness, and again because such communities are better fitted to local conditions); the use of local-provenance material and local ecotypes (assumed to preserve local genetic diversity and locally adapted populations); and the use of local soils and substrates (assumed to be better fitted to local conditions, to best support local vegetation, and to have lower 'embodied energy' than other substrates). Many of these assumptions do not hold true in pure ecological terms, but they are highly beneficial in creating distinctive green roofs that reflect local conditions. Finally, the author sets out a framework that considers aesthetic as well as scientific criteria when designing green roofs for biodiversity.

The creation of wildlife habitat on building surfaces has long been recognised as one of the principle benefits of green roofs. It assumes particular importance where high density urban development eliminates or severely restricts green space, or threatens or removes habitats at ground level. Moreover, the types of plant and animal communities that spontaneously develop on walls and roofs, together with other surfaces with non-existent or skeletal substrates add an additional dimension to urban ecosystems, more closely resembling the sort of vegetation that occurs naturally on cliffs, rock outcrops, scree slopes and gravely river edges (14), all of which may not otherwise be present in the area. Roofs can provide very important habitats for specialist rare or endangered species (4). As interest in green roofs and biodiversity has grown, greater focus has been given to techniques that guide vegetation development towards desired biodiversity or nature conservation objectives (for example, by using specific substrates, seed mixtures of native species, or varying depths of substrate), rather than, or in addition to, using commercially-available sedum-based systems. As a result, particular approaches to installing and maintaining green roofs have come to be known as 'biodiverse roofs', 'biodiversity roofs', or 'green roofs for biodiversity' (eg. 5), and such roofs tend to have certain characteristics, and are informed by techniques and 'rules' derived from habitat creation and restoration ecology theory. Examples of such rules include:

- The use of native species only.
- The use of locally-characteristic plant communities.
- The use of the use of local-provenance material (seed or plants collected from the locality) and local ecotypes.
- The use of local soils and substrate materials

Insert figure 1 here – images of biodiversity roofs.

In some cases, such guidance has become the basis for green roof policy. For example, the canton of Basel, Switzerland has planning regulations that decree that for green roofs over 500 m2 in area, the substrates have to be of appropriate natural soils and come from the surrounding region, and spontaneous colonization is encouraged (2).

Stipulations such as these tend to become the 'received wisdom' and accepted uncritically, whereas in reality scientific evidence does not necessarily support some of these key principles that are held dear by nature conservationists and restoration ecologists, or there may be numerous exceptions to the rule (12, 18). The aim of this paper is not to deny the value of adopting these principles. Rather it seeks to address two implications of the application of these principles to create 'biodiversity roofs'.

1. By definition, there is an implication that other roof types are not biodiversity roofs, or that they are somehow not as valuable . For example, the widespread assumption is that native plants are superior to non-native plants in their biodiversity benefit (12), and that green roof vegetation composed of non-native vegetation has much less value than native vegetation. **The aim of this paper is not to dispute that roofs which are derived from this process are not good for biodiversity, but rather to refute that other types of roof are not as valuable .**
2. Promoting biodiversity as an over-riding factor can lead to a uniform and inflexible approach (ironically, reducing overall diversity), and can also fail to account for the needs of people. Whilst traditional approaches to nature conservation have tended to ignore the importance of human influence and interaction with the landscape, an important strand of European urban ecology as it has developed in the last two decades has been to celebrate human agency, and the artificiality of urban and post-industrial environments (6). Environmental Psychology studies have indicated that

site context is extremely important in determing how acceptable the public or site users find wild or naturalistic vegetation. **A second aim of this paper is to urge a greater consideration of aesthetics as well as science when prescribing green roofs for biodiversity.**

Ecological Aesthetics

The routine experience of nature-like vegetation in towns and cities for most people is currently restricted to very specific settings: undeveloped or vacant land, abandoned allotments, woodland patches, vegetation beside rivers or other water bodies, and designated urban nature sites. These settings usually have one thing in common: they are often associated with abandonment and decay (11), and general perceptions of danger. Although policy makers and urban nature protagonists may believe in the inherent benefits of 'Nature In Cities', if it is not accepted by the general public then these environments can never be truly sustainable. This is perhaps particularly true of 'nearby nature' – the areas and patches of public green close to people's homes which to some extent urban dwellers have no choice as to whether they use or not (or look at in the case of roofs). It becomes a crucial point if there is to be any move towards a more general ecologically-informed approach to landscape design and planning in our towns and cities.

There has been virtually no exploration of differing public and professional attitudes towards, and perceptions of, wildlife-friendly and sustainable urban landscape. Landscape preference studies (usually carried out using photographic or digitally-manipulated images rather than direct on-site evaluation where proper contextual information is available) indicate general public preference for natural, green surroundings in urban areas, and negative responses to a predominance of hard surfaces and built structures in urban views. However, the intrinsic benefit of 'naturalness' to people's sense of well-being can perhaps be exaggerated by urban nature protagonists. In one of the small number of investigations that have sought to identify the underlying reasons behind urban dweller's preferences for different urban nature-spaces, (naturalistic river-side spaces in Chicago), naturalness (i.e presence of vegetation and wildlife) was highly rated, and the aesthetic qualities of solitude, quiet, peacefulness and scenic beauty were frequently mentioned. However these were outweighed by concerns over 'cleanliness' – a catch-all term that covered factors such as tidiness, lack of litter and good environmental quality (i.e lack of pollution). In other words, nature on its own is simply not enough. Interestingly, a more complex picture of people's aesthetic responses was uncovered, whereby combinations of natural vegetation with distinctive human creations such as bridges and buildings feature highly in people's aesthetic preferences, rather than purely natural scenes with no clear reference points (7). These findings are in line with the few other investigations that indicate a potential level of acceptance of naturalistic vegetation so long as there are very obvious 'cues to care' within the landscape**,** both in its design and management (15) There is also plenty of evidence to suggest that colour, and plenty of it, greatly increases public acceptance of nature-like vegetation (11). ***Conclusion:*** *a uniform approach to supporting biodiversity on green roofs fails to take account of aesthetic factors and public preferences. Simple 'cues to care', and* *increasing the flowering component of vegetation to maximize colourful effects, can increase acceptance in visible and accessible locations.*

Some key concepts in creating biodiversity roofs

The following section investigates in more detail some of the key assumptions that underlie the creation of biodiversity roofs.

1. Native species

In this discussion we shall not even attempt to get involved with the complex discussion of what is a native species, and how do we define nativeness, but instead shall concentrate on the generally-held assumption that native species are somehow superior in a biodiversity context than non-native species. Native species are typically seen as being inherently ecological, whereas exotic (non-native) species are not, unless considered in the context of the country they hail from, in which case they immediately become ecological! (9). Non-native species are often claimed to be less well-fitted for local climate and environmental conditions, and therefore need greater maintenance, care and protection to ensure their survival. At the same time, exotic species are claimed to be highly invasive, dangerous, and too successful! The fact is that invasiveness has little to do with geographical origin, but is instead related to whether plants possess certain biological traits such as high seed production, effective dispersal, and low palatability to herbivores. Many native species are highly invasive and effectively dominate vegetation, leading to much reduced diversity. Similarly, many exotic species may be ideally suited or fitted to a particular environment, because they come originally from very similar environments in their own countries. There are invasive natives and there are invasive aliens. In Britain, for example, the commercially available cultivated exotic flora is in excess of 70,000 taxa, only a tiny percentage of which are extensively naturalised (3), and fewer still having anywhere near the adverse ecological impact of invasive natives. It is also important to take into account the habitat non-native species provide for fauna in towns and cities. As with native species, non-native species differ in their value as a habitat or foraging resource but it is clear that they are very important for nature conservation in urban landscapes, as can be gauged for invertebrates by the work of Owen (16).

One of the most frequently made arguments concerning the use of native plant species is that they support a greater number of other species (e.g invertebrates) than non-native species, because of co-adaptation, and are therefore better for biodiversity. Generally speaking, the longer a plant has been established in a region's flora, the more insects and other invertebrates may be associated with it. This has been demonstrated most famously for trees (13). However, as Kendle and Rose point out in a wide-ranging critique of habitat restoration policies (12) this doesn't necessarily hold true for all plant-insect relationships, and indeed many native tree species will score less well than introduced exotics. Non-native species may fill an important gap or food source at a time when natives are not in flower. They conclude that, while, on balance, natives do often support more feeding invertebrates, but this does not merit an assumption that the conservation value of non-natives is negligible.

Some of the most relevant research regarding the value of non-natives to biodiversity comes from investigations into the habitat value of gardens. For example, Jennifer Owen has meticulously recorded the plants and animals occurring in her typical suburban garden in Leicester, England for the past three decades (16). A summary of the findings are shown in Table 1. The garden is not specifically planted with native species, and yet, just in this small plot, a significant proportion of the entire British representation of important families of plants and animals are found. She regards private gardens as the UK's largest nature reserve, and much of this arises from the diversity of non-native plants to be found in gardens.

	Species in garden	Species in British Isles	Garden as % British Isles
Native flowering plants	166	c.1500	11.1
Centipedes	7	46	15.2
Harvest spiders	10	23	43.5
Grasshoppers and crickets	3	28	10.7
Lacewings	18	55	32.7
Butterflies	21	62	33.9
Moths	263	881	29.9
Wasps	41	297	13.8
Ground beetles	28	342	8.2
Ladybirds	9	24	37.5

Table 1. Numbers of species in a Leicester garden and in the UK. Adapted from Owen (16)

Further evidence comes from the Biodiversity in Urban Gardens in Sheffield (BUGS) project. Seventy gardens of all types, sizes and locations were intensively sampled for their invertebrate biodiversity over a period of three years. Using the data gained, various comparisons were made between the amount of diversity present in the gardens, and different variables, such as size of garden, location of garden, intensity of management, whether or not the garden was planted primarily with native species or not. The analysis indicated that the use of native species resulted in no significant differences in terms of invertebrate biodiversity. The main factor that explained the variations in biodiversity was the structure of the vegetation – are there tree, shrub and herbaceous layers present for example. The actual composition of the vegetation made less difference. (19). In other words, the key factor in urban biodiversity is not the geographical origin of the plant species used (although this is critical for some fauna), but rather taxonomic diversity and spatial complexity of planting and landscape spaces. In short; lots of different plant species arranged in as many layers as possible. Finally, insistence on natives-only on sites that do not have designated nature conservation value has unfortunate connotations in a multi-cultural society (21). ***Conclusion****: while the use of native species is desirable for many reasons, the opposite argument that non-native species have no or much reduced value for promoting biodiversity does not necessarily hold true, depending on context.*

2. The use of local plant communities

Local plant communities are again assumed to be very appropriate and fitted to local environmental conditions. The use of local plant communities is often advocated because it is assumed that assemblages of plants that occur together in the wild have co-evolved together and are therefore more efficient at using resources that randomly mixtures of plants. Thus Lundholm states that *'there is a body of theory that predicts that the evolution of plant functional characteristics occurs at small, neighbourhood scales, thus ecosystem functioning may depend on whether or not the individuals comprising the plant community are drawn from populations that have interacted in a common location'* (14*).* Where it is possible to use rooftops to recreate endangered or habitats that may be the target of local biodiversity action plans then this is a very positive activity. But the view that functioning naturalistic communities can only be created by putting together species that may be found together in the wild is a misunderstanding of the nature of plant communities. Seeing plant communities as fixed entities that are adapted to local conditions tends to ignore the relatively short timescales in which these communities have developed. Communities fluctuate in time in their composition to reflect changing environmental conditions over periods of decades, centuries and millennia. The idea of static communities starts to fall apart when considering the sorts of assemblages that develop on disturbed urban sites, for example demolition sites or 'wasteland' consisting of skeletal substrates such as brick rubble or crushed concrete. These communities consist of a cosmopolitan mix of native species and escaped non-native species from gardens and parks and may contain many exotic species. For example, in a survey of the vegetation of five different abandoned urban sites in Sheffield, the majority of the most visually prominent species were non-natives (Table 2). Moreover, many of the non-native species perform valuable functions in that they flower in the late season, when most British native species have finished flowering.

English Name	**Scientific Name**	**Main period of visual effect (the more stars, the more prominent)**		
		Spring/Early Summer	**Mid-Summer**	**Late Summer/Fall**
Bramble	*Rubus fruticosa*	*	**	*
Buddleia	*Buddliea davidii*	**	**	****
Canadian Goldenrod	*Solidago canadensis*	*	**	****
Cow Parsley	*Anthriscus sylvestris*	***	*	
Goat's Rue	*Galega officinalis*	**	****	*
Japanese Knotweed	*Reynoutria japonica*	**	**	****
Lupin	*Lupinus polyphyllus*	****	**	*
Michaelmas Daisy	*Aster novi-belgii*		*	****
Raspberry	*Rubus ideaus*	*	**	*
Rosebay Willowherb	*Chamerion angustifolium*	*	****	***
Shasta Daisy	*Leucanthemum maximum*	*	****	*
Soapwort	*Saponaria officinalis*		***	
Tansy	*Tanacetum vulgare*	**	****	**

Table 2. Visibly prominent species on abandoned urban sites in Sheffield, UK. Non-native plants shown in red.

These 'urban common' communities (6) 'self-assemble' in a secondary succession on cleared sites from propagules that are present and available in the area. They are relatively recent in their development, are not found in rural areas, and only come about because of human activity, and yet they have most of the characteristics of spontaneous semi-natural communities (17). It is a small step from this to create new naturalistic plant assemblages that may be directly suited to the conditions of a particular site, but which have no natural counterpart. A considerable body of experience is building in Europe on the use of such artificial communities as sustainable vegetation types for urban landscape sites (9). Are these synthetic communities ecologically and aesthetically intrinsically less valuable than those that result from random combinations of chance events? Why is human agency seen as less valid when fostering new plant naturalistic vegetation types, when it was unconsciously or consciously employed in the past to help create semi-natural vegetation such as meadows, steppe, prairie, and various woodland communities that we now cherish as "nature"? ***Conclusion:*** *using native plant communities on green roofs is a valuable activity, but the notion of a community with a fixed list of target species that can be replicated on a roof is not the only option for creating functioning nature-like assemblages of plants. Using local plant communities can, however, re-inforce local character and distinctiveness.*

3. Local Provenance, and Local Sources of Plants

A universal view has been adopted in the ecological community that local populations have evolved to be adapted and fitted to their environments, and that populations from other locations are less well adapted. As a result, there has been a long-standing assumption that, where possible, locally sourced plants and seeds should be used in ecological restoration schemes, rather than material derived from sources further away. In fact there is little or no theoretical or experimental evidence to support this assumption (18).

The underlying assumptions that lie behind an insistence on locally-sourced material have been challenged by Wilkinson (21). He questions our view of what are typical local conditions, citing year to year changes in average weather conditions, and longer-term climatic shifts over periods of centuries that make little sense in timescales relevant to natural selection and evolution. As an example he cites the case of mature oak trees that may have germinated during the 'Little Ice Age' period of the 17th Century, when average temperatures were 1.5 degrees lower than those of today. What is the logic of using acorns from those trees to grow new trees to suit local conditions in the 21st Century? Similarly, in the context of current climate change, how relevant to use in the future are ecotypes that are suited to today's climate? Wilkinson concludes that successful germination and establishment of plants in vegetation simply reflects those that are best genetically adapted to survive in that particular year. In fact, fitness has little to do with geographical distance from a site (differences in aspect and altitude may mean that local populations may vary considerably), but 'ecological distance' in that propagules come from a site that is ecologically similar to the target site.

Most urban sites, and particularly green roofs, are heavily transformed particularly in terms of soil conditions, and climate, and the assumption that original genotypes will be better fitted than non local genotypes is inherently too unreliable to be a defining objective of practice. Natural selection results in local populations that are well enough fitted but no more than this, non local genotypes may be equally well fitted (8). But there is also a genetic argument that continually using material selected from local populations results in 'inbreeding depression', and a reduction in fitness, particularly in the context of environmental change, and that injections of genes from other populations has a positive effect. ***Conclusion**: In urban and green roof situations it is often difficult to sustain the view that seed and other propagules of native plants used in these landscapes must be derived from a local population. A pragmatic reason for adopting this position is that in many situations it is difficult to locate local populations to act as a seed source.*

4. Use of Local Soils and Substrates

The use of local soils has been proposed as a basis for biodiversity roofs. For example, in the Canton of Basel local soils are used because conservation of soil resources is seen as being a core component of environmental conservation (2). Combinations of local soils and locally collected seeds may result in replication of local plant communities and habitats. Soils in any one place are the result of unique and locally distinctive combinations of climatic, geological and biological factors, and are therefore directly suited to the location in which they arise. They also support a micro-flora that is directly adapted to local conditions, and in particular a range of mychorrhizal fungi that may be beneficial to the growth and establishment of vegetation, and they will also contain a range of plant propagules – seeds and other fragments of plants, that reflect the vegetation of the site. The logic of using local soil material therefore seems clear. It is important, however, to realize that the chemical, physical and biological characteristics of a soil are altered as soon as it is disturbed or removed from a site. Placing a local soil on to a green roof does not mean that it is the same soil that will remain on the roof. How will a soil obtained from a ground-level habitat perform when placed on a roof top, with all the associated microclimatic conditions that that entails? A soil that, in its natural environment, is composed of several layers (the typical topsoil, subsoil and bedrock or underlying layers), will function in a different way when decapitated and spread over a relatively thin layer over an impermeable base. In particular, the microbial flora may be severely disrupted, especially if the soil is stockpiled or stored before use (1). If 'natural soils' are to be used, then it is sensible to consider an equivalent situation to that which might occur on the roof – a thin, free draining, low fertility soil over a relatively impermeable bedrock (such as often occurs over limestone).

It is likely that the more disturbance-sensitive or ruderal plant species will be the main beneficiaries of this process, and by their very definition, these are weedy species. This may not necessarily be a problem, depending on the desired outcome, but a low diversity, uninteresting vegetation may result, particularly if the soil has some fertility within it, or with deeper substrate depths, in which more aggressive or competitive species can survive. In the specific context of invertebrates it has been proposed, because the local microclimate and neighbouring habitats play a vital role in species assemblage, it is preferable to use local substrates recycled from the site in question (4). While this may indeed be the case, there is no evidence that the use of recycled substrates from the site is the only way to achieve this – substrates with similar characteristics may achieve exactly the same result. Many mobile species that find disturbed urban sites are opportunists in that they are seeking particular structural qualities for their habitat, and are not tied to specific substrates.

Brick rubble and crushed concrete of urban brownfields are clearly modern, artificial materials that mimic, for example, calcareous rock screes

It is therefore possible to create ideal habitat opportunities by using artificially constructed substrates and non-local materials. However, the strongest argument for using locally-derived substrates and soils is related more to sustainability principles in general, rather than biodiversity in particular. The use of such materials considerably reduces embodied energy costs (i.e manufacture and transport costs) and therefore should be encouraged on these grounds, wherever possible. ***Conclusion****: using local soils may be problematic. Using locally-derived materials as a basis for substrates provides a strong basis for sustainable green roofs.*

Overall Conclusion

This paper has sought to put forward a balanced argument in relation to the role of native species, and reflecting the locality in creating green roofs. As Kendle and Rose (12) state (spefically in the context of landscape policies that favour native species): '*are native-only policies justified? Of course not. They are often better, and we would subscribe to the argument that local character and local species should always be given a presumption in their favour when planting anything, but this is not the same as endorsing condemnation of alternatives'* Evidence suggests that, while native species do indeed have many benefits, in terms of supporting biodiversity, substrate qualities, and the spatial and vertical structure of vegetation is also of importance, regardless of geographical origen, as is diversity of content. Far from being seen as a threatening conclusion that upsets long-held convictions, and somehow opens us up to a world of anarchy and 'anything goes', this conclusion should be seen as highly liberating, opening up a limitless range of opportunities for green roof vegetation that can be seen as promoting biodiversity.

If we accept that substrate and vegetation structure and character are crucial factors, then much effort should be given to setting up and creating ideal conditions for the establishment and long-term persistence of naturalistic vegetations, the content of which may vary according to context – in effect it is about ecology and biodiversity as *process* rather than lists of names. We should view ecological communities, and the possibilities for their creation as *continua*, rather than absolute and fixed points. In an urban green roof context, these continua should take as much account of aesthetics and visual criteria as they do of scientific ones. Dunnett and Hitchmough have proposed a framework or model for the creation and management of urban naturalistic vegetation for any particular site that combines two sets of factors (10):

1. **Ecological Factors: How important is nature conservation at any particular site?** In effect, what is the role and importance of native species and locally-characteristic plant communities. For some sites, it may be obligatory to use native species, or to encourage particular target plant communities, in others it may not.
2. **Cultural Factors: How acceptable is 'wild' vegetation in any particular site?** In many locations, very wild (and predominantly green) vegetation may be entirely appropriate and acceptable. This is linked to visibility and accessibility, but can also be made more acceptable by interpretation and education. In other locations it may be entirely unacceptable (because of socio-

economic factors, use or history of a site). In these instances it may be perfectly possible to establish green roofs and vegetation with high biodiversity value, but factors such as colour, flowering intensity, or the use of patterns and other design techniques may come into play.

		Cultural Factors (how acceptable is ‘wildness’?		
		Wild appearance		Ordered, neat and tidy appearance
		Predominantly ecological approach		Predominantly horticultural approach
Ecological Factors (importance of nature conservation)	‘Locally-characteristic habitats and native plant species			
	Native plant species			
	Native species, and mixes of native and exotic plant species			
	Exotic plant species			

Table 3. A model for biodiverse green roofs. Each cell represents a particular combination of species composition and vegetation character

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