Green infrastructure and ecosystem services - is the devil in the detail?

Article

Accepted Version

It is advisable to refer to the publisher's version if you intend to cite from the work. See Guidance on citing.

To link to this article DOI: http://dx.doi.org/10.1093/aob/mcw129

Publisher: Oxford University Press

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

1   VIEWPOINT PAPER

2

3   Green Infrastructure and Ecosystem Services – Is the Devil in the Detail?

4

5   Ross W.F. Cameron[1]*[†] and Tijana Blanuša[2,3†]

6

7   *[1]Department of Landscape, University of Sheffield, S10 2TN, UK*

8   *[2]School of Agriculture, Policy and Development, University of Reading, RG6 6AR, UK*

9   *[3]Royal Horticultural Society, Plant Sciences Department, Garden Wisley, Woking GU23*

10   *6QB, UK*

11   **For correspondence: r.w.cameron@sheffield.ac.uk*

12   *[†]Joint first authors*

13

14

1   **Abstract**

2   *Background* - Green infrastructure is a strategic network of green spaces designed to deliver

3   ecosystem services to human communities. Green infrastructure is a convenient concept for

4   urban policy makers, but the term is used too-generically and with limited understanding of

5   the relative values or benefits of different types of green space and how these complement

6   one another. At a finer scale/more practical level– little consideration is given to the

7   composition of the plant-communities, yet this is what ultimately defines extent of service

8   provision. This paper calls for greater attention to be paid to urban plantings with respect to

9   ecosystem service delivery and for plant science to engage more-fully in identifying those

10   plants that promote various services.

11

12   *Scope* - Many urban plantings are designed based on aesthetics alone, with limited thought on

13   how plant choice/composition provides other ecosystem services. Research is beginning to

14   demonstrate, however, that landscape plants provide a range of important services, such as

15   helping mitigate floods and alleviating heat islands, but that not all species are equally

16   effective. The paper reviews a number of important services and demonstrates how genotype

17   choice radically affects service delivery.

18

19   *Conclusions* – Although research is in its infancy, data is being generated that relates plant

20   traits to specific services; thereby helping identify genotypes that optimise service delivery.

21   The urban environment, however, will become exceedingly bland if future planting is simply

22   restricted to monocultures of a few 'functional' genotypes. Therefore, further information is

23   required on how to design plant communities where the plants identified:- a/ provide more

24   than a single benefit (multi-functionality) b/ complement each other in maximising the range

25   of benefits that can be delivered in one location and c/ continue to maintain public acceptance

1   through diversity. The identification/development of functional landscape plants is an

2   exciting and potentially high impact arena for plant science.

3

4   **Key words:** alien plants, biodiversity, building energy-efficiency, carbon sequestration,

5   ecosystem services, green infrastructure, human health and well-being, policy, pollution,

6   storm-water management, temperature regulation, urban.

7

8

9

10

11

1   INTRODUCTION

2

3   *What is green infrastructure?*

4   Green infrastructure (GI) is a term that was coined to provide an antonym to grey

5   infrastructure (Benedict and McMahon, 2012). Grey infrastructure is the built components of

6   cities including buildings, roads, pavements, sewers and other structural utilities. Green

7   infrastructure is meant to spatially complement grey infrastructure and at the same time

8   counterbalance some of the negative effects associated with grey infrastructure. Natural

9   England in the UK (Anon, 2009) define green infrastructure as:

10   'A strategically planned and delivered network comprising the broadest range of high quality

11   green spaces and other environmental features. It should be designed and managed as a

12   multifunctional resource capable of delivering those ecological services and quality of life

13   benefits required by the communities it serves and needed to underpin sustainability. Its

14   design and management should also respect and enhance the character and distinctiveness of

15   an area with regard to habitats and landscape types'.

16   Green infrastructure is composed of a range of green landscape typologies, including

17   parks, nature reserves, street trees, gardens, river corridors, ponds, green roofs and walls,

18   farmed land and allotments etc. as well as linking elements such as the 'green corridors'

19   found alongside roadways and railway lines [NB water features themselves are sometimes

20   referred to as components of 'blue infrastructure']. Although 'green infrastructure' is a very

21   convenient concept to describe an urban green network, the term is used by policy makers all

22   too generically with little understanding of the balance and interlinking of the different

23   typologies (or indeed their different 'values' in terms of ecosystem service (ES) delivery).

24   Mel (2008) raised concerns that any underestimation of the complexity of green spaces

25   within the urban-rural matrix could undermine the value of these spaces and hinder their

1 function. In practical terms, GI is now seen by most city planners as a necessary requirement,

2 but what actually populates these greenspaces that are 'blocked out' between the buildings is

3 often given inadequate attention (Matthews et al., 2015). Furthermore, implementing new, or

4 improving existing green space is hampered by financial constraints, limited expertise, a lack

5 of tools to value the different green space types as well as a lack of comprehension of how

6 landscape typology affects service provision (Sandström et al., 2006; De Groot et al., 2010;

7 Hunter and Luck, 2015). At a finer scale – i.e. at a plant or plant-community level, frequently

8 little consideration is given to the composition of these spaces and rarely in terms of the

9 benefits that might be conferred other than purely aesthetics. Even in relatively detailed

10 policy documents such as the European Commission's 'Building a Green Infrastructure for

11 Europe (EU, 2013) only one plant species is mentioned in relation to its ES delivery; namely

12 the value of the seagrass *Cymodocea nodosa* to support fishing stocks. Likewise, in a

13 comprehensive review on 'The Multifunctionality of Green Infrastructure' (EU, 2012), there

14 is no mention of any specific plant species within the 37 page report; although both these

15 reports begin to acknowledge that different typologies (habitats) provide distinctive ES.

16   As stated in the definition above, GI should be designed and managed to accentuate

17 the ESs and quality of life benefits to human society. These ecosystem 'services' are

18 normally defined as 1/ supporting (e.g. soil formation, photosynthesis, primary production,

19 nutrient and water cycling); 2/ provisioning (e.g. food, fibre, fuel, fresh water, genetic

20 resources, natural pharmaceuticals and chemicals); 3/ regulating (ecosystem processes

21 including regulation of air and water quality, climate, pests and disease) and 4/ cultural

22 (including cognitive development, spiritual enrichment, recreation and aesthetic experiences)

23 (Anon, 2005). There are a number of instances where these services are well understood, and

24 in a botanical context where the 'suppliers' are readily identified, e.g. in the provision of food

25 via the major graminea crops of the world (wheat, rice, sorghum etc.). There are numerous

1   additional cases, however, where optimum service provision is difficult to articulate in terms

2   of plant genotypes. This is where the plant scientist can play an important role, both in

3   defining more precisely the benefits of GI and in determining how these are dictated by

4   genotype choice; the level of service delivery being determined by the selection of

5   appropriate plant species, but also within a horticultural context, by cultivar choice within a

6   species.

7

8   *The Urban Context*

9   In an urban GI context, plant genotype choice is very much determined historically by

10   aesthetics (private gardens), cultural symbolism (civic squares), ecological suitability and

11   niche opportunities (wasteland or 'brownfield' sites) and functionality in relation to food

12   (allotments, vegetable plots and orchards). We have some notion of what plant genotypes

13   inhabit or could be used to populate these 'spaces' in terms of their suitability for certain

14   environmental conditions and soils types. The issue of plant selection becomes much more

15   difficult however, when GI is designed around wider human needs, for example to:

16   • regulate urban air temperature, noise and atmospheric pollution;

17   • intercept rainfall, reduce storm water run-off and mitigate flash flooding;

18   • maximise the thermal insulation of buildings and thus reduce energy consumption.

19   Even when a role for plants *per se* has been recognised in such situations, the choice of

20   genotype has been seen as largely irrelevant up to now. But should this be the case? Do all

21   plants respond in a similar way, have comparable functional traits or provide broadly the

22   same level of ecosystem service?

23

24   THE RESEARCH AGENDA

1   Research has been carried out over the last few years, largely driven by these questions.

2   These research programmes have not only attempted to better quantify the extent to which

3   plants contribute to certain 'urban' ESs (e.g. Tzoulas *et al.,* 2007; Cameron *et al.,* 2012;

4   Gómez-Baggethun and Barton, 2013) but also to begin to identify genotypes that optimise the

5   desired service provision (e.g. Freer-Smith *et al.,* 2005; Blanusa *et al.,* 2013). However, only

6   a small fraction of the potentially useful genotypes have been studied so far, and further

7   evaluations are required to furnish policy makers with more comprehensive and accurate lists

8   of beneficial plants. The urban environment, however, will become a bland place indeed, if

9   planting is limited to simply a few 'functional' genotypes placed strategically at relevant

10 locations. Information is thus required on how to design entire plant communities where the

11 plants identified:- a/ provide more than a single benefit (multi-functionality) and b/

12 complement each other in terms of maximising the range of benefits that can be delivered in

13 the one locale. Such concepts are not new in urban horticulture. Plants have been chosen to

14 provide a range of complementary flower colours to appeal to human aesthetics, for example

15 pastel blues harmonising with pale pink in an Edwardian flower border (Bisgrove, 2013). The

16 difference now is that these plant communities should not only be visually appealing, but also

17 enhance the functionality of the site. A case in point, a city-centre roadside planting may need

18 to be designed in future to: provide nectar and pollen for native invertebrates, act as a filter to

19 remove particulate matter emitted by passing vehicles, provide localised cooling through

20 shading and evapotranspiration, and help relieve psychophysiological stress experienced by

21 pedestrians as they walk along the road, as well as be deemed aesthetically pleasing in its

22 own right. Not only this, but this plant community may need to be resilient enough to tolerate

23 periods of sub-optimal irrigation, high aerial temperatures in summer and the effects of de-

24 icing salts applied in winter. To date, little information exists to provide the appropriate plant

25 palette.

1   Research in this context is not solely focussed on identifying plants for future use. It is

2   also important in understanding the extent to which existing popular cultivars and their ES

3   delivery are vulnerable to abiotic, biotic and even societal change. For example, for a cultivar

4   that is currently dominant in the landscape and which provides a specific positive service,

5   then a change in popularity either to a different species or even just a different clonal form,

6   may alter the delivery of that service. As an illustration, the replacement of golden/light green

7   foliage conifers commonly placed in garden hedges (e.g. × *Cuprocyparis leylandii*

8   'Castlewellan Gold' or *Cupressus macrocarpa* 'Goldcrest') with cultivars possessing darker

9   foliage is likely to reduce the albedo of the hedges, and increase the amount of solar energy

10   absorbed in that location/neighbourhood. Even subtle changes in cultivar abundance due to

11   e.g. fashion, might change the service delivery level that a given species confers.

12

13

14   *Urban Services – Old and New*

15   For certain services, differences in genotype have been evident over many decades largely

16   through anecdotal observations. The identification of plants specifically to aid wildlife

17   conservation falls into this category. Only since the concept of ESs has become mainstream,

18   however, has the full service potential of urban plants been more widely investigated

19   (Cameron and Hitchmough, 2016). For a number of these more recently-defined services,

20   evidence is now also beginning to build as to the extent to which plant choice matters. A

21   range of service areas are highlighted below, with evidence of how genotype choice can

22   affect the level of service delivery.

23

24   HOW MUCH DOES GENOTYPE CHOICE MATTER?

25   *1. Urban biodiversity*

1   Plant choice is often determined by a genotype's ability to support certain fauna taxa or

2   guilds. Paradoxically, this does not result in simply recommending native plant species, but

3   potentially also utilising non-native (alien) species to support native fauna; a point that has

4   caused much debate around the relative merits/risks associated with planting non-native

5   species in an urban environment (Shackelford *et al*., 2013; Standish *et al*., 2013). As an

6   example, the Asiatic shrub *Buddleia davidii* has long been valued by UK gardeners for its

7   ability to provide nectar to native *Lepidoptera* species (Hardy and Dennis, 2008); being

8   considered more effective in this respect than any native shrub during mid-late summer (a

9   consequence of which the species' common name is 'butterfly bush'). Recent systematic

10   studies support the notion that native is not always best. Helden *et al*. (2012) ranked both UK

11   native and non-native tree species for their value in supporting phytofagus invertebrates and

12   their associated avian predators. The results demonstrated that not all native trees are

13   necessarily superior in providing habitat/food resource compared to non-natives, e.g. natives

14   such as *Corylus avellana* and *Sorbus aucuparia* host fewer *Hemiptera* (true bugs) than non-

15   native *Sorbus intermedia* or *Quercus rubra*. Although there are genuine concerns that some

16   non-native plants are invasive and cause radical reductions in native flora and fauna (Alpert

17   *et al.* 2000), there are situations where introduced alien species have restored services that

18   were previously lost after the elimination of the dominant native species. In California, for

19   example, stands of non-native *Eucalyptus globulus* provide habitat that is equally rich in

20   understorey plants, leaf litter invertebrates, amphibians and birds as the native *Quercus*

21   *agrifolia / Umbellularia californica* dominated forests (Sax, 2002). Species composition

22   varies between the two woodland types, but overall richness does not. Other conservation-

23   based services that non-native plants provide include: nesting/feeding habitat for birds (Chen

24   2001; Berens *et al*., 2008; Sogge *et al*., 2008; Bajema *et al*., 2009;) refuge habitat for rare

1   invertebrates (Chiba, 2010) and acting as 'nurse crops' to allow more effective establishment

2   of native vegetation (Lugo, 2004, Sullivan *et al*., 2007).

3   As with *Buddleia*, many non-native plant species are encouraged because they supply

4   nectar and pollen to pollinating insects, such a bees and hoverflies, although concerns have

5   been raised about how this impacts on pollination rates within native plant species due to

6   increased competition and cross pollination (Bjerkness *et al*., 2007). Certain key factors

7   determine the value of non-native plants to native invertebrates, including the ability to

8   access nectar or pollen and the volume of nectar available (Potts *et al*., 2003; Carvalheiro *et*

9   *al*., 2014). Inter-relationships are often prevalent if the plant is from the same biogeographical

10   region, albeit not the same country (so called 'near natives'), as there may have been some

11   co-evolution in the past with the native insects, or closely-related species. For example in UK

12   gardens, plants native to nearby European countries, North America and northern Asia (i.e.

13   the Holarctic ecozone) may be particularly beneficial to the native insects, as their

14   evolutionary histories have overlap (Goulson *et al*., 2008; Salisbury *et al*., 2015). So *Salvia*

15   *nemorosa* with a natural distribution within central Europe, when planted in the UK offers a

16   similar service to pollinators as the native *Salvia pratensis* (Carreck *et al*., 1997; Anon,

17   2013a). Another factor affecting the value of non-native plants as a food source relates to the

18   feeding behaviour of the insects themselves. In bumble bees, species with catholic

19   (polylectic) diets, such as *Bombus pratorum* and *B. terrestris* actually favour plants out-with

20   their biogeographical range, whereas those that are more specialist feeders e.g. *B. hortorum*

21   and *B. pascuorum* are more reliant on native or near-native plants (i.e. from the Palaearctic

22   ecozone) (Fig. 1)(Hanley *et al.,* 2014).

23   Irrespective of these factors around evolutionary overlap or feeding strategies there

24   can be remarkable differences in flower attractiveness based on cultivated forms even within

25   the same plant species. Garbuzov and Ratnieks (2015) recorded that within aster, *Aster novi-*

1   *belgii* the cultivars 'Alice Haslam' and 'Dandy' had 15.2 and 10.1 insects visits m^{-2} of plant

2   cover respectively, compared to no visits in the morphologically similar cultivars 'Sheena' or

3   'White Wings'. Similar large variations were recorded across cultivars of *Lavandula*

4   (Garbuzov and Ratnieks, 2014). In essence, either relatively small morphological differences,

5   or more fundamental (but less obvious) physiological differences (e.g. carbohydrate form and

6   concentration in the nectar) are determining whether a genotype is a useful service provider

7   or not.

8

9   *2. Local temperature regulation*

10 Vegetation provides a localised cooling service through i. shading land and built surfaces

11 from solar irradiance, ii. evapotranspiration, with solar energy being converted to latent heat

12 (thus avoiding a rise in leaf and surrounding air temperatures), iii. transforming a small

13 proportion of thermal energy to chemical energy *via* photosynthesis and iv. an albedo effect,

14 reflecting incoming solar energy back to the atmosphere thereby reducing the potential for

15 short wave irradiance to be converted to long wave infra-red wavelengths (i.e. heat) at ground

16 level. Species vary in their ability to interact with solar irradiance, and hence the capacity to

17 cool their immediate locality. Street and park trees are highly-valued, especially in the

18 tropics, for their ability to cool ground surfaces and the surrounding air, although the extent

19 of cooling is radically altered by the characteristics of the chosen tree (Fig. 2). Lin and Lin

20 (2010) demonstrated that those species typified by dense canopies (high leaf area indices –

21 LAI) and thick leaves (e.g. *Ficus elastica*) were effective at cooling the soil surface, whereas

22 lightly-coloured foliar species such as *Ulmus parvifolia* and *Pterocarpus indicus* were better

23 placed to directly cool the air below the canopy. Within parks, correlations between increases

24 in tree canopy cover and reductions in air temperature have been noted in Ethiopia (0.2^{o}C for

25 every 10% increment in cover). Groves of trees dominated by *Eucalyptus* (*E. grandis*, *E.*

1 *camaldulensis* and *E. globulus*) showed greatest temperature reductions followed by stands of

2 *Olea* (*O. europaea* and *O. capensis*) while populations of *Grevillea robusta* and *Cupressus*

3 *lusitanica* were less effective at cooling (Feyisa et al., 2014). In warm, arid climates where

4 stomatal conductance (g_s) may be suppressed during the hottest periods of the day as an

5 adaptation to conserve water, shade cooling may be a more critical factor in aiding human

6 thermal comfort (Shashua-Bar et al., 2010; Feyisa et al., 2014).

7 Even in temperate climates such as the UK, greater attention is being paid to

8 understanding and adopting those tree species that provide greater street cooling.

9 Investigations into the influence of evapotranspirational cooling (Rahman et al., 2015)

10 showed that the more rapid growing species tended to have greatest (g_s) and thus enhanced

11 cooling capacity (Table 1). Indeed genotypes that combined high g_s with wide canopies and

12 high LAI such as *Pyrus calleryana* and *Crataegus laevigata* provided 3 to 4 times more

13 cooling than alternatives such as *Sorbus arnoldiana* and *Prunus* 'Umineko'. These latter

14 genotypes showing some susceptibility to urban stress, a possible cause of relatively low g_s

15 values. The red-leaved *Malus* 'Rudolph' was tolerant of urban conditions, but also provided

16 low cooling potential. This may relate to colour affecting the energy balance of the leaf, or

17 that leaves with an atypical colour often correspond to lower g_s; Vaz Monteiro et al., (2016)

18 found this to be so in *Heuchera* cultivars where the red/ purple leaved *Heuchera* 'Obsidian'

19 has lower g_s and higher leaf temperatures than cultivars with green or gold/yellow foliage.

20 Smaller scales of 'green intervention' are also used to promote local cooling,

21 particularly on or around buildings. Most green roof systems utilise *Sedum* spp. due to their

22 tolerance of shallow substrates and drought stress. Recent research, however, showed that

23 these are not the best species to employ if cooling is the over-arching priority (Blanusa *et al*.,

24 2013; Vaz Monteiro et al., 2016). Rather, species with light-coloured, non-succulent, leaf

25 canopies were superior in their cooling capacities to that of *Sedum,* due to a combination of

1 higher values for transpiration, LAI and latent heat loss, and lower values for both sensible

2 and soil heat transfer. Indeed, species choice alone could result in 2, 3 and 5 fold differences

3 in latent, sensible and soil heat fluxes, respectively. As with trees, short stature shrubs (e.g.

4 S*alvia officinalis* and *Stachys byzantina*) which possess traits including high LAI, high

5 evapotranspiration rate and light-coloured, silvery or hirsute leaves appear most effective at

6 cooling.

7   *Stachys was* also shown to provide >7.0°C cooling effect on a green wall system

8 (comparable to the common evergreen climber *Hedera heli*x. By blocking stomatal and

9 cuticular water loss with poly (1-acetyloxiethylene) sealant in a proportion of the plants, the

10 relative cooling effects of shading and evapotranspiration could be calculated. Data indicating

11 that *Hedera* was more reliant on shading to provide a cooling influence than *Stachys* (Fig 3).

12 When evaluated on a per leaf area basis, these species were out-performed, however, by

13 *Fuchsia*, *Jasminum* and *Lonicera* (Fig 4).Again, the mechanisms by which the cooling was

14 conferred varied markedly between species (Cameron *et al*., 2014)*. Fuchsia* promoted

15 evapotranspirational cooling, whereas shade cooling was more important in *Jasminum* and

16 *Lonicera.* This variation in mechanisms is important to recognise, because specific

17 manipulation of a given species can further enhance the desired traits, for example, the

18 effectiveness of individual leaves can be influenced through careful training of the stems. In

19 species that confer cooling *via* shade, attaining *multiple* layers of leaves which maximise light

20 interception is the objective. Conversely, with species that cool *via* evapotranspiration then

21 providing a *single* layer of evenly-spaced leaves may be the priority in an attempt to optimise

22 moisture transfer from the leaves to the surrounding atmosphere.

23

24   *3. Energy conservation*

1   The cooling ability of plants in summer and their ability to insulate buildings in winter not

2   only impact on human thermal comfort, but also energy conservation and economics. Akbari

3   *et al*. (2001) estimated that increasing the urban forest within the USA would reduce national

4   energy use by 20% and save over $10B p.a. through reduced reliance on artificial air

5   conditioning and improvements in air quality. Using tree belts to protect buildings from cold

6   wind helps entrap warm air around the building fabric and reduces energy loss by conduction

7   and convection of heat from the interior of the building. Models indicated shelter from trees

8   reduced winter energy consumption in Scottish buildings by 17% (Lui and Harris, 2008). An

9   empirical study using replicated heated brick cuboids, showed that placing a green façade

10   around the structures reduced mean winter energy use by 38% (and under some severe

11   weather conditions improved savings up to 45%)(Cameron *et al*., 2015). Subsequent studies

12   indicated that thicker-leaved *Prunus laurocerasus* improved air temperature at a wall surface

13   during cold nights, compared to smaller-leaved, less-densely foliated *Cotoneaster franchetti*.

14   Yet the latter species was overall the more beneficial as it enhanced the temperature within

15   the wall cavity, due to it allowing more solar heat gain onto the wall during the daylight hours

16   than the *Prunus*, whilst also conferring some insulation effect at night (Fig. 5).

17

18   *4. Storm-water retention*

19   Vegetation plays a key role in capturing, retaining and detaining precipitation, and if

20   placed/designed in harmony with hydrological flow pathways mitigates storm-water flooding.

21   Selection and age of park/street trees affect the ability to capture rainfall and store it on

22   leaves, stems and bark (Xiao and McPherson, 2002). Due to its greater canopy and leaf size

23   and more extensive branch structure *Platanus* x *hispanica* retains a greater volume of

24   rainwater than e.g. *Liquidamber styraciflua* (Fig. 6). 'Fine–textured' canopies, as promoted

25   by the numerous needles in evergreen conifer species e.g. *Pinus strobus* are very effective at

1 holding moisture within the tree canopy too. Similarly, species possessing rough bark with

2 many grooves and fissures (e.g. *Quercus rubra*) hold more water than equivalent smooth-

3 barked species (e.g. *Betula lenta*). For a 300 mm diameter tree, normative bark water storage

4 capacities ranged from approximately 100 l for *B. lenta* to 250 l for *Q. rubra* (Levia and

5 Herwitz, 2005).

6   For green roofs, storm water management too is influenced by plant selection

7 (Lundholm *et al.,* 2010; Schroll *et al.,* 2011). Nagase and Dunnett, (2012) indicated water

8 retention was improved by using grasses and forbs rather than succulents, largely due to

9 structural differences As much of the water retained on a green roof is held within the pore

10 structure of the substrate (VanWoert *et al.,* 2005), however, the ability to remove this existing

11 water via evapotranspiration (i.e. re-charge the storage capacity) before the next storm event

12 is also critical. Plant choice is also important here, as by deploying genotypes with high

13 transpiration rates the substrate can be dried quickly and the storage capacity restored over a

14 relatively short timeframe (Kemp pers. comm.).

15

16   *5. Carbon sequestration*

17 Using biomass as a predictor of carbon levels within urban trees, McPherson and Simpson

18 (1999) indicated that species could be ranked based on their ability to absorb carbon dioxide,

19 e.g. after 40 years growth *Quercus ilex > Ceratonia siliqua > Eucalyptus globulus >*

20 *Cinnamomum camphora > Pinus radiata > Pinus strobus > Cupressus macrocarpa*. These

21 data, however, do not indicate how much carbon might be transported to the soil via leaf

22 litter, root dieback or root exudates. Other studies suggest that this could be significant, with

23 75% of terrestrial carbon held within soils (Edmonson *et al*., 2014). Again such studies

24 indicate that genotype influences the soil carbon pool. Soil organic carbon stocks within

25 urban parks were enhanced under *Fraxinus excelsior* (26 kg m^{-2} of land area) and mixed

1   stands of *Acer pseudoplantanus*/*A. platanoides* (19 kg m^{-2}) compared to stands of *Quercus*

2   *robor* or even other mixed woodland types (both 14 kg m^{-2}) (Edmonson *et al.,* 2014).

3

4   *6. Mitigating the effects of soil, aerial and water pollutants*

5   The beneficial services provided by certain plants are acknowledged within parts of the land

6   remediation sector. Tolerance to heavy metal elements and thus the ability to phytoremediate

7   contaminated soils varies markedly within tree genera such as *Salix* (Punshon and Dickinson,

8   1999); tolerance in this genus being clone- or hybrid-specific, rather than species-specific.

9   This is due to either different selection pressures based on population provenance or active

10   breeding between tolerant genotypes.

11   Leaf structure affects the extent by which plants are able to capture particulate matter

12   (PM) from the air (Beckett *et al*. 2000; Freer-Smith *et al*. 2005; Kardel *et al*., 2011; Blanusa

13   *et al.,* 2015). As such, the choice of street tree impacts on the potential to remove particle-

14   based pollution along roadways. Particulate matter emitted from diesel engines is a specific

15   health concern; with PM <10 μm dia. (PM10) able to enter human airways, PM <2.5 μm

16   (PM2.5) accessing pulmonary air sacs and PM <0.1 μm entering the blood system. In a study

17   evaluating the pollution capture potential of Italian street trees, it was evident that *Tilia*

18   *cordata* and *Platanus* ×*hispanica* were the favoured choice for capturing particles <10 μm,

19   whereas *Quercus cerris* and *Quercus ilex* were more effective at capturing PM >10 μm

20   (Blanusa *et al*. 2015). UK studies also differentiated species effects with *Pinus nigra* var.

21   *maritima* and *Sorbus aria* being superior to other trees for trapping PM >10 μm, with *Pinus*

22   also effective at accumulating PM <10 μm (Beckett *et al*., 2000). Speak *et al*. (2012) found

23   that grasses (*Agrostis stolonifera* and *Festuca rubra*) were more effective at PM <10 μm

24   capture than either broad-leaved *Plantago lanceolata* or succulent *Sedum album* when

25   investigating typical green roof vegetation. This was attributed to grass species having

1   complex canopy structures which reduce near-surface air flow and increase deposition rates,

2   as well as possessing parallel grooves on their leaves which trap particles and prevent their

3   re-suspension. Although large areas of green space are required to reduce air pollutants across

4   the entire urban matrix, discrete interventions using vegetation along roadways or to target

5   point sources of pollution such as industrial complexes may have a place in mitigating

6   problems at a local scale.

7   Plants also act as biofilters to remove pollutants from storm-water run-off. Read *et al*.

8   (2008) showed that volume of total suspended solids, concentrations of organic and inorganic

9   N and P, and concentrations of Cu varied 2-4 fold among the species tested. Moreover, for

10   pollutants such as NO_x, NH_4^+, Mn, Pb and Fe differences between species could be as much

11   as 20 fold. When root mass was taken into account, remediation potential was even more

12   marked; *Carex appressa*, *Melaleuca ericifolia*, *Juncus flavidus* and *J. amabilis* being

13   significantly more effective at retaining/absorbing N and P than *Leucophyta brownie*,

14   *Microlaena stipoides* and *Acacia suaveolens*.

15

16   *7.   Human health and well-being*

17   The value of plants in providing therapeutic landscapes has been under intensive study for the

18   last two decades (e.g. Tzoulas *et al*., 2007; Sandifer *et al*., 2015). The key attributes of green

19   space in this context is an ability to alleviate stress in humans (attention restoration) (Kaplan,

20   1995) and to encourage physical activity in a consistent and sustained manner (e.g. gardening

21   or hill walking) (Cameron, 2014). Others consider that plant-derived volatile chemicals such

22   as α-pinene and β-pinene have a direct role by enhancing the body's immunological function

23   and/or providing anti-cancer properties (Li *et al*., 2007) although the evidence for this is more

24   circumspect. Again the assumption has been that all green spaces have equal merit in stress

25   alleviation, but there is some evidence to suggest that the quality of the landscape influences

1   restoration potential. Plant choice may be one of the sub-factors affecting quality of

2   landscape. Although working with a relatively small population, Li *et al*. (2012) indicated

3   that plants noted for their green foliage or predominately purple-blue flower hues (*Lavandula*

4   *angustifolia*) resulted in more positive psychological responses in participants than species

5   that exhibited red (*Papaver rhoeas*), yellow (*Brassica napus*), or white (*Leucanthemum*

6   *vulgare*) flower colours. This was supported by lower ratings of irritability, fatigue and

7   anxiety and higher scores of vigour. In contrast, exposure to all flower communities

8   irrespective of predominant colour induced physiological improvements in the participants

9   compared to exposure to non-natural scenes. This included decreases in systolic and diastolic

10   blood pressure, heart rate, electrocardiogram readings and fingertip pulse rates and increased

11   galvanic skin response. There is also a limited amount of evidence that humans have a

12   preference for particular plant forms (Heerwagen and Orians, 1993; Lohr and Pearson-Mims,

13   2006; Lee *et al*., 2014), for example flat-topped specimen trees (e.g. *Acer palmatum*, *Cornus*

14   *controversa*, *Pinus sylvestris* var. *scotica*) reminiscent of *Vachellia tortilis* (umbrella thorn

15   acacia) – a key landscape 'icon' present during human evolution on the African savannahs.

16   Whether this sort of visual preference actually translates into a health benefit remains to be

17   determined.

18   Noise is considered a stress-inducing factor, and plants are used to absorb, diffuse and

19   deflect noise (noise attenuation). Shelter belts of vegetation are now utilised to protect

20   residents from road, rail and industrial sources of noise. Dense plantings of shrubs, where

21   plants are a few metres higher than the receiver of the noise are considered optimal for noise

22   attenuation. Species such as *Bambusa dolichoclada* and *Garcinia subelliptica,* characterised

23   by dense foliage and low forking branches correlate with greater noise reduction compared to

24   *Nageia nagi* with broader-spaced branches and leaves (Fang and Ling, 2003). As with other

25   phenomena discussed previously, plant traits also interact with sound waves. Greater density,

1   height, length and width of shelter belts help diffuse noise more effectively, whereas

2   increasing leaf size and branching characteristics aid absorption of sound waves. Even in

3   situations where vegetation does not alter decibel level *per se*, the presence of plants seem to

4   provide a psychological benefit and recipients perceive the noise to be lower than it actually

5   is (Irvine *et al*., 2009).

6

7   *8.   Crime and security*

8   Parks and other green spaces are often associated with crime and anti-social behaviour

9   (James et al., 2009) and although crimes do undoubtedly occur in parks, often the perceptions

10   of crime are greater than the reality. Indeed there is evidence that green space can mitigate

11   against criminal activity, or at least certain types of activity. Kuo and Sullivan (2001) for

12   example, correlated a loss of green views from apartment blocks with increased incidences of

13   domestic violence; the mechanisms being that the green vistas were providing a beneficial

14   restoration effect from physio-psychological stress, but on the removal of this therapeutic

15   influence (trees within sight of the apartment blocks had been cut down) this stress could

16   manifest itself as aggression. Other research has suggested that re-greening vacant urban

17   spaces, also inhibits criminal activity. In Philadelphia (USA) between 1999 and 2008

18   approximately 4,400 open derelict spaces were cleaned-up, planted with trees, grass and other

19   landscape plants, and surrounded by wooden fences, thus providing an impression of greater

20   care and maintenance being conferred to each of the sites (Branas et al., 2011). Regression

21   analyses associated re- greening with consistent reductions in gun assaults across the four

22   different sections of the city studied ($P < 0.001$) and consistent reductions in vandalism in

23   one of these sections ($P < 0.001$). The extent to which these positive responses are linked to

24   more / better quality vegetation *per se* or simply to a perception that the sites were more

25   effectively managed is difficult to prove. The fact that residents also reported less stress

1   around the re-vegetated plots, however, may indicate there was at least some restorative

2   effect being activated. Increasing tree cover has also been linked with reductions in robbery,

3   burglary, theft as well as shooting, with modelling by Troy et al., (2012) suggesting a 10%

4   increase in tree canopy cover across the urban matrix correlates with a 12% reduction in

5   crime rates, even when confounded factors such as socio-economic considerations are

6   accounted for. These aspects need further exploration and we are not at the point where

7   specific genotypes can be advocated to stop homicides! Nevertheless, trees especially those

8   with abroad crown or a high crown/trunk ratio that people seem to prefer (Lohr and Pearson-

9   Mims, 2006; Gerstenberg et al., 2016), may be the ones to consider when promoting a

10   relaxed ambience (see examples above, but also at a larger 'landscape scale' selections such

11   as *Acer cappadocicum*, *Quercus robur*, *Morus alba*, *Catalpa bignonioides* and *Prunus*

12   *yedoensis*).

13   In contrast to trees, shrubs, or at least dense belts of shrubs are positively associated

14   with crime or perceptions of crime (Troy et al., 2012). Such plantings can conceal criminals

15   before an attack or afford criminals a place to hide themselves or their stolen goods. To

16   counteract this shrubs / small trees that either have bare stems at the base, or can be readily

17   pruned to remove basal foliage (e.g. *Prunus laurocerasus*, *Corylus avellana*, *Cotoneaster*

18   *cornubia, Cercis siliquastrum*) are advocated for those park sites where retaining sight lines

19   through the vegetation is important to reduce the risk of crime. Here, however is an example

20   of a trade-off between two different ecosystem services – the precise opposite of this

21   vegetation design / shrub form being required to attenuate noise problems. Around the home,

22   other shrub species provide a distinct service though, notably those with thorns or sharp

23   serrations to the leaves. Species/cultivars within genera such as *Pyracantha*, *Berberis, Rosa,*

24   *Ilex*, *Rubus* and *Ulex* being commonly utilised to protect the domestic property from

25   intruders.

1

2   *9. Educational and cultural opportunities around engagement with nature*

3 In a society that is rapidly becoming urbanised, urban green space is a vital component for

4 citizens, and children in particular, to engage with nature. Engagement in the natural world

5 has been linked to health benefits (see above), but also personal and social development,

6 positive attitudes, values and greater resilience to stressful life events, opportunities for self-

7 discovery and un-structured play, improved cognitive functioning as well as acting as a

8 catalyst for social interactions that themselves promote an aptitude for learning (Wells and

9 Evans, 2003; Charles and Louv, 2009; Gundersen et al., 2016). Indeed, such engagement

10 enhances ecological literacy with corresponding 'life chances', including opportunities for

11 careers in the natural environment, not least in the environmental and biological sciences. A

12 report from the Royal Society for the Protection of Birds -RSPB (Anon, 2013b), however,

13 suggested that up to 80% of children in the UK have 'insufficient connection to nature'. This

14 has implications for educational opportunities and well-being for the children, but also for the

15 future conservation of species, as a lack of knowledge often relates to a lack of care (Charles

16 and Louv, 2009). This is one of the reasons why conservation bodies such as the RSPB and

17 the UK Wildlife Trusts are now investing in research and promotional campaigns around this

18 issue. Interestingly, the RSPB report indicates that engagement with nature can be highest in

19 urban situations, suggesting that urban green spaces are playing a significant role in allowing

20 wildlife to be present and appreciated. Highly-visual animal taxa encourage this engagement,

21 but so to do 'iconic' or cultural linked plant species, e.g. for children in western cultures

22 *Helianthus annuus* (sunflower), *Papaver rhoeas*, (corn poppy) *Aesculus hippocastanum*

23 (horse chestnut or 'conker tree'), *Taraxacum officinale* (dandelion) and *Narcissus* cultivars

24 (daffodils) amongst many others. In addition, being involved with food growing in home

25 gardens, allotments and community gardens educates children about natural processes and

1 enhances awareness about food. Moreover, such activities can improve social capital, within

2 and out with the family (Thompson et al., 2007), and introduce children to healthier eating

3 habits (Carney, 2012).

4

5 *Disservices*

6 Despite the range of services provided by landscape plants, some species also present

7 drawbacks (disservices). Landscape architects are under pressure to avoid plants that drop

8 fruit onto pavements, so male plants are the preferred choice rather than the female

9 equivalent where this is a problem e.g. either only the male form of *Ginkgo biloba* or the

10 seedless form 'Fastigiata' are recommended as roadside plantings. As well as being

11 unsightly, over-ripe fruit, e.g. from domestic plum (*Prunus domestica*) attract nuisance insect

12 species, notably wasps and flies. Trees that are associated with large amounts of leaf litter

13 (e.g. *Aesculus, Juglans, Populus, Salix* spp.) are best avoided in pedestrian precincts and

14 those linked with high honeydew secretions (sugary exudates from aphids and scale insects)

15 e.g. *Tilia x europaea* are not appropriate for planting within car parks, due to marking the

16 paintwork of cars. Poor choice of species also correlates with problems associated with

17 trapping litter (*Cotoneaster* spp.), excessive pollen production (*Betula*) or the release of

18 biovolatile organic compounds (which elicit ozone formation and reduce air quality e.g.

19 *Pinus, Eucalyptus* spp.), irritant hairs (*Fremondodendron californica*) or even direct toxic

20 effects if ingested (*Laburnum anagyroides*). Other species are notorious for the level of

21 maintenance they require to keep them in shape and within their designated boundaries (e.g.

22 *Cupressus × leylandii*). Again choice of species becomes paramount in minimising the

23 potential for disservices, and promoting positive traits.

24

25 *Multiple benefits*

1   Research within the authors' teams has started to investigate the multiple services offered by

2   green roof plants. Certain leaf/canopy traits identified as contributing to localized cooling

3   (Vaz Monteiro *et al.,* 2016) are also closely correlating with a species' capacity to mitigate

4   flooding by reducing surface run-off (Kemp pers. comm.). In these latest experiments, *Salvia*

5   *officinalis* and *Stachys byzantina* (previously identified as the species with greatest cooling

6   capacity from our small selection of model species) demonstrated the greatest ability to retain

7   water in the canopy (about 5% of that applied) and to increase the 're-charge potential' of the

8   substrate (they increased water holding capacity by 50%, compared to only 30% with *Sedum*)

9   before a subsequent rainfall event. In this case, the common trait of high evapotranspiration

10 rate has a positive influence on both the cooling service and the ability to recharge the water

11 holding capacity of the substrate (Fig. 7).

12   Identifying single functional traits that have potential to provide multiple services has

13 been an objective in other ecosystem management approaches (e.g. de Bello *et al*., 2010). In

14 addition to our studies highlighting the benefits of *Salvia* and *Stachys* on urban temperature

15 and water management, these two species are identified with wider service provision [the

16 hairs of *Stachys* leaves provide nesting material for wool-carder bees *Anthidium manicatum*

17 (Garbuzov and Ratnieks, 2014) and are effective at trapping aerial pollutants (Shackleton *et*

18 *al*., 2013); *Salvia* provides nectar (Mačukanović-Jocić *et al*., 2011) and pollen (Bozek, 2002)

19 for honey bees, *Apis mellifera*, and its foliage is a fundamental ingredient in Mediterranean

20 cuisine and a source of essential oils (Carrubba *et al*., 2014)].

21   Other studies show too that certain species are better than others in promoting

22 multiple services. In woodland systems for example, both *Picea* and *Betula* forests increase

23 timber resources, dead wood occurrence (important habitat provision) and soil carbon

24 accumulation compared to woodland stands of alternative species (Gamfeldt *et al.*, 2013).

25 *Pinus* on the other hand has less influence on soil carbon, but provides timber, deadwood and

1   a more open canopy that promotes *Vaccinium* groundcover; the berries of which are used as a

2   local food source by both humans and wildlife. So different woodland types may offer

3   multiple services, but also a different suite of services based on the community composition

4   (Isbell *et al*., 2011); an important point to consider when designing plant communities in the

5   urban landscape.

6

7   *What next?*

8   The concept that plants provide a range of ESs to the urban environment has become

9   gradually recognised over the last two decades, but the notion that plant choice and their

10   community structure and dynamics may be important components in this service delivery

11   remains to be universally acknowledged. From the point of view of most practitioners, plant

12   choice within urban GI still tends to be determined by what survives and what is aesthetic

13   (and in some circumstances, e.g. urban nature reserve, the geographic origin of the plants).

14   This paper highlights though, that genotype selection can make a radical difference to level of

15   ES delivery, and further research is required to help populate a more comprehensive data

16   base relating plant selection to key benefit/s. This will allow practitioners to select

17   appropriate genotypes to meet specific situations and scenarios. This will inevitably involve

18   developing inventories, and allied publications to disseminate information and advice to end

19   users. In very practical terms, it would be useful to see this new information added to the

20   labels of commercially retailed plants, such that these not only state the plants aesthetic

21   qualities e.g. 'good autumn colour', but also add information around their service provision

22   e.g. 'helps cool the patio' or 'improves wall insulation'. To date, this service provision has

23   only been documented with respect to wildlife conservation value ('fruit attracts birds',

24   'perfect for pollinators' etc.), but this should go further. At a more strategic level, information

25   on 'model' functional plant communities and case studies of where these have been put into

1   practice should be made available to policy makers and other stakeholders. As outlined

2   above, many policy makers now understand the 'whys' for GI, but focus now needs to shift to

3   the 'hows' and 'wheres' to help ensure effective implementation.

4   Plants that optimise ES provision need to be embedded into the urban fabric more

5   effectively. This means providing them with the appropriate space and necessary resources.

6   Indeed, the body of data collected to date challenges a number of current paradigms about

7   urban GI. Rather than trying to get robust, stress-adapted species to just survive on green

8   roofs and walls, placement of appropriate infrastructure (e.g. deeper substrates and artificial

9   irrigation) could allow for much more functional species to be employed. The advantages

10   gained potentially significantly outweigh any additional costs associated with the enhanced

11   infrastructure.

12   Site and management limitations currently threatened plant survival and hence

13   functionality in many urban situations. Even larger and more expensive plants such as

14   standard trees may fail due to site limitations. These may relate to issues such as compaction

15   leading to poor soil structure with inadequate aeration or drainage properties, pollutants,

16   excessively high or low pH (influenced by residual building materials), phytotoxicity through

17   de-icing salts and other 'urban' contaminants, as well as direct physical damage to roots and

18   trunks, e.g. from trenching associated with utility provision and maintenance within

19   streetscapes (Jim, 1998; Cameron and Hitchmough, 2016). Insufficient irrigation remains a

20   problem for many landscape plants most notably during their establishment phase. These

21   factors will need to be addressed, especially if the philosophy moves away from simply 'what

22   will survive' to 'what provides function' i.e. potentially a greater use of less-resilient but

23   perhaps more functional plants in future. Despite the financial implications, however, of

24   dealing with these issues effectively, increasing attention is already being paid to ensuring

25   greater plant longevity, at least from the more technically-advanced landscape companies.

1   For example, many street trees are now planted into 'structured' soils – where the aggregate

2   is designed to withstand compaction and remain well-aerated over time (Buhler et al., 2007).

3   Likewise, better integrated approaches to urban design exploit rainfall run-off and recycled

4   waste water more effectively, thereby meeting plants irrigation requirements; the more

5   sophisticated systems being automated to save on human labour too. The encouraging aspect

6   here is, as the cost-benefit analyses moves in favour of the benefits (i.e. society fully

7   understands the value of the plantings) then higher costs can be, and often are, justified.

8   Relatively expensive –'micro' green walls (so called 'air pollution units') are being

9   introduced to bus stops and other locations along roadsides, with air actively passed through

10 the rhizosphere in an attempt to remove aerial contaminates such as nitrous oxides (Henry,

11 2015). If these prove to be effective, they are likely to be adopted as local authorities become

12 more concerned about urban air pollution. Economic models and traditional views on who are

13 the custodians of urban landscapes may also change in line with ES provision. If trees

14 provide greater thermal comfort in and around shopping precincts (Taleghani et al., 2016;

15 Sanusi et al., 2016), then tree plantings may be implemented and maintained by the retailers

16 rather than the local authority, as more comfortable employees and customers correlates with

17 potentially greater sales returns (Kolb et al., 2012); see point below too about the role of

18 residents /volunteers.

19   Urban design also needs to be more imaginative, and aim to exploit the plant traits to

20 their full. Planted living walls could be mobile and their position altered to reflect the needs

21 of the building during different seasons e.g. in a northern hemisphere scenario, façades would

22 be placed on a building's southern aspect and used to provide direct shade to the building

23 during hot, sunny summer days, but their orientation altered on the cooler, duller days of

24 winter, to maximise natural daylight from the south to illuminate the building (Figs. 8 and 9).

1   Further research is warranted to investigate the feasibility and cost-effectiveness of such

2   approaches.

3   Advances should not be limited to a technical nature alone, however. Existing

4   paradigms around the social/societal context may need to be challenged too, particularly with

5   respect to the management of urban green landscapes. There may be movement away from

6   central civic control to those situations where residents, volunteers and more locally-

7   organised groups take on greater responsibility for the management of the new plant

8   communities. This may not just be solely due to financial constraints on local authorities, but

9   also the fact that some of the service delivery (e.g. health and well-being) depends on citizens

10   taking a more active role within, and indeed actively advocating for, their greenspaces.

11   Detailed information is required before an individual genotype can be fully assessed

12   for its functional merits. This limits the number of species/cultivars that can be evaluated

13   within a given time and could lead to a situation where only a small proportion of the useful

14   plant genotypes are identified and actively endorsed for their ES provision, at least initially.

15   The urban environment is going to be poorly served, however, if only 'monocultures' of a

16   few 'functional keystone' genotypes are slavishly promoted and used. At the same time it is

17   not feasible to evaluate in depth, the ES potential of every one of the 400,000 genotypes

18   available to the landscape sector. Thus, we argue that an initial step forward is to deepen our

19   understanding about how particular structural/physiological traits (e.g. colour, hairiness, size

20   of canopy and/or root system, inherent evapotranspiration rate) correlate with the provision of

21   specific ESs. By providing an extended choice of plant genotypes which offer good service in

22   various categories ('cooling', 'rainfall mitigation', 'pollutant trapping' etc.), the diversity of

23   urban planting will be increased whilst also improving overall ES delivery. The extent to

24   which the possession of 'generic' structural traits, however, actually relates to the magnitude

25   of service delivery remains to be tested in full. For example, do all grey-leaved plants provide

1   a similar albedo? Obviously too, where space is limited, it is desirable to identify genotypes

2   that deliver more than a single service.

3   Additionally, although some species have a greater number of functional traits than

4   others, designing more diverse plant communities is likely to provide greater resilience in the

5   long term (Isbell *et al*, 2011; Lundholm, 2015), as well as being intrinsically more interesting

6   *per se*. So the urban plant communities of the future should incorporate a range of genotypes

7   which are targeted at a particular service (e.g. atmospheric cooling) but also include others

8   that cover different ES provision requirements (e.g. noise abatement), as well as adding yet

9   further genotypes, simply to help ensure variety and diversity. Similarly, a more complete

10   understanding of the desired goals of these communities will in itself help drive their design

11   and management. For example, plant communities that are designed to attract *Lepidoptera* for

12   example, may need to provide a source of nectar for longer than any one (transient flowering)

13   plant species alone can give. Similarly the community should include plant species that act as

14   hosts to the larval stages, as well as simply feeding the adults; thus allowing the insect to

15   complete its entire lifecycle within a fairly small geographical range. Unlike the rural

16   environment, where emphasis should remain on native species and natural/semi-natural

17   ecosystems, the urban environment has more opportunity to experiment with how vegetation

18   can be used more effectively and with greater innovation (with appropriate safeguards) to

19   optimise ES delivery. The concept of GI is now 'in place' in many of our towns and cities,

20   but its true potential will only be realised when we elaborate and enrichen 'the details', and

21   develop a diverse matrix of functional greenspaces.

22

23   CONCLUSIONS

24   This paper calls for greater attention to be paid to individual plants when considering

25   ecosystem service provision in an urban context. The arguments presented here indicate,

1   quite simply, that plant choice matters! It is no longer appropriate for urban green space to be

2   populated with plant species based on an *ad hoc* manner relating to a vague notion of

3   aesthetics, or even simply on a 'what can survive' basis. As urbanisation increases and there

4   is greater pressure on land for development, green spaces need to be able to justify their

5   inclusion within the urban matrix, based on effective and wide-ranging service delivery.

6   More research is required to understand better how plant traits impact on that service

7   delivery, and how functional communities of plants can be designed to address specific

8   problems or provide a range of important services with a limited space. Our knowledge base

9   in selecting appropriate plants / communities is in its infancy, but as the value of, and

10   requirement for, urban green infrastructure become more apparent, there will be increasing

11   pressure to ensure that plant choice is optimised and that this choice is based on strong

12   scientific rationale. As such, this is an exciting and important new area for plant research.

13   More-over the opportunity for scientists and practitioners to transform the urban matrix

14   through more effective and wider used of plants (in some case quite literally turning our grey

15   cities green) has significant and notable impact for plant science, globally. This arena of

16   research has opportunities to link plants directly to the key issues of the day including human

17   health and well-being, climate change adaptation, crime reduction, social cohesion and

18   through better habitat provision for wildlife, allowing us to still engage with nature

19   irrespective of where we live. In a human society now largely urbanised (Hall and Pfeiffer,

20   2013), implementing 'more effective' green infrastructure will have substantial benefits,

21   perhaps in due time becoming the second most important aspect of plant cultivation globally

22   after that aligned to commercial food production.

23

24

25   LITERATURE CITED

1   **Akbari H, Pomerantz M, Taha H. 2001.** Cool surfaces and shade trees to reduce energy use

2   and improve air quality in urban areas. *Solar Energy* **70:** 295-310.

3   **Alpert P, Bone E, Holzapfel C. 2000.** Invasiveness, invasibility and the role of

4   environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology,*

5   *Evolution and Systematics* **3:** 52-66.

6   **Anon. 2005.** *Ecosystems and human well-being Vol 5.* Millennium Ecosystem Assessment,

7   Washington, DC: Island Press.

8   **Anon. 2009.** Green Infrastructure Guidance. Natural England. www.

9   naturalengland.org.uk/publications. Accessed 13 October 2015.

10   **Anon. 2013a.** Urban Pollinators http://urbanpollinatorsblogspotcouk/2013/09/pollinator-

11   friendly-garden-plants-forhtml. Accessed 14 September 2015.

12   **Anon. 2013b**. Connecting to Nature – Finding out how connected to nature the UK's children

13   are. Royal Society for the Protection of Birds.

14   https://www.rspb.org.uk/Images/connecting-with-nature_tcm9-354603.pdf. Accessed 28

15   April 2016.

16   **Bajema RA, DeVault TL, Scott PE, Lima SL. 2009.** Reclaimed coal mine grasslands and

17   their significance for Henslow's Sparrows in the American Midwest. *The Auk* **118:** 422–

18   431.

19   **Benedict MA, McMahon ET. 2012.** *Green infrastructure: Linking landscapes and*

20   *communities.* Island Press.

21   **Beckett KP, Freer-Smith PH, Taylor G. 2000.** Particulate pollution capture by urban trees:

22   Effect of species and windspeed. *Global Change Biology* 6: 995-1003.

23   **Berens DG, Farwig N, Schaab G, Böhning-Gaese K. 2008.** Exotic guavas are foci of

24   forest regeneration in Kenyan farmland. *Biotropica* **40:** 104–112.

1 **Bisgrove R. 2013.** The colour of creation: Gertrude Jekyll and the art of flowers. *Journal of*
2   *Experimental Botany* **64:** 5783-5789.

3 **Bjerknes AL, Totland Ø, Hegland SJ, Nielsen A. 2007.** Do alien plant invasions really
4   affect pollination success in native plant species? *Biological Conservation* **138:** 1-12.

5 **Blanusa T, Fantozzi F, Monaci F, Bargagli R. 2015.** Leaf trapping and retention of
6   particles by holm oak and other common tree species in Mediterranean urban
7   environments. *Urban Forestry & Urban Greening* **14**: 1095-1101.

8 **Blanusa T, Vaz Monteiro MM, Fantozzi F, Vysini E, Li Y, Cameron RWF. 2013.**
9   Alternatives to *Sedum* on green roofs: Can broad leaf perennial plants offer better 'cooling
10   service'? *Building and Environment* **59:** 99-106.

11 **Bozek M. 2002.** Flowering biology and pollen flow of three species from genus *Salvia* L.
12   *Annales Universitatis Mariae Curie-Sklodowska Sectio EEE Horticultura* (Poland).

13 **Branas CC, Cheney RA, MacDonald JM, Tam VW, Jackson TD, Ten Have TR. 2011.** A
14   difference-in-differences analysis of health, safety, and greening vacant urban space.
15   *American Journal of Epidemiology*, **174:** 1296-1306.

16 **Buhler O, Kristoffersen P, Larsen SU. 2007**. Growth of street trees in Copenhagen with
17   emphasis on the effect of different establishment concepts. *Arboriculture and Urban*
18   *Forestry* **33:** 330.

19 **Cameron RW. 2014.** Health and Well-Being In: *Horticulture: Plants for people and places*,
20   Volume 3 Springer, pp 1001-1023.

21 **Cameron RW, Blanuša T, Taylor JE, Salisbury A, Halstead AJ, Henricot B, Thompson**
22   **K. 2012.** The domestic garden–Its contribution to urban green infrastructure. *Urban*
23   *Forestry & Urban Greening* **11:** 129-137.

24 **Cameron RWF, Hitchmough J. 2016**. *Environmental horticulture: Science and*
25   *management of green landscapes.* Boston, CAB International.

1 **Cameron RWF, Taylor JE, Emmett MR. 2014.** What's 'cool' in the world of green

2 façades? How plant choice influences the cooling properties of green walls. *Building and*

3 *Environment* **73:** 198-207.

4 **Cameron RWF, Taylor JE, Emmett MR. 2015**. A *Hedera* green façade - Energy

5 performance and saving under different maritime-temperate, winter weather conditions.

6 *Building and Environment* **92:** 111-121.

7 **Carney M. 2012**. Compounding crises of economic recession and food insecurity: A

8 comparative study of three low-income communities in Santa Barbara County. *Agriculture*

9 *and Human Values*, **29:** 185-201.

10 **Carreck NL, Williams IH, Little DJ. 1997.** The movement of honey bee colonies for crop

11 pollination and honey production by beekeepers in Great Britain. *Bee World* **78:** 67-77.

12 **Carrubba A, Catalano C. 2009**. Essential oil crops for sustainable agriculture – A review

13 In: *Climate Change, Intercropping, Pest Control and Beneficial Microorganisms.*

14 Springer, pp 137-187.

15 **Carvalheiro LG, Biesmeijer JC, Benadi G, Fründ J, Stang M, Bartomeus I, Kunin WE.**

16 **2014.** The potential for indirect effects between co-flowering plants via shared pollinators

17 depends on resource abundance, accessibility and relatedness. *Ecology Letters* **17:** 1389-

18 1399.

19 **Charles C. and Louv R. 2009**. Children's nature deficit: What we know and don't know.

20 *Children and Nature Network*, pp.1-32.

21 **Chen LY. 2001.** Cost savings from properly managing endangered species habitats. *Natural*

22 *Areas Journal* **21:** 197–203.

23 **Chiba S. 2010.** Invasive non-native species' provision of refugia for endangered native

24 species. *Conservation Biology* **24:** 1141– 1147.

1   **de Bello F, Lavorel S, Díaz S, Harrington R, Cornelissen JH, Bardgett RD, Harrison**

2   **PA. 2010.** Towards an assessment of multiple ecosystem processes and services via

3   functional traits. *Biodiversity and Conservation* **19:** 2873-2893.

4   **De Groot RS, Alkemade R, Braat L, Hein L, Willemen L., 2010.** Challenges in integrating

5   the concept of ecosystem services and values in landscape planning, management and

6   decision making. *Ecological Complexity* **7:** 260-272.

7   **Edmondson JL, O'Sullivan OS, Inger R, Potter J, McHugh N, Gaston KJ, Leake JR.**

8   **2014.** Urban tree effects on soil organic carbon *Plos One* **9:** e101872.

9   **EU. 2012**. The Multifunctionality of Green Infrastructure. Science for Environment Policy –

10   In-Depth Report, European Commission.

11   http://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf.

12   Accessed 6th April, 2016.

13   **EU. 2013.** Building a Green Infrastructure for Europe, European Commission.

14   http://ec.europa.eu/environment/nature/ecosystems/docs/green_infrastructure_broc.pdf.

15   Accessed 6th April, 2016.

16   **Fang CF, Ling DL. 2003.** Investigation of the noise reduction provided by tree belts.

17   *Landscape and Urban Planning* **63:** 187-195.

18   **Feyisa GL, Dons K, Meilby H. 2014**. Efficiency of parks in mitigating urban heat island

19   effect: An example from Addis Ababa. *Landscape and Urban Planning*, **123:** 87-95.

20   **Freer-Smith PH, Beckett KP, Taylor G. 2005.** Deposition velocities to *Sorbus aria, Acer*

21   *campestre, Populus deltoides* × *trichocarpa* 'Beaupré', *Pinus nigra* and ×

22   *Cupressocyparis leylandii* for coarse, fine and ultra-fine particles in the urban

23   environment. *Environmental Pollution* **133:** 157-167.

Gamfeldt L, Snäll T, Bagchi R, Jonsson M, Gustafsson L, Kjellander P, Bengtsson J. 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications* **4:** 1340.

Garbuzov M, Ratnieks FL. 2014. Quantifying variation among garden plants in attractiveness to bees and other flower-visiting insects. *Functional Ecology* **28:** 364-374.

Garbuzov M, Ratnieks FL. 2015. Using the British National Collection of asters to compare the attractiveness of 228 varieties to flower-visiting insects. *Environmental Entomology* **1:** 9.

Gómez-Baggethun E, Barton DN. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics* **86:** 235-245.

Goulson D, Lye GC, Darvill B. 2008. Decline and conservation of bumble bees. *Annual Review of Entomology* **53:** 191-208.

Gundersen V, Skår M, O'Brien L, Wold LC, Follo G. 2016. Children and nearby nature: A nationwide parental survey from Norway. *Urban Forestry & Urban Greening* **17**: 116-125.

Hall P, Pfeiffer U. 2013. *Urban future 21: A global agenda for twenty-first century cities.* Routledge.

Hanley ME, Awbi AJ, Franco M. 2014. Going native? Flower use by bumblebees in English urban gardens. *Annals of Botany* **113:** 799-806.

Hardy PB, Dennis RL. 2008. Resources for British butterflies (Lepidoptera: Hesperioidea, Papilionoidea). The alien consumer component and its significance for butterfly habitats. *European Journal of Entomology* **105:** 649-657.

Heerwagen JH, Orians, GH. 1993. Humans, habitats, and aesthetics. *The biophilia hypothesis.* Island Press, pp 138-172.

1   **Helden AJ, Stamp GC, Leather SR. 2012.** Urban biodiversity: Comparison of insect

2   assemblages on native and non-native trees. *Urban Ecosystems* **15:** 611-624.

3   **Henry E. 2015.** Units offer relief from air pollution. *Horticulture Week*

4   http://www.hortweek.com/units-offer-relief-air-pollution/landscape/article/1354885.

5   Accessed 8th April, 2016.

6   **Hunter AJ, Luck GW. 2015.** Defining and measuring the social-ecological quality of urban

7   greenspace: a semi-systematic review. *Urban Ecosystems* **18:** 1139-63.

8   **Irvine KN, Devine-Wright P, Payne SR, Fuller RA, Painter B, Gaston KJ. 2009.** Green

9   space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local*

10   *Environment* **14:** 155-172.

11   **Isbell F, Calcagno V, Hector A, Connolly J, Harpole WS, Reich PB, Loreau M. 2011.**

12   High plant diversity is needed to maintain ecosystem services. *Nature* **477:** 199-202.

13   **James P, Tzoula K, Adam MD, Barber A, Box J, Breuste J, Elmqvist T, Frith M,**

14   **Gordon C, Greening KL, Handley J. 2009.** Towards an integrated understanding of

15   green space in the European built environment. *Urban Forestry & Urban Greening* **8:** 65-

16   75.

17   **Jim CY. 1998**. Urban soil characteristics and limitations for landscape planting in Hong

18   Kong. *Landscape and Urban Planning* **40:** 235–249.

19   **Kaplan S. 1995.** The restorative benefits of nature: Toward an integrative framework.

20   *Journal of Environmental Psychology* **15:** 169-182.

21   **Kardel F, Wuyts K, Maher BA, Hansard R, Samson R. 2011.** Leaf saturation isothermal

22   remanent magnetization (SIRM) as a proxy for particulate matter monitoring: Inter-species

23   differences and in-season variation. *Atmospheric Environment* **45:** 5164-5171.

24   **Kolb P, Gockel C, Werth L. 2012**. The effects of temperature on service employees'

25   customer orientation: An experimental approach. *Ergonomics* **55:** 621-635.

Kuo FE, Sullivan WC. 2001. Environment and crime in the inner city does vegetation reduce crime? *Environment and Behavior* **33:** 343-67.

Lee KE, Williams KJ, Sargent LD, Farrell C, Williams NS. 2014. Living roof preference is influenced by plant characteristics and diversity. *Landscape and Urban Planning* **122:** 152-159.

Levia DF, Herwitz SR. 2005. Interspecific variation of bark water storage capacity of three deciduous tree species in relation to stemflow yield and solute flux to forest soils. *Catena* **64:** 117-137.

Li Q, Morimoto K, Kobayashi M, Inagaki H, Katsumata M, Hirata Y, Krensky AM. 2007. Visiting a forest, but not a city, increases human natural killer activity and expression of anti-cancer proteins. *International Journal of Immunopathology and Pharmacology* **21:** 117-127.

Li X, Zhang Z, Gu M, Jiang DY, Wang J, Lv YM, Pan HT. 2012. Effects of plantscape colours on psycho-physiological responses of university students. *Journal of Food, Agriculture and Environment* **10:** 702-708.

Lin BS, Lin YJ. 2010. Cooling effect of shade trees with different characteristics in a subtropical urban park. *HortScience* **45:** 83-86.

Liu Y, Harris DJ. 2008. Effects of shelterbelt trees on reducing heating-energy consumption of office buildings in Scotland. *Applied Energy* **85:** 115-127.

Lohr VI, Pearson-Mims CH. 2006. Responses to scenes with spreading, rounded, and conical tree forms. *Environment and Behavior* **38:** 667–688.

Lugo AE. 2004. The outcome of alien tree invasions in Puerto Rico. *Frontiers in Ecology and the Environment* **2:** 265–273.

Lundholm JT, MacIvor JS, MacDougall Z, Ranalli M. 2010. Plant species and functional group combinations affect green roof ecosystem functions. *PloS One* **5**: 1-11.

1 **Lundholm JT. 2015.** Green roof plant species diversity improves ecosystem
2 multifunctionality. *Journal of Applied Ecology* **52:** 726-734.

3 **Mačukanović-Jocić M, Stevanović ZD, Mladenović M, Jocić G. 2011.** Flower
4 morphophysiology of selected Lamiaceae species in relation to pollinator attraction.
5 *Journal of Apicultural Research* **50:** 89-101.

6 **Matthews T, Lo AY, Byrne JA. 2015.** Reconceptualizing green infrastructure for climate
7 change adaptation: Barriers to adoption and drivers for uptake by spatial planners.
8 *Landscape and Urban Planning* **138:** 155-63.

9 **Mell I. 2008**. Green infrastructure: Concepts and planning. In FORUM ejournal **8**: 69-80.

10 **McPherson EG, Simpson JR. 1999.** Carbon dioxide reduction through urban forestry. In:
11 *General Technical Report PSW-171*, USDA Forest Service, Pacific Southwest Research
12 Station, Albany, CA.

13 **Nagase A, Dunnett N. 2012.** Amount of water runoff from different vegetation types on
14 extensive green roofs: Effects of plant species, diversity and plant structure. *Landscape*
15 *and Urban Planning* **104:** 356-363.

16 **Potts SG, Vulliamy B, Dafni A, Ne'eman G, Willmer P. 2003.** Linking bees and flowers:
17 How do floral communities structure pollinator communities? *Ecology* **84:** 2628-2642.

18 **Punshon T, Dickinson N. 1999.** Heavy metal resistance and accumulation characteristics in
19 willows. *International Journal of Phytoremediation* **1:** 361-385.

20 **Rahman MA, Armson D, AR. 2015**. A comparison of the growth and cooling effectiveness
21 of five commonly planted urban tree species. *Urban Ecosystems* **18:** 371-389.

22 **Read J, Wevill T, Fletcher T, Deletic A. 2008**. Variation among plant species in pollutant
23 removal from stormwater in biofiltration systems. *Water Research* **42:** 893-902.

1 **Salisbury A, Armitage J, Bostock H, Perry J, Tatchell M, Thompson K. 2015.** Enhancing

2 gardens as habitats for flower-visiting aerial insects (pollinators): Should we plant native

3 or exotic species? *Journal of Applied Ecology* **52:** 1156–1164.

4 **Sandström UG, Angelstam P, Mikusiński G. 2006.** Ecological diversity of birds in relation

5 to the structure of urban green space. *Landscape and Urban Planning* **77:**39-53.

6 **Sanusi R, Johnstone D, May P, Livesley SJ. 2016**. Street orientation and side of the street

7 greatly influence the microclimatic benefits street trees can provide in summer. *Journal of*

8 *Environmental Quality* **45:** 167-174.

9 **Sandifer PA, Sutton-Grier AE, Ward BP. 2015.** Exploring connections among nature,

10 biodiversity, ecosystem services, and human health and well-being: Opportunities to

11 enhance health and biodiversity conservation. *Ecosystem Services* **12:** 1-15.

12 **Sax DF. 2002.** Equal diversity in disparate species assemblages: A comparison of native and

13 exotic woodlands in California. *Global Ecology and Biogeography* **11:** 49-57.

14 **Schroll E, Lambrinos J, Righetti T, Sandrock D. 2011.** The role of vegetation in regulating

15 stormwater runoff from green roofs in a winter rainfall climate. *Ecological Engineering*

16 **37:** 595-600.

17 **Shackelford N, Hobbs RJ, Heller NE, Hallett LM, Seastedt TR. 2013.** Finding a middle-

18 ground: The native/non-native debate. *Biological Conservation* **158:** 55-62.

19 **Shackleton K, Bell N, Smith H, Davies L. (2013).** The role of shrubs and perennials in the

20 capture and mitigation of particulate air pollution in London http://contenttflgovuk/role-gi-

21 pmpollutionpdf. Accessed 23 October 2015.

22 **Shashua-Bar L, Potchter O, Bitan A, Boltansky D, Yaakov Y. 2010.** Microclimate

23 modelling of street tree species effects within the varied urban morphology in the

24 Mediterranean city of Tel Aviv, Israel. *International Journal of Climatology*, **30:** 44-57.

Sogge M, Sferra S, Paxton E. 2008. Saltcedar as habitat for birds: Implications to riparian restoration in the southwestern United States. *Restoration Ecology* **16:**146–154.

Speak AF, Rothwell JJ, Lindley SJ, Smith, CL. 2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. *Atmospheric Environment* **61:** 283-293.

Standish RJ, Hobbs RJ, Miller JR. 2013. Improving city life: Options for ecological restoration in urban landscapes and how these might influence interactions between people and nature. *Landscape Ecology* **28:** 1213-1221.

Sullivan JJ, Williams PA, Timmins SM. 2007. Secondary forest succession differs through naturalised gorse and native kanuka near Wellington and Nelson, New Zealand. *Journal of Ecology* **31:** 22–38.

Taleghani M, Sailor D, Ban-Weiss GA. 2016. Micrometeorological simulations to predict the impacts of heat mitigation strategies on pedestrian thermal comfort in a Los Angeles neighborhood. *Environmental Research Letters* **11**:024003.

Taylor JE. 2012. *Green walls: The thermoregulatory role of plants adjacent to brick walls in a temperate climate*. PhD Thesis, University of Reading, UK.

Thompson S, Corkery L, Judd, B. 2007. The role of community gardens in sustaining healthy communities. In *Proceedings of the State of Australian Cities National Conference*. University of South Australia.

Troy A, Grove JM, O'Neil-Dunne J. 2012. The relationship between tree canopy and crime rates across an urban–rural gradient in the greater Baltimore region. *Landscape and Urban Planning* **106**: 262-270.

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, James P. 2007. Promoting ecosystem and human health in urban areas using green infrastructure: A literature review. *Landscape and Urban Planning* **81:** 167-178.

1   **VanWoert ND, Rowe DB, Andresen JA, Clayton LR, Fernandez RT, Xiao L. 2005**.

2   Green roof stormwater retention: Effects of roof surface, slope, and media depth. *Journal*

3   *of Environmental Quality* **34:** 1036-1044.

4   **Vaz Monteiro MM, Blanusa T, Verhoef A, Hadley P, Cameron R. (2016).** Relative

5   importance of transpiration rate and leaf morphological traits for the regulation of leaf

6   temperature. *Australian Journal of Botany*. ISSN 0067-1924.

7   **Wells N, Evans G. 2003.** Nearby nature: A buffer of life stress among rural children.

8   *Environment and Behaviour* **35:** 311-330.

9   **Xiao Q, McPherson EG. 2002**. Rainfall interception by Santa Monica's municipal urban

10   forest. *Urban Ecosystems* **6:** 291-302.

11

1   **Figure Legends**

2

3   Figure 1. Total number of flower visits by UK bumble bee (*Bombus*) species recorded in

4   urban gardens on flowering plants derived from the Palaearctic region (UK native and non-

5   native) and from out-with this region including locations where bumblebees naturally occur

6   (sympatric) or outside their natural evolutionary range (allopatric). Overall *B. hortorum* and

7   *B. pascuorum* showed a preference for Palaearctic plants ($P <0.01$), whereas *B. terrestris*

8   showed a preference for non-Palaearctic plants ($P<0.01$). *B. pratorum* did not visit any native

9   UK plant species. (Modified from Hanley *et al.,* 2014).

10

11 Figure 2. The effect of subtropical tree species on changing air (ΔTa) and land surface (ΔTs)

12 temperature under their canopies. Data refer to mean temperature differences measured

13 during July and August, 2007 in Taiwan using a replicate of ten specimens per species.

14 *Ulmus parvifolia* and *Pterocarpus indicus* provided significantly greater air cooling, and

15 *Ficus elastica* significantly greater surface cooling than other species ($P <0.001$) (Modified

16 from Lin and Lin, 2010).

17

18 Figure 3. Comparison of mean cooling (temperature differential, ^{o}C) for walls screened with

19 different species and bare control walls T*p*, and derived values for cooling due to shade (T*p*

20 $_{sh}$), evapo-transpiration (T*p* $_{et}$) and evaporation from medium (T*m*). Bars = LSD ($P = 0.05$)

21 respectively; d.f. = 32. (Modified from Cameron et al., 2014)

22

23 Figure 4. Comparison of mean cooling (temperature differential, ^{o}C) for walls screened with

24 different species and bare control walls, based on leaf area index T*p*, and derived values for

1 cooling due to shade (T*p* sh), evapo-transpiration (T*p* et) and evaporation from medium (T*m*).

2 Bars = LSD (*P* = 0.05) respectively; d.f. = 32. (Modified from Cameron et al., 2014)

3

4 Figure 5. The effect of vegetated façades (thick-leaved, high LAI, *Prunus laurocerasus* vs

5 small-leaved, low LAI, *Cotoneaster franchetti*) and non-vegetated façades on mean air

6 temperatures at a wall surface and within the cavity space of the wall. Data recorded at

7 approximately 21.00 h during sub-zero conditions on 11 separate days between Jan-Mar

8 2011. Each treatment was represented by three replicate walls, and values for 21.00 h meaned

9 from readings recorded at 20.50, 21.00 and 21.10 h respectively at each occasion. Bars =

10 LSD (*P* =0.05, d.f. 107) (Taylor, 2012).

11

12 Figure 6. Tree size and character (leaf / branch habit and duration of leaf retention) affect

13 rainfall interception. Larger trees (increasing diameter at breast height) capture more rainfall,

14 but also note differences between deciduous species) (modified from Xiao and McPherson,

15 2002).

16

17 Figure 7. The relationship between the volume of rainfall captured in a set volume of

18 substrate (i.e. water storage capacity, after 3 days of previous evaporation/transpiration

19 activity) and the amount of net radiation converted to latent heat (i.e. energy *consumed* in the

20 process of transpiration, thus leading to temperature reduction) as affected by different plant

21 species, with bare substrate used in comparison. High evapotranspiration rates associated

22 with *Stachys* allow this species to dry out green roof substrates quickly, thereby increasing

23 the ability of the roof to retain rainwater after any subsequent rainfall events, thus reducing

24 run-off to drains and sewers. The conversion of liquid water to the gaseous phase though

25 evapotranspiration, also uses energy as latent heat, thus there is less increase in local air

1   temperatures, compared to other species or bare substrate. (S. Kemp, University of Reading,

2   UK, unpubl. res.).

3

4   Figure 8. 'Mobile' green façade system used to alter temperature on the southern wall

5   (northern hemisphere) of a single storey building (diagram shows wall and façade from

6   above). A = During summer façade is positioned to directly intercept solar irradiance and

7   cool the building through shade and evapotranspiration. Prevailing summer breezes are

8   funnelled between the building and the façade thereby providing further cooling. B = Green

9   façade comprises plants grown in troughs, each section of façade being able to be divided in

10   the middle and orientated around 90° (e.g. using castors and guiding ground rail); façades

11   push in towards the building, like doors. The position of the façades can be altered e.g.

12   autumn and spring to change the amount of irradiance hitting the building wall. C = During

13   winter the façades afford solar irradiance to reach the building wall, thereby maximising

14   natural light entering the building and creating a warmer environment around the building

15   wall. Now the façades act as baffles deviating any cold wind away from the wall, trapping

16   pockets of warm air and further elevating the temperature of the building envelop on the

17   southern aspect.

18

19   Figure 9. Some green façades are designed to be mobile and used as temporary walls to

20   create wind, solar irradiance and sound 'baffles'. Photo courtesy of Sean Farrell, University

21   of Staffordshire. UK.