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The Domestic Garden – Its Contribution to Urban Green Infrastructure

Ross W.F. CAMERON[1], Tijana BLANUŠA[2, 3, *], Jane E. TAYLOR[3], Andrew SALISBURY[2], Andrew J. HALSTEAD[2], Béatrice HENRICOT[2] and Ken THOMPSON[4]

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

[2]Plant Sciences Department, Royal Horticultural Society, Garden Wisley, Woking GU23 6QB, UK

[3]School of Biological Sciences, University of Reading, Whiteknights, Reading RG6 6AS, UK

[4]Department of Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK

*Author for correspondence: tijanablanusa@rhs.org.uk, Telephone: +44-(0)118-378-6467

Abstract

Domestic gardens provide a significant component of urban green infrastructure but their relative contribution to eco-system service provision remains largely un-quantified. 'Green infrastructure' itself is often ill-defined, posing problems for planners to ascertain what types of green infrastructure provide greatest benefit and under what circumstances. Within this context the relative merits of gardens are unclear; however, at a time of greater urbanization where private gardens are increasingly seen as a 'luxury', it is important to define their role precisely. Hence, the nature of this review is to interpret existing information pertaining to gardens /gardening *per se*, identify where they may have a unique role to play and to highlight where further research is warranted. The review suggests that there are significant differences in both form and management of domestic gardens which radically influence the benefits. Nevertheless, gardens can play a strong role in improving the environmental impact of the domestic curtilage, e.g. by insulating houses against temperature extremes they can reduce domestic energy use. Gardens also improve localized air cooling, help mitigate flooding and provide a haven for wildlife. Less favourable aspects include contributions of gardens and gardening to greenhouse gas emissions, misuse of fertilizers and pesticides, and introduction of alien plant species. Due to the close proximity to the home and hence accessibility for many, possibly the greatest benefit of the domestic garden is on human health and well-being, but further work is required to define this clearly within the wider context of green infrastructure.

Keywords:

carbon footprint; ecosystem services; green space; private garden; well-being.

1. Introduction

Recent research has highlighted the positive role urban green infrastructure can provide in terms of ecosystem services (de Groot et al., 2002; Tratalos et al., 2007) and health agendas (Tzoulas et al., 2007). Yet, urban green infrastructure (parks, public green space, allotments, green corridors, street trees, urban forests, roof and vertical greening, private gardens) covers a range of landscape types of varying complexity and morphology. Do all hold equal value? Domestic gardens are quoted as an important component of green infrastructure (e.g. Loram et al., 2007), but their specific contribution is rarely assessed, and hence their relative value within the wider urban green space is difficult to quantify. For example, in terms of green space provision for the future should urban planners be prioritising private gardens around building stock, or rather, invest in more open, communal green spaces? Therefore, the aims of this review are to examine the evidence relating private domestic gardens to ecosystem service provision, to understand how form, function and management of gardens may influence the extent of that service, and to identify where further research is required. The relationship between the domestic garden and the four broad strands of ecosystem service function (provisioning, regulating, cultural and supporting; MA, 2003) are incorporated, although much of the literature focuses mainly focuses on the first three of these. We anticipate that the existing data on gardens highlighted here, in addition to new research initiatives, will help to provide a greater precision to existing models relating green infrastructure to human and ecosystem 'health' (Tzoulas et al., 2007).

2. What is an urban domestic garden?

For the purpose of this review we define the private domestic garden as the area adjacent to a domestic dwelling, which itself is either privately owned or rented. A key element is that the resident/s have autonomy over the garden, albeit they may wish to delegate responsibility to others (professional designer, hired gardener etc.). We attempt to differentiate and exclude, 'open' green space and communal gardens, for example where management may be by committee, or at the discretion of a housing association or local authority. Conversely, locations that have been 'guerrilla gardened', i.e. public areas that have been illegally planted by individuals are also omitted, despite these often reflecting individual autonomy, self-expression etc. We also exclude public parks and gardens, although their design may in many ways reflect those of private domestic gardens. Similarly, allotment sites where local bylaws may influence what may / may not be grown also fall outside our definition. Lastly, the emphasis has been on urban gardens and their role, rather than encompass large rural gardens where the dividing line between garden and extensive landscaped estate can be difficult to distinguish.

In highly urbanised societies up to 90% of the population reside in urban areas, and in cultures such as the UK 87% of households have access to a domestic garden (Gibbons et al., 2011). Depending on age and location of cities, domestic gardens contribute between 22 and 36% of the total urban area (Gaston et al., 2005; Mathieu et al., 2007), and perhaps as much as 3-4% of total land mass (Alloway, 2004; Gibbons et al., 2011). Similarly, they constitute a significant proportion of the urban green space, more than 50% in Dunedin, New Zealand, (Mathieu et al., 2007) and 35- 47% in the UK (Loram et al., 2007). Urbanization, however, is decreasing the proportion of area dedicated to gardens (Mathieu et al., 2007; Smith, 2010), through infill development, i.e. existing gardens being sold for development, or newer housing stock having smaller gardens.

Gardens are highly heterogeneous in form and function. At one extreme, they may comprise a few square meters of multi-layered diverse vegetation to, at the other, large areas of single dimension paving with no vegetation at all. Loram et al. (2007; 2008) reported that domestic garden size varied between 3.6 m^2 and 2290 m^2 within UK cities, with median garden size between 96 m^2 and 213 m^2. Housing type and density influences the proportion of green space available (Whitford et al., 2001). Although these authors did not differentiate between private gardens and other local green space, namely communal lawns, street trees / roadside verges or vegetated pedestrian pathways the data are illustrative of how housing age and type can influence presence and access to local green space. The highest proportion of surrounding green space was associated with 1930's era semi-detached houses (57%), intermediate with the modern low rise flats (30%) and lowest with the modern terraced housing (13%) (Whitford et al., 2001). Grass was the dominant green cover but the percentages varied (32.6%, 14.4% and 6.1%, respectively); trees covered 11%, 0.3%, and 0.9% respectively. Within domestic gardens lawns constitute 60% (UK, Gaston et al., 2005) or 55% (New Zealand, Mathieu et al., 2007) of the area. In the USA, lawns (private, public and sports turf) cover between 8 and 16 million ha, far surpassing land coverage of major crops, (e.g. cotton, Robbins et al., 2001).

Greater housing density is linked to smaller garden sizes, but not necessarily less urban green space (Smith et al., 2009). Socio-economic variables (e.g. population and housing density, education, home ownership) were apparently better predictors of the extent and the type of vegetation cover in private gardens than solely biophysical variables (e.g. rainfall, soil fertility, solar radiation etc., Luck et al., 2009). Larger domestic gardens (Smith et al., 2005), those associated with older properties (Hope et al., 2003), or with higher income or tertiary-educated residents tend to have proportionally more vegetation, greater diversity of plants, and more complex garden styles (Daniels and Kirkpatrick, 2006).

Front and back gardens often differ in character, with visual impact more important in front gardens, with the back used for functional purposes; this is, however, probably an oversimplification and an outdated concept (Daniels and Kirkpatrick, 2006). For example, UK trends over the last decade suggest that vegetation and aesthetic character have been lost from the front garden, due to off-road parking (Perry and Nawaz, 2008). Irrespective of location, vegetation is being replaced in favour of ‘low maintenance’ hard standings such as patios or decked areas (Smith, 2010).

3. Garden vegetation, temperature regulation and energy conservation

The relationship between green infrastructure and the mitigation of the urban heat island effect is currently under close scrutiny (Takebayashi and Moriyama, 2007; Alexandri and Jones, 2008; Huang et al., 2008), as climate change models highlight the increased likelihood of heat waves (Meehl and Tebaldi, 2004). Modelling approaches suggest that increasing the proportion of green space within the urban matrix, can reduce surface, and hence air temperatures. Gill et al. (2007) suggest a 10% increase in urban green infrastructure would negate the 4^{o}C increase predicted for Manchester, UK over the next 80 years. Type of urban green infrastructure and even plant species (Blanusa et al., unpublished), however, are likely to affect this cooling potential.

Urban trees are considered a major factor in providing cooling, *via* shade and evapo-transpiration, and are estimated to offer over 950 MJ (almost 270 kWh) cooling per day, per tree, due to evapo-transpiration effects alone (Huang et al., 1990). The extent to which gardens contribute to cooling is unclear. Domestic gardens account for 25% of the non-woodland trees in the urban matrix (Davies et al., 2009). Akbari et al. (1997) predicted that up to a quarter of the cooling effect by urban trees in USA cities may relate to garden/street trees contributing to direct cooling of the adjacent buildings. This will vary depending on the tree size, species, maturity, and architecture (Simpson, 2002), but more detailed research is needed to understand which type of buildings benefit from which trees, and to determine specific requirements for a range of scenarios.

Reducing the energy load on buildings by shading and evaporative cooling can reduce the reliance on / improve efficiency of, mechanical air conditioning units. US data suggest that strategic positioning of plants could reduce domestic buildings' energy consumption by 20-40% (Akbari et al., 1997; 2001; Huang et al., 1990). However, it was also suggested that greater savings may be accomplished if highly reflective building surfaces were used instead (Akbari et al., 2001); it is of interest therefore, to evaluate plants with a particularly high albedo within this context.

Despite the potential for urban vegetation to provide cooling, effectiveness relates to soil water availability. As climate change events reduce summer precipitation (for Europe) and heat waves exacerbate soil moisture deficits (IPCC, 2007), cooling through evapo-transpiration is likely to be compromised. For example, the cooling potential of turf is strongly linked to watering (McPherson et al., 1989). Hence, greater scrutiny is required in future research to elucidate the relative cooling associated with shade, albedo and evapo-transpiration.

Beyond trees, a wider range of vegetation has potential to improve cooling, e.g. through planting next to, or on, a building. Sufficiently robust data are still lacking for green facades, especially as different mechanisms are used to irrigate them. Recent work with turf applied as vertical greening, however, showed that this reduced interior surface temperatures by > 2^{o}C (Cheng et al., 2010). Green roofs also reduce interior temperatures through improved insulation via the substrate as well as the potential for evaporative cooling (Santamouris et al., 2007; Sailor, 2008). There is a suggestion that the strategies to conserve energy in temperate climates cannot be generalized, due to the "complex interactive effects of shade and wind reduction" (McPherson et al., 1988). Indeed, Bowler et al. (2010) point that there are insufficient data to provide specific recommendations. At the garden level, vegetation can influence the energy loads on individual buildings, but how this impacts on air temperatures across the wider urban environment is unclear. There also remain unresolved issues with respect to the scale on which urban climate parameters and vegetation are measured and how they are compared (Stewart, 2011).

In terms of winter temperature regulation and energy savings there is much less information available, although preliminary studies are encouraging (e.g. 17% saving in energy, Liu and Harris, 2008).Vegetation around houses enhances winter energy saving by reducing the velocity of air over buildings ('wind break'), removing draughts and minimizing temperature differences between existing and incoming air (McPherson et al., 1988). Careful planting design is paramount to ensure that wind tunnels are not directed towards the house, and that maximum solar gain is retained in winter (Knowles, 2003).

4. Carbon balance

Little information specifically identifies the role of the domestic garden in carbon dynamics, but the effectiveness of garden plants and soils for carbon storage will strongly depend on design (types of vegetation and coverage, see Figure 1), management, and the longevity of plantings. An average of 2.5×10^3 g m^{-2} of carbon is stored in domestic gardens with 83% in soil (to 600mm depth), 16% in trees and shrubs and only 0.6% on average in grass and herbaceous plants (Jo and McPherson, 1995). Indeed, there may be as much carbon stored within the top 100mm of soil profile alone, as in the entire vegetation biomass above ground (e.g. compare data for forests and forest soils, Figure 1). Soil carbon storage, however, is reduced by soil disturbance during replanting as organic matter is oxidized (Bolinder et al., 2007). Gardens that mimic forest or low maintenance meadow landscapes, or follow practices aligned with permaculture principles e.g. minimum soil cultivation, low chemical use, heterogeneous vegetation, use of recycled water and organic matter are likely to have the least impact in terms of CO_2 release (Pouyat et al., 2002; Favoino and Hogg, 2008). These suggestions, however, require testing in the domestic garden context. Even practices designed to aid carbon sequestration, such as tree planting, may have surprisingly long pay-back times. Due to the embedded energy associated with tree production and the volume of soil CO_2 released during planting, newly planted trees have been estimated to become 'carbon neutral' only after 3-10 years (Nowak and Crane, 2002; Schlosser et al., 2003).

Gardening is often promoted as an environmentally-friendly pastime, but this notion may be questioned when the intensity of garden activities are considered. Today's gardeners rely greatly on mechanized tools, synthetic fertilizers and pesticides (with high embodied energy, see section 5). In addition, potable water use has an energy load associated with its cleaning and distribution, and use of 'hard' landscaping materials bring their own embedded carbon, as well as the energy in growing and retail of nursery plants.

Perhaps the lawn provides the greatest illustration of the diverging attitudes to gardening in this respect with, at one extreme, naturalized grassland (meadows) having a low environmental footprint, in contrast to a heavily-maintained sward (Qian and Follett, 2002; Trudgill et al., 2010). The former requires a single annual cut, in contrast to high frequency mowing associated with formal lawns (e.g. weekly during optimum growth). Although accurate estimations of carbon use through mowing are difficult to attain (Reid et al., 2010), Jo and McPherson (1995) suggest petrol-powered mowing releases 1.5-fold the carbon sequestered by the lawn itself. Two stroke engines particularly are considered detrimental with a 7-fold higher by-product emission compared to four stoke engines (Volckens et al., 2008). Intensively-managed lawns are also associated with high fertilizer and herbicide inputs (and in warmer, affluent countries, high water use – see section 7). Despite this, where urbanisation results in housing development on land previously degraded or heavily cultivated, the creation of a lawn can help replace soil organic carbon originally lost through oxidation (Zirkle et al., 2011).

Longer-lived woody plants can provide greater carbon sequestration than annual plants due to reduced tillage and storage in biomass. Comparison between five shrub species indicated carbon storage in biomass ranges from 4.7-7.2 x 10^6 g carbon ha^{-1}, and atmospheric carbon uptake ranges from 0.56-0.80 x 10^6 g carbon ha^{-1} $year^{-1}$ (Jo, 2002). Total carbon sequestered in urban trees in the USA is estimated to be 700 x 10^{12} g (Nowak and Crane, 2002). Assuming that the ratio of garden to street / parkland trees in the USA is similar to that of the UK (i.e. 25%), this may equate to 175 x 10^{12} g of carbon sequestered in urban garden trees. This could be an over-estimation as garden trees are often smaller than parkland specimens. Caution is required, however, as these data do not include carbon emissions associated with tree maintenance which can lead to a negative life-time carbon balance (Nowak et al., 2002); carbon sequestration is usually modelled on a small unit basis (ha) (Brainard et al., 2006) and involves numerous assumptions and uncertainties when scaled up.

While there is a significant volume of carbon in garden trees, it is minor compared to the carbon stored in the world's forests (359 x 10^{15} g carbon, Dixon et al., 1994). This also needs to be viewed in light of total amount of excess carbon that needs to be sequestered annually to mitigate climate change, 1.8 ± 1.4 x 10^{15} g CO_2e (Dixon et al., 1994) [CO_2e being the amount of all greenhouse gases, when converted into equivalent units of carbon dioxide]. Therefore, although increasing the number of urban trees provides a range of environmental benefits, justifying new plantings solely to offset global deforestation, or fossil fuel emissions, seems irresponsible.

5. Garden chemicals

Chemicals, primarily fertilizers and pesticides, have widespread use (e.g. 50-74% of all homeowners in the UK and USA respectively, Robbins et al., 2001; Grey et al., 2006). Their application, particularly on lawns, is apparently linked to home property values, with more affluent residents using them more frequently (Robbins et al., 2001). In the USA, local by-laws encourage the use of garden chemicals and promote intensive management (e.g. lawns regularly mown and weed free, Robbins et al., 2001; Clayton, 2007).

The production/use of artificial *fertilizers* contribute significantly to greenhouse gas emissions (Howarth et al., 2002), with impact being particularly high from nitrogen fertilizer production based on the Haber-Bosch process. In contrast, manufacture of phosphate and potassium fertilisers is 20-fold less energy intensive. Composted organic matter offers a lower carbon cost alternative for supplementing nitrogen than using an inorganic nitrogen fertiliser NH_4NO_3 (Lillywhite and Rahn, 2008). Lawn fertilizer use in particular affects greenhouse gas emissions (Livesley et al., 2010) with lawns emitting up to 10 times more N_2O than neighbouring agricultural grassland. The higher emissions are thought to be due to the higher irrigation rates and soil temperatures found in urban lawns (Bijoor et al., 2008).

Garden *pesticides* are significant contributors to USA's non-point source water pollution (Robbins et al., 2001). Surface run-off, although not specifically quantified for domestic gardens, can include chemicals as well as particulate matter that can contribute to the pollution of watercourses (Overmyer et al., 2005). Parts of the gardening community are, therefore, encouraging lower chemical use and organic approaches, largely due to concerns over environmental issues. For example, the use of organic composts (green waste and spent mushroom) to support pest (e.g. aphid) control by encouraging predatory species (e.g. spiders and beetles) has shown some success (Bell et al., 2008). Furthermore, green spaces themselves can reduce pollution through capture of particulates and dissolved pollutants (Davis et al., 2001), although effectiveness will depend on the properties of the pollutant and the magnitude of benefits is yet to be assessed in the domestic context.

6. Run-off and flooding

Gardens provide storm attenuation ‘services’ to the urban matrix. Vegetation, trees especially, intercept intense precipitation, hold water temporarily within their canopy thus reducing peak flow and easing demand on urban drains (Xiao and McPherson, 2002). In addition, vegetation mitigates flood risk by increasing infiltration into the soil reducing surface flow (Dunne et al., 1991). Despite these advantages, hard paving in domestic gardens is increasing. Perry and Nawaz (2008) found a 13% increase in impervious surfaces over 30 years in the city of Leeds UK, 75% of which was due to paving of residential front gardens; this was linked to more frequent and severe flooding in the area. Pauleit and Duhme (2000) found that lower density housing with gardens had 3-fold less storm water run-off than higher density stock. The benefits of vegetated front gardens have been recognised by the UK planning system; from 2008 permission is required for impermeable paving (Anon, 2009).

7. Water use

Gardens are frequently associated with heavy water use, particularly during periods of dry weather. The proportion of potable water used for the domestic garden escalates with increased aridity. In western Australia, 56% of domestic water use is associated with domestic gardens (Syme et al., 2004). Similar values were found for Barcelona, Spain; on average, 30% of household water use is consumed within the garden, and this rises to 50%

during the summer (Domene and Sauri, 2006). Climate change will increase demand for garden water in temperate regions, although surprisingly few studies have investigated details of this. Mulching flower beds minimises moisture evaporation and has the added benefit of limiting gaseous emissions (Livesley et al., 2010). In lawns, organic *vs* intensive style of turf management can reduce water consumption up to 10-fold (Morris and Bagby, 2008).

Water use in the domestic garden needs to be systematically assessed. Despite moves to increase efficiency of garden water use (e.g. seep hose irrigation), greater attention to water storage (e.g. water butts) and grey water use, it is likely, that potable water use in the garden will become increasingly restricted. This is partly due to increased water demand, e.g. greater housing density, climate change, and the carbon associated with mains water supply (Strutt et al., 2008).

8. Peat

The use of peat in gardens, and horticulture in general, is controversial due to habitat destruction and carbon emissions linked with peat extraction (Alexander et al., 2008), despite the fact that the majority of peat harvested is consumed by power stations (Alanne and Saari, 2006). Peat used as a soil conditioner and as potting medium for the English amateur garden market was 2.03 x 10^6 m^3 in 2009 (Anon, 2010a), a consumption rate that has led the UK's government to propose stopping garden peat use by 2020 (Anon, 2010a).

9. Air quality

Although urban trees are often cited as removing aerial pollutants (e.g. Yang et al., 2005; Nowak et al., 2006; Jim and Chen, 2008) and garden trees (and other vegetative forms) no doubt contribute to capturing overall pollutant loads, recent research suggests that relatively wide belts of woodlands are required to elicit measurable benefits (Pataki et al., 2011). Domestic gardens therefore may have only a minor role in helping mitigate point pollutant sources such as roads, or industrial outlets. Some plants are also considered to be strong emitters of biogenic volatile organic compounds, implying their role in contributing to the formation of photochemical smog in the urban environment (Niinemets and Peñuelas, 2008; Peñuelas and Staudt, 2010). On balance, there is a high level of uncertainty about the role of the urban vegetation in air pollutant removal (Pataki et al., 2011); this is the case even more so for domestic gardens where there is no direct evidence available.

10. Biodiversity

Fifty years ago there was a widespread belief that gardens, highly managed and dominated by alien plants, provided few resources for native animals (Elton, 1966). However, as published reports of wildlife in domestic gardens began to accumulate, it became clear that the value of urban gardens for biodiversity may be substantial (Davis, 1978; Vickery, 1995). Indeed, some declining species, once common in low-intensity farmland, are now more abundant in urban areas, and particularly in domestic gardens (Gregory and Baillie, 1998). For some bird species, urban gardens support a significant fraction of the total UK population providing valuable habitat and supporting some nationally important sub-sets of species (Chamberlain et al., 2009). In a comprehensive study, Owen (2010) revealed that her rather ordinary garden in Leicester (UK) was visited over a 30-yr period by around a quarter of all the insect species recorded from the entire country. By focusing for just three years on one family of parasitoid wasps (*Ichneumonidae*), Owen discovered 15 species new to the UK and four previously undescribed species. Gardens are such a good habitat for hoverflies (*Syrphidae*) that here they greatly outnumber their supposed wasp mimics (Azmeh et al., 1998). The BUGS project which surveyed 61 domestic gardens in Sheffield, UK (Smith et al., 2006a; Thompson, 2007), confirmed Owen's conclusion that private gardens, taken together, might reasonably be described as the UK's most important nature reserve. The BUGS project also demonstrated that neither small size nor isolation from countryside seem to be a problem; small, city-centre gardens support much the same invertebrate wildlife as large, suburban ones. Other recent research has tended to endorse this view; in Manhattan, New York, gardens with sunny, flower-rich patches supported diverse pollinator communities (Matteson and Langellotto, 2010), and in Toronto, small 'microcosms' (soil-filled pots, with or without vegetation) introduced into gardens recruited plants, seeds and invertebrates in much the same way as those placed in grassland or forest (Sperling and Lortie, 2010).

The widespread perception of 50 years ago that gardens are of little wildlife value was clearly mistaken, but what *sort* of wildlife is supported by gardens? Gardens seem to be used by only a small proportion of mammals, although this minority may be very frequent garden visitors (Baker and Harris, 2007). Nor are the invertebrates that frequent gardens in large numbers a random selection. Among butterflies, whose ecology can be predicted with some certainty from the biology of their larval host plants (Dennis et al., 2004), it is clear that garden butterflies are largely generalist, mobile species, and that specialist, sedentary species are only rarely able to make use of urban gardens (Bergerot et al., 2010; Owen, 2010). Similarly, gardens sustain very large populations of a small group of ubiquitous, generalist bumblebees, while rarer specialists are confined to less-disturbed semi-natural habitats (Goulson et al., 2006).

Pessimists point out that the rather generalist, mobile and adaptable nature of garden wildlife means it is the fraction most likely to survive anyway, with or without the assistance of gardens and gardeners. Conversely, even these adaptable species are not always able to survive in the most intensively farmed landscapes: see, for example, the extraordinarily 'poor bee', fauna of Dutch arable land (Kleijn et al., 2001), and the evidence that pollinators in general are increasingly beleaguered in agricultural landscapes outside gardens (Cussans et al., 2010). While gardens will never replace species-rich semi-natural habitats, they are nevertheless a useful complement to such habitats and, moreover, increasingly provide urban residents with their only close encounters with the natural world.

11. Plant composition and pest species

Gardeners have always been drawn to exotic and unusual plants, and even today plant hunters search for unusual genotypes that can be introduced into the garden trade. This results in a large proportion of non-native plant species, selected genotypes (varieties) or accidental or intentionally bred hybrids (Smith et al., 2006b) in the garden; increasingly many of these 'exotic' garden plants are traded internationally (Smith et al., 2007). Historically, the garden trade has introduced a wide range of alien plant species (e.g. Reichard and White, 2001), a number are now invasive weeds, e.g. *Acacia spp*. in South Africa (Kull et al., 2007), *Clematis vitalba* in Australia and New Zealand (Williams and West, 2000), resulting in huge costs associated with eradication, e.g. over 34 bn US $ in the USA (Olson, 2006). Increasing international trade in plants also introduces non-native pest and pathogen species (Henricot and Gorton, 2005; Tubby and Webber, 2010). In the UK, the ornamental trade can account for 90% of human-assisted introductions of plant pests (Smith et al., 2007) and 53% of new plant pathogens have been recorded on ornamental plants, compared to only 15% on native species (Jones and Baker, 2007).

The high diversity of plant species in gardens may also encourage invertebrate or pathogen species to jump host. This is supported by evidence that plants uncommon in the wild, but frequently cultivated, may be more susceptible to invertebrate herbivores in gardens; for example, at least nine species of moth (*Lepidoptera*) larvae have been recorded feeding on *Potentilla fruticosa* in a UK urban garden (Owen, 2010) but in the wild no moth species had been recorded exploiting this plant (Thompson et al., 2003).

Climate change and associated impacts on the urban environment, e.g. heat islands, seem to be encouraging species survival and migration. Some pests that normally require the protected conditions of a glasshouse can now survive outdoors, while other pests may become more prevalent. *Icerya purchasi* (cottony cushion scale) has been long known as an occasional pest in UK glasshouses (Green, 1931), but it is now a problem on outdoor plants (Watson and Malumphy, 2004). Heat island and allied abiotic stresses have also been linked to a higher incidence of a pest species, such as clearwing moth, *Podesia syringae*, on *Fraxinus pennsylvatica*; providing evidence that elevated urban temperatures can alter species composition and pest abundance (Cregg and Dix, 2001).

12. Gardens, health and well-being

Gardening as a pastime is often seen as a form of 'retreat', but also relates to ownership, identity and the ability to interact with nature (Clayton, 2007; Gross and Lane, 2007). Therefore, the gardens influence on an individual's well-being may relate in part to that individual's attitude to gardening. The health (and allied social) benefits associated with engagement with the green space are now well documented (e.g. Hartig et al., 2003; St Leger, 2003; van den Berg et al., 2010) and largely centring on the attention restoration theory (ART) (Kaplan, 1995), or the psychophysiological stress recovery theory (PSRT) (Ulrich et al., 1991). Cited benefits are wide ranging and include improvements in pain relief, blood pressure, heart rate, less frequent illness, improved cognitive function (Hartig et al., 2003; Tzoulas et al., 2007). In contrast, other studies suggest that generic links between health and green infrastructure are weak (Lee and Maheswaran, 2011), or the response is dependent on factors such as sample population studied (Ottosson and Grahn, 2005), the form, extent or quality of the green infrastructure (Milligan and Bingley, 2007; Mitchell and Popham, 2007), the nature of the 'green' activity undertaken (Barton and Pretty, 2010) or ancillary factors such as ease of access, degree of motivation or perceptions of safety (Lee and Maheswaran, 2011).

Some studies on green infrastructure include domestic gardens / gardeners within the experimental methodology employed, but many do not. Indeed, some that attempt to relate health and proximity to green space, actually exclude the private garden, as the resolution of the GIS systems employed fail to adequately account for them (Maas et al., 2008). So where do gardens and gardening fit in terms of the generic relationship between green space and health? Those studies that primarily focus on gardening (or activities that are directly analogous) highlight the benefits such as reduced mortality, higher bone density, lower blood pressure and cholesterol levels (Walsh et al., 2001; Milligan et al., 2004). Gardening can help reduce the risk of the onset of dementia (Simons et al., 2006) and aid those suffering from it (Lee and Kim, 2008). To maximize health benefits, Magnus et al. (1979) claim that consistent, moderate exercise throughout the year is advantageous; hence regular 'all season' gardening should be encouraged. Regular physical activity can reduce risk of coronary heart disease, ischemic stroke, Type 2 diabetes, hypertension, osteoporosis, anxiety, depression and certain types of cancer (Park et al., 2009). Gardening is one of a number of pastimes that are linked with encouraging greater physical activity, including sustaining long-term engagement through opportunities for creativity, communication and self-expression (Blair et al., 1991). The intensity of physical activity, however, will vary with type of gardening activity, age and ability of participant (Dallosso et al., 1988).

Despite the body of evidence supporting gardening as a healthy and restorative pastime, it is not risk free. Over a 30 day period, Powell et al. (1998) suggested that 2.1 million USA citizens (1.1% of the population) could suffer injury in the domestic garden. Gardening activities have been blamed for increased incidence of injury through misuse of tools (especially lawn mowers, van Duijne et al., 2008), dermatitis (McMullen and Gawkrodger, 2006), and certain pathogens (O'Connor et al., 2007). Although these negative factors can be substantial, they appear to be out-weighed by the advantages cited in relation to increased physical activity and perceived restorative effects.

13. Domestic gardens in a cultural context

Although community gardens, particularly city orchards or allotments have been linked to improving social capital (Glover et al., 2005) and large 'landscape' or 'heritage' gardens are imbued with historical and cultural significance (e.g. Turner, 2011), the role of the urban private garden is more ambiguous. The domestic garden can be seen as an extension to the household (Alexander, 2002), and therefore a forum for family (and friends) to interact and spend leisure time. Positive memories of childhood are often linked with the family garden (Gross and Lane, 2007) and provide strong place attachment (Brook, 2003). One of the possible causes for an increase in gardening within western societies in recent years is that it may be seen as an anti-dote to anxieties and perceived risks associated with changes in lifestyle, including the development of technology, globalization and wider environmental degradation (Bhatti and Church, 2004). This relates back to the garden being a place where an individual can exert control, where perhaps this ability has been lost in other societal institutions and the political system. Domestic gardens at the interface between the home and public space are also considered to be places of real ambiguity, with a range of conflicting paradoxes, e.g. between consumerism and environmentalism (Bhatti and Church, 2001; 2004; Longhurst, 2006). In contrast to community gardens, the design of some private gardens may act intentionally as a barrier to the wider environment and society (Alexander, 2002). The tall, stone boundary walls and deep hedges placed at the perimeter of 18th Century Victorian villa gardens (UK) are perhaps epitomising a highly class-conscious society.

The practical uses that a domestic garden is put to, may also strongly reflect culture or historical context. During World War Two, increased numbers of domestic gardens in the UK were used for food production, a trend that has repeated itself during subsequent periods of economic austerity, when food prices have risen (Lang, 1999, Carney, 2011). Also recent migrants from rural to urban environments may see the domestic garden primarily as a land resource for providing food and not as an aesthetic feature *per se* (Head et al., 2004). Indeed, Risbeth (2005) argues that attitudes to domestic gardens can be strongly cultural, with white, middle class residents in the UK appreciating the privacy and security offered by a private garden, whereas “Bengali and Afro-Caribbean participants play out their scenes in cafés, kitchens, streets and parks – never their back gardens”. Although attitudes to gardens *per se* may vary, an interesting juxtaposition is that one of the key elements within them, i.e. flowers, have universal appeal and can be a unifying factor across cultures (Risbeth, 2005).

14. Gardens as therapeutic landscapes

Increasingly, the broad principles relating health and green space are being acknowledged by policy makers e.g. World Health Organisation (Edwards and Tsouros, 2006) Greenspace Scotland (Croucher et al., 2007) and the Faculty of Public Health, UK (Anon 2010b) but practitioners are this still left with the dilemma as to what sort of landscapes and facilities should be provided? Do all green landscapes and activities hold similar health benefits? Part of the problem is that green space has often been ill-defined in terms of specific components, scale or extent. Perhaps the infinite variability in natural landscapes may explain some of the inconsistencies in the data linking green space to well-being. Essentially, there is an argument that not all forms of green space act in the same way (Lee and Maheswaran, 2011), with corresponding implications for the role of domestic gardens and their design (Ottosson and Grahn, 2005; Ivarsson and Hagerhall, 2008). Despite conceptual models being developed to relate green infrastructure to health (e.g. Tzoulas et al., 2007), these too are dependent on the details associated with each type of green space being present to fully test the models, and help define relative benefits.

In terms of 'attention restoration' (stress relief) gardens are thought to facilitate some, or all, of the components identified with the ART (Ivarsson and Hagerhall, 2008). They may be particularly important in the prevention and recovery from illness, due to their general accessibility within an urban matrix (providing the opportunity for exercise and engagement with nature, quite literally, at many people's 'back door'). Surprisingly few studies though have focused on the private domestic garden and gardeners (Gross and Lane, 2007). In contrast, most reported studies relate to community gardens, or the value of gardens / gardening for those with defined health-related problems (Milligan et al., 2004; Park et al., 2009). In reality, the majority of those who garden may do it in relative isolation or in small groups, and may not be consciously doing so from a health benefit perspective. Therefore more research is required to categorize the benefits and drawbacks for the 'average gardener' and ideally, within the specific context of the domestic garden.

In their study on the restorative value of different landscapes, Ivarsson and Hagerhall (2008) indicated that landscapes with a high level of natural features, rather than e.g. urban elements, provided greatest restoration. Even within natural features hierarchy was evident (Herzog et al., 2003). Flowers and water had a higher correlation with quality of life traits than animals, trees, hills, natural aromas or sounds (Ogunseitan, 2005). Interestingly, Barton and Pretty (2010) too found enhanced health benefits when 'green exercise' was performed within sight of water. If certain natural features are more beneficial than others from a health perspective, then those gardens that incorporate them may enhance the positive psychological responses (Stigsdotter and Grahn, 2002). Even for individuals not suffering health problems, design of garden may be important in offsetting stress associated with work, commuting, family life etc., but this warrants further investigation. It is also true though, that health *per se* may not be at the forefront of most gardeners objectives; aesthetic desires and functional criteria will also determine garden design (Chen et al., 2009). Furthermore, domestic gardeners usually have a large element of control over the design and management of gardens, and this can be linked with other positive psychological experiences including self-esteem, feeling of achievement and fulfilment of talent and skill.

15. Conclusions

Domestic gardens are undoubtedly an important component in many people's lives, but attitudes towards them are not uniform. To some, they are an essential element of life providing opportunity for engagement with nature, self-actualisation, creativity or well-being; to others, they are at best a parking lot, or worse, represent an additional chore to an already busy lifestyle.

The environmental benefits of gardens appear mixed. Domestic gardens help provide improved thermal comfort to their residents, have potential to reduce domestic energy consumption and minimize storm run-off. They also clearly provide much needed habitat for wildlife within the urban environment, but management issues may result in gardens contributing to greenhouse gas emissions rather than offsetting them. Their role in sustainable use of resources may veer to the negative side of the equation (use of water, pesticides, fertilizers, etc.); in some countries garden activities have been directly responsible for the introduction of invasive species, with huge consequences for native biodiversity and the economics associated with eradication measures. This report highlights a number of areas where future research should be targeted, but such future studies need to embrace the fact that domestic gardens, as with the wider green space, are variable, and the effects / influences of contrasting garden styles need to be incorporated into any methodology.

Perhaps the gardens' greatest benefit (to humans at least) is the potential to provide a forum for exercise, and to facilitate respite from stress. As outlined, green spaces appear to provide a range of benefits linked with health and well-being, but more specific information is required about whether and where the domestic garden fits in with some of these broad conclusions and to challenge some of the generic assumptions that all green spaces act in the same way. This is important, as western society faces the challenges of a more sedentary lifestyle, greater incidences of obesity and increasing occurrence of mental health problems. If domestic gardens do indeed provide a fundamental role in promoting physical exercise and well-being, then they are ideally placed to address these issues directly due to their relative accessibility for much of the population. This has implications for the planning process, as currently many new housing developments omit private gardens and prefer to incorporate communal green areas, or only provide minimal private garden space. Conversely, there may be little point in every house having a garden if their potential is not realised. Educational processes may be required to encourage engagement, especially as society becomes increasingly displaced from the natural world and food cultivation, but evidence is required of the clear benefits before such activity could be undertaken.

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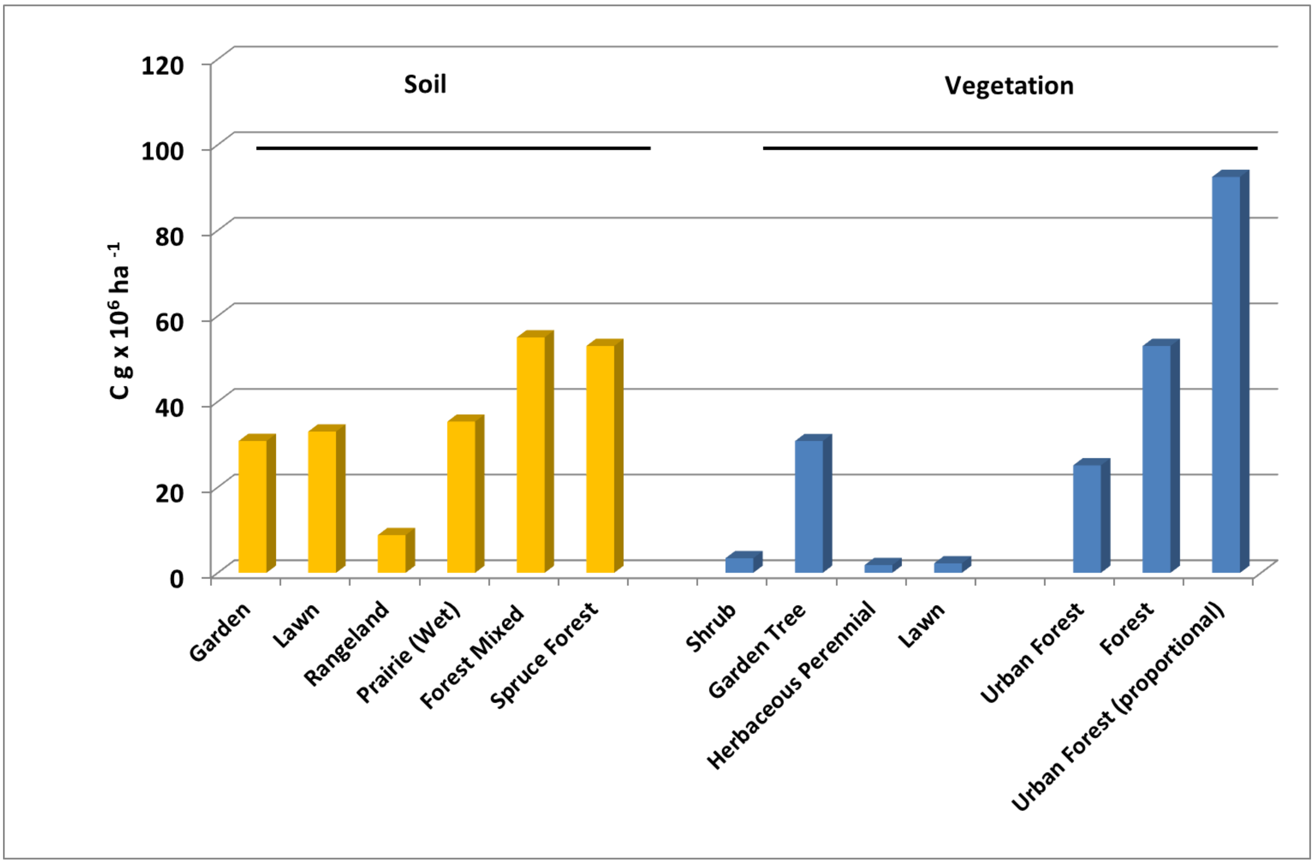
Figure 1. Typical carbon levels (g x 10^6 ha^{-1}) stored in soils (upper 100mm only) and vegetation. Garden vegetation types compared to forest vegetation, including less densely planted urban forests.



Data derived from Jo and McPherson, 1995; Thuille et al., 2000; Schuman et al., 2002; Nowak and Crane, 2002; Euliss et al., 2006; Gough and Fritz, 2009.

NOTE:

1. Soil data shown is normalized for upper 10 cm of soil profile only, to facilitate comparisons. Total soil carbon storage, however, will be considerably greater in soils that have deeper organic profiles. For example, deeper root zones associated with prairie or meadow vegetation may increase soil organic matter by 3-4 fold over domestic lawns.
2. Values depicted are examples to provide relative scales only. *In situ* values vary considerably based on soil type, temperature, precipitation and density of vegetation.
3. 'Urban Forest proportional' relates to a scenario where the discrete, separate sections of urban forestry join and provide continuous cover across the urban matrix (Nowak and Crane, 2002). Carbon sequestration would be greater than conventional non-thinned forests because:
    a. Planting densities are less thus allowing individual trees to access more light / atmospheric CO_2.
    b. Average tree size is larger resulting in greater carbon storage within individual trees.
    c. There are greater localized concentrations of CO_2 in urban environments due to anthropogenic factors.