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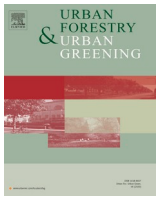

Short communication

"Do we need to see gardens in a new light?" Recommendations for policy and practice to improve the ecosystem services derived from domestic gardens

Ross Cameron [1]

Department of Landscape Architecture, University of Sheffield, Sheffield, UK

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1. Introduction

Domestic gardens (yards) are common in many cities, particularly in more affluent suburban areas. They can constitute a significant proportion (22–36 %) of the entire urban area (Cameron et al. 2012) and for example, within Europe 56 % (Spain) to 90 % (UK, Netherlands) of residential properties include outside space (Coisnon et al. 2019). Originally, gardens (public and private) were linked with religious faiths and associated with spiritual experiences, being seen as places of contemplation, healing and fostering 'a oneness with nature'. But this raises an interesting question; how are today's private, *domestic* gardens viewed? Do they reflect this 'oneness' with nature and provide a capacity for spiritual uplift? Alternatively, are they now a manifestation of consumerist behaviour, out of sync with the wider natural environment and indeed, perhaps the epitome of a non-sustainable lifestyle? These are important questions, as due to the large area dedicated to private gardens, they can have profound effect on the functionality of our cities. This paper outlines the many fundamental benefits (ecosystem services - ES) domestic gardens *can* provide to city residents, yet in reality may not do so, due to the way they are often designed, managed and used. The paper highlights potential changes in policy and practice that can help address these short-comings. In doing so, it aims to promote more sustainable garden management, greater opportunities for urban biodiversity, a healthier city landscape and perhaps even foster pro-environmental behaviours that help meet other wider environmental and sustainability targets. Unlike previous eras, where private garden management has largely been left to the discretion of the home owner, radical changes in policy and practice are now required if local authorities are to deal effectively with the impacts of climate change and biodiversity loss at the city level. In effect, we need to see gardens in a new light!.

2. What is a domestic garden?

Domestic gardens or 'yards' are the open spaces around, and associated with, a residential property. In reality, they have multi-functional uses. They are used: for utilitarian purposes e.g. to dry laundry, park the car, maintain tools; for recreation e.g. to play, relax and socialise; to grow food; to provide aesthetic interest via flowering or textural plants; or as habitat for wildlife and allow opportunities to engage with nature. They are considered a key component of urban ecosystems, food security and strongly influence landscape quality (Al-Mayahi et al. 2019). Gardens are gaining interest from policy makers due to their combined effect on such issues at a city scale (Šiftová 2021).

3. The pros and cons of domestic gardens

The design and management of a garden is key in determining the type and level or ES it provides (or alternatively the problems it can cause). Gardens that are dominated by impermeable hard surfaces (e.g. concrete pavers) and with limited vegetation and habitat provision for wildlife ('Grey') are likely to provide few ES (Fig. 1.). Those that are vegetated but have limited plant diversity and are intensively managed ('Intensive') will provide intermediate ES, whereas gardens with a high proportion of vegetation, low energy and other resource inputs, and mimic natural vegetation stands or transitional ecotones ('Green'

E-mail address: r.w.cameron@sheffield.ac.uk.
[1] ORCID: 0000-0002-7786-0581.

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gardens) will tend to maximise urban ES.

Recently there has been a trend to convert vegetated garden space to hard standing area (i.e. a move from 'green' to 'grey' in garden styles). Front gardens particularly, are commonly paved over to facilitate off-road car parking (e.g. 56 % of front gardens in Edinburgh, UK, Kelly, 2018). This along with patio construction and a desire for lower maintenance gardens has resulted in the loss of vegetated areas (by 40–75 %) and greater soil sealing (≤60 % in the Netherlands) in the last 2 decades (Stobbelaar et al. 2021). Such trends have implications for flooding and urban heating at a city scale. Well-vegetated landscapes reduce rain-water run-off by 44–50 % (Kadaverugu et al. 2021), through plants detaining rainwater in their canopies, and non-sealed soils allowing better infiltration of water.

Plants cool the local environment via shading and evapotranspiration, improving human thermal comfort and mitigate urban heat island phenomena. Garden plants typically cool the air by 2–3 °C and surface temperature by 10–15 °C (Cameron et al. 2014; Zhang, 2020). Garden trees, hedges, shrubs and climbers also protect buildings from cold winds and low temperatures in winter, and improve building energy efficiency by 20–30 % (Cameron et al. 2015). Similarly, such garden features mitigate noise (Van Renterghem, 2019), and make sounds seem less intrusive when they visually block its source. Conversely, machinery such as lawn mowers enhance noise nuisance (Dittrich and Spellerberg, 2016). Increasingly, vegetated barriers are used to protect garden space from air pollution, for example from vehicles on adjacent roadways. Plants with fine leaves, hairs or waxy leaf cuticles are particularly useful at absorbing particulate matter (del Carmen Redondo-Bermúdez et al. 2021). Some plants should be avoided though as volatiles or pollen from them can reduce air quality or induce allergenic reactions (e.g. *Betula* spp.).

It is not just 'grey' garden space that causes problems. Gardens that are largely green but intensively-managed ('intensive') or use non-sustainable resources have some negative environmental credentials. Intensively-managed gardens can rely on petrol driven machinery and use surprisingly high quantities of synthetic fertilisers and pesticides (Taylor and Lovell, 2015). Frequent use of fertilisers leads to high nutrient loads within soils e.g. 300 and 1400 kg ha^{-1} for phosphorus and nitrogen, respectively (Small et al., 2019) which subsequently pollute water courses. Fertiliser manufacture is itself energy intensive and nitrogen fertilisers (and soil cultivation) release nitrous oxide (N_2O) – a potent greenhouse gas. Pesticides too can be applied at unintentionally high concentrations and indiscriminate garden applications are linked to local decreases in insect and bird populations (Paul, 2015). Moreover, the domestic pesticide market is valued at US$7700 M and is growing (Anon, 2021). Due to concerns around environmental degradation and citizen exposure, France has banned the use of synthetic pesticides in public spaces. Energy use by petro-chemical powered equipment is significant. Mowers consume typically 1.3–5.7 L hr^{-1} petrol (Strohbach et al. 2012). Most energy is spent on mowing fine lawns on a regular basis e.g. = 1.33, vs low intensity 'meadow lawns' = 0.03 Mg CO_{2e} ha^{-1} yr^{-1} (Wesström, 2015). Carbon emissions are not only linked to maintenance machinery; patio heaters used to heat outdoor seating areas equate to 0.14 Mt CO_{2e} yr^{-1} in the UK alone (Boardman, 2006).

Gardens are significant 'consumers' of natural resources, including potable water, peat, oil-based plastics, stone and timber (e.g. for patio decking). Excessive irrigation is associated with lawns/ornamental borders and can account for 20–25 % of total potable water supplies (Al-Mayahi et al. 2019). Peat is used as a growing medium/soil improver, but its extraction damages unique habitat and releases CO_2. Extraction rates across Europe equate to 62 M m^3 yr^{-1} (Kern et al. 2017) and as such the UK proposes to ban peat use by 2024. Plastic containers used in the retailing/growing-on of plants is another problem that garden horticulture faces, and as some containers are single use, they have impact on land-fill and pollution within the environment (Meng et al. 2016). Artificial turf has become popular in gardens over the last decade, but leaves micro-plastic residues and inhibits soil macro and micro biota (Cheng et al. 2014). Timber may not always come from ethical and sustainable sources, and better regulation is required in some regions.

Gardens have potential to sequester carbon but it depends on previous land use (e.g. hard surface materials being replaced by vegetation) and management practices. Well-managed, low energy 'woodland' gardens can achieve 15–70 kg C m^{-2}. Garden products though, including purchased plants, have embodied carbon. Gardens rely on bulky or heavy materials (aggregates, compost etc.) commonly transported considerable distances, so have a transport 'carbon footprint'.

As with other ecosystems depending on style and management, gardens range from being relatively poor for wildlife, to being very biologically-rich landscapes (Cameron et al. 2012). Garden styles that mimic natural vegetation types and provide heterogeneous features (such as ponds and log piles) are more advantageous for wildlife than

Fig. 1. Garden styles can be divided into those where vegetation is minimal or absent (top-left 'Grey'), vegetation is present but lacking in diversity and is intensively managed (top-right 'Intensive') or vegetation is abundant, diverse and mimics natural habitats (bottom-left – 'Green'). The latter style can be applied in even quite utilitarian parts of the garden such as the driveways (bottom right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

those of a single vegetation/landscape typology. Less-intensively cultivated areas, providing refuge for invertebrates and small mammals (Goddard et al. 2013). Although much attention has been paid on flowering plants providing food resources to pollinating insects, other plants types (e.g. ruderal weeds) are required nearby to support the larval stages of such species; an aspect that is not always well-communicated to home gardeners. On the 'down-side' non-native garden plants can become invasive in the wider landscape, and although this relates to < 1 % of introduced species, the ecological costs are vast (Haubrock et al. 2021). Moreover, traded plants are also a potential source of new invertebrate and pathogen pests to endemic species. The costs of controlling or eradicating invasive species is estimated (for 2017) at US$29,198 M pa (Diagne et al. 2021).

Home gardening that involves the cultivation of food contributes to household budget savings and is a viable alternative to bought fresh produce. Growing one's own crops can provide a more nutritional diet and acts as a catalyst for children to eat more healthily (Van Lier et al. 2017). Gardens have psychological and physical health benefits too. Vegetation in garden space has been linked to reduced stress levels and improved cortisol profiles (Chalmin-Pui et al. 2021b). Domestic gardening has been correlated with better health and was deemed restorative during lockdowns associated with the Covid 19 pandemic (Chalmin-Pui et al. 2021a). Gardening induces positive emotions, encourages creative skills, promotes a sense of achievement and improves cognitive function; factors that influence longer-term mental health. Proximity to soil and vegetation impacts the human microbiome, indirectly affecting mental health (Robinson et al. 2021). Regular gardening restores and maintains physical fitness (Chalmin-Pui et al. 2021a). The advantage of home gardening is that this can be undertaken relatively easily due to its proximity to one's house. Gardening is not risk free though, with e.g. 300,000 injuries reported in the UK pa. Gardening can raise awareness about wider environmental issues and encourage engagement with nature. Although keen gardeners may use relatively large volumes of water, some are also at the vanguard of conserving water, e.g. by using water butts. Wildlife gardening (wildscaping) is becoming increasingly popular due to concerns over species loss, but in its turn it can promote greater commitment to, and engagement in, other wider conservation behaviours (Jones et al. 2021). Active behaviours such as growing fruit and vegetables raise awareness about climate change, pesticide misuse, non-sustainable practices and 'food miles' (Artmann et al. 2021). Local tree planting encourages the conservation of trees and forests elsewhere.

4. The need for policy changes

New policies that more accurately reflect society's needs and indeed 'change the norms' have a role to play, in ensuring gardens remain environmentally–sensitive and contribute to, not undermine, ES delivery. An example of this was the change in UK law that required planning permission to be sought if ≥ 5 m^2 of front garden space was converted to impermeable surface. Other legislation may be required in time, although these perhaps should be more progressive and encourage positive, rather than punish bad, behaviour. Nevertheless, there are areas where positive behaviour change has not worked through voluntary schemes and legislation has been brought in (e.g. banning peat use in the UK). Irrespective of this – garden environments and gardening practices offer many opportunities for more positive incentives, for example, reduction in water bills or local taxes for those who garden with a high proportion of unsealed soil, or who plant and maintain trees of a certain stature (both factors likely to reduce local flooding). Goddard et al. (2013) proposed diverse government grants for pro-environmental management (e.g. home composting or creating ponds) and for those households that installed appropriate technologies (e.g. used renewable energy or adopted rainwater collection). Legislation around urban planning can be a powerful 'top-down' system to reject those 'development' applications that harm existing gardens, and be used to protect fully-grown trees, hedgerows or special garden 'habitats'.

5. Recommendations - what needs to change?

Based on the literature and current common practice the author recommends the following legislative and 'good practice' changes. How some of these changes can be achieved will vary across different contexts and countries, and specifics remain to be elaborated on, but the purpose of this paper is to clearly identify areas where positive change is required.

5.1. Legislative changes

Gardens with a high proportion of plants acknowledged as a health facility, and their retention protected or inclusion in new urban plans considered mandatory: Gardens should be fully valued for their contribution to human health and well-being, and protected because of this. For many, access to a garden or other form of local green space was a 'life-line' for their sanity during the Covid 19 Pandemic, where travel was restricted by distance and time. They have capacity to be used more effectively for green prescribing and other preventative measure against poor health.

Fifty percent of garden space should be vegetation: For effective ES delivery, local authorities need to encourage more gardens to fall into the 'green' category. For house owners with ≥ 50 % of their garden space planted-up, there should be financial rewards. Systems such as GIS can verify the proportion of vegetation cover. Further financial incentives could be awarded to those gardens ≥ 100 m^2 total area where a new tree is planted or an old one maintained.

Atmospheres, water and soils need to be better connected: At least 66 % of any garden should comprise permeable materials that allow water and air to infiltrate into the soil. Artificial grass covering an area in excess of 10 m^2 should be prohibited.

Chemical applications to be limited: Certain invertebrates and microbial organisms may need to be controlled but this should be encouraged through breeding of ornamental plants to have greater resilience to pests and pathogens in the first place (this has partially been achieved for *Rosa*), integrated pest management approaches, and through the use of natural chemicals approved via organic certification schemes. Following moves in France, synthetic, pesticides should be banned for home garden use.

Non-sustainable horticultural products to be phased out: The ban on peat use should be adopted at a global level. Regulation on timber supplies need to be tightened to avoid the use of illegally harvested timber and plant pots should be able to be recycled or made of compostable material.

5.2. Best practice guidance

Gardens as tools to promote pro-environmental behaviour: Domestic gardens reflect individual styles and autonomy, and any attempt to develop simple blueprints for garden styles and activities that result in 'pro-environmental' gardens, but take the fun out of gardening need to be avoided. The aspiration here is not to develop a series of identical 'cloned' 'environmentally-friendly' gardens, but rather to identify the potential for gardeners themselves to engage with principles and motivations that promote more opportunities for wildlife, reduce energy and material consumption and increase opportunities for well-being. To impose a new set of tightly-regulated rules for gardening and enforce gardeners to follow them is to miss the point. Nevertheless, principles around more 'environmental' gardening need to considered, critiqued and adopted. It is hoped that environmental approaches and sustainable management of garden space will lead to wider awareness of environmental issues in general and promote more positive behaviour towards natural/semi-natural environments.

Gardens are valued as 'habitat': This means gardens need to be largely 'green'. The trend for vegetated areas to be converted to hard standing needs to be reversed. More imaginative design of car parking space is required, with permeable gravel being encouraged over sealed pavers, and plants added to those areas the car does not traverse directly. Single-stemmed trees provide canopies above the car, whilst using little space at ground level.

Reduction in mowing frequency: Close-mown lawns particularly, have an intense management regime, with weekly cutting being common. This mowing could be beneficial if carried out via a manually-pushed mower as this promotes physical exercise (90 min mowing uses 580 calories, Slotterback et al. 2006) or more acceptable if mowers use renewable energy, but this activity often still relies on petrol engines. Where lawns are maintained largely for aesthetics rather than access or informal sport, there is an argument for a higher cut height (and less frequent mowing) or to convert the lawn to a more florally diverse 'meadow'. Not only does this reduce energy consumption (e.g. only 1–4 cuts per year), it tends to support more wildlife.

Local authorities to encourage, not discourage, endemic or spontaneous 'natural vegetation' (including those species considered conventional weeds): Owners who have gardens that look unmanaged and untidy through low maintenance regimes of native plants should not be penalised or criticised, but rather promoted as a 'norm'. Active engagement with the garden (whether 'wild', unkempt or otherwise) should be encouraged where possible, due to the potential health and nature engagement opportunities. Despite promoting native species to support the endemic fauna, non-native plants should not be banned unless there is an invasion risk. This is because non-natives provide i. strong aesthetic interest to the gardener, ii. Some unique opportunities for wildlife (e.g. many non-native flowering plants extend the season of pollen and nectar supply to native invertebrates), iii. better resilience against a changing climate (e.g. enhanced drought tolerance) and iv. other specific ES.

Recycling materials and home composting: Management should limit the use of non-renewable resources and leave 'organic waste' on the land. Composting helps recycle 'soft' plant material and dead wood can be stored as piles within the garden (assuming fire risk is minimal). Policy makers should provide home-composting bins for free.

Diversity in features and plant composition encouraged: Garden design and management should consider plant/habitat heterogeneity to maximise ES and promote biodiversity. Ponds, wet areas, dry banks, woodland edges etc. all provide resources for different taxa.

Plant breeders to place more emphasis on inherent pest and pathogen resistance: This will help reduce pesticide use and remove those ornamental plants that seem 'dependent' on pesticides to remain free of pests. Modern breeding strategies in *Rosa* for example, have managed to reduce pathogen susceptibility, whilst actually increasing the floral performance of the genotype.

6. Conclusions

For many urban dwellers, gardens provide an almost unique potential to engage with the outdoors and the wider natural world. This engagement with nature seems to be critical in encouraging people to care for the wider natural environment (as well as potentially their own well-being). Garden space can provide close and regular engagement with other living entities, but to do so effectively means often increasing the proportion of vegetation present and managing gardens more sensitively. This paper outlines how policy and best practice guides could be used to improve the 'environmental credentials' of gardens and hence their potential to maximise ES. In so doing, domestic gardens provide an opportunity to achieve greater resilience against environment extremes, help mitigate against loss of biodiversity and provide a vital amenable, restorative 'habitat' for many city dwellers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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