Ecosystem services of collectively managed urban gardens: exploring factors affecting synergies and trade-offs at the site level

Abstract

Collective management of urban green space is being acknowledged and promoted. The need to understand productivity and potential trade-offs between co-occurring ecosystem services arising from collectively managed pockets of green space is pivotal to the design and promotion of both productive urban areas and effective stakeholder participation in their management. Quantitative assessments of ecosystem service production were obtained from detailed site surveys at ten examples of collectively managed urban gardens in Greater Manchester, UK. Correlation analyses demonstrated high levels of synergy between ecological (biodiversity) and social (learning and well-being) benefits related to such spaces. Trade-offs were highly mediated by site size and design, resulting in a tension between increasing site area and the co-management of ecosystem services. By highlighting synergies, trade-offs and the significance of site area, the results offer insight into the spatially sensitive nature of ecosystem services arising from multi-functional collectively managed urban gardens.

Introduction

It is recognised that urban areas, now home to the majority of the global population, are at the nexus of understanding how ecosystem services contribute to human well-being and the challenges present in enhancing and safeguarding those services (Andersson et al., 2014; Luederitz et al., 2015). The TEEB (2011) *Manual for Cities* offers one of the first attempts at providing guidance on urban ecosystem services and, more recently, the Cities and Biodiversity Outlook project represents the first global assessment of the impacts of urbanisation on biodiversity and ecosystem services (Elmqvist et al., 2013). These evaluations demonstrate that vital ecosystem services benefiting human well-being can be produced within the city, such as noise pollution mitigation, surface water attenuation and regulation of air quality. Urban areas are characterised by spatial heterogeneity and can contain biodiverse habitats (Smith et al., 2006; Davies et al., 2009; Goddard et al., 2010; Cameron et al., 2012). Urban gardens contribute to ecological diversity in the urban mosaic (Goddard et al., 2010) but are largely overlooked in green infrastructure planning (Breuste, 2010; Middle et al., 2014). Furthermore, large-scale ecological assessments, such as those already cited, pay little attention to such spaces beyond the well-evidenced benefits as habitat provision for pollinators. Closer investigation of urban gardens, the ecosystem services they produce and factors affecting productivity, therefore, is needed to better integrate such spaces into wider planning considerations.

The current study will contribute to this process by exploring trade-offs in ecosystem service provision in a case study of collectively managed urban gardens (CMUGs). The multi-functionality (Pourias et al., 2015; Bell et al., 2016), varying levels of productivity (McClintock, 2014) as well as cultural and biological diversity (Barthel et al., 2013; Borysiak, 2016) associated with such spaces provide a promising basis for an exploration of trade-offs in ecosystem service provision. Furthermore, CMUGs comprise small but highly spatially variable green spaces and hence provide the opportunity to explore scale effects in service provision at this level. This represents an important consideration, given that green space in urban areas is a very limited and threatened resource (Reginster and Rounsevell, 2006; Schäffler and Swilling, 2013) and, therefore, its productivity in terms of ecosystem services is of critical importance. If CMUGs are to be effectively integrated into urban planning frameworks, through, for example, the creation of community gardens in public parkland as suggested by e.g. Middle et al. (2014), their capacity to be effectively "scaled up" will rely on an understanding of their performance at different scales of operation.

Collective approaches to urban green space management

Urban gardens, through their ability to produce important ecosystem services (Krasny and Tidball, 2015; Speak et al., 2015; Kamiyama et al., 2016; Cabral et al., 2017), are not only a valuable source of natural capital, they also provide an interface for environmental learning and awareness (Andersson et al., 2014) and, particularly when managed collectively by stakeholders, an important medium for knowledge exchange (Barthel et al., 2014) and social cohesion (Okvat and Zautra, 2011). User participation in natural resource management has received support through international environmental policy (CBD, 2001; MEA, 2005) echoed by an acknowledged increase in stakeholder-led natural resource management, particularly in urban areas (Colding et al., 2006; Barthel et al., 2010; Rosol, 2010; UK NEA, 2011; Colding and Barthel, 2013; Barthel et al., 2015). The civic ecological approach to natural resource management, and the potential benefits which may result, have been explored conceptually through an appreciation of management practices in urban green spaces of diverse or uncertain ownership (Rosol, 2010; Barthel and Isendahl, 2013; Bendt et al., 2013). Attempts to describe such diverse, and often transient spaces, have employed an equally diverse and burgeoning terminology including: *civic ecology* (Krasny and Tidball, 2015), *urban environmental movements* (Barthel et al., 2013), *social-ecological innovation* (Olssen and Galaz, 2012; Dennis et al., 2016a), *community-based urban land management* (Svendsen and Campbell, 2008), *urban greening* (Westphal, 2003), *community gardens* (Camps-Calvet et al., 2016) and *community agriculture* (Barthel and Isendahl, 2013). In this paper, we refer to such spaces as *collectively managed urban gardens* (CMUGs) in line with other studies which have placed similar emphasis on the collective nature of these sites as their defining attribute (e.g. Rosol; 2010; Barthel et al., 2013; Bendt et al., 2013; Andersson et al., 2014). Bendt et al. (2013) draw on the notion of *communities of practice* (Wenger, 2000) to describe the social mechanisms (namely, joint enterprise, mutual engagement and a shared repertoire of rules and resources) upon which collectively managed gardens are established and sustained. Herein, the centrality of communities of practice is likewise adopted in the definition, selection and discussion of the CMUGs investigated.

Examples of collectively managed urban gardens typically include community allotments (Colding et al., 2013), gardens (Pourias et al., 2015) and orchards (Travaline and Hunold, 2010) as well as less traditional, highly improvised spaces such as green roofs and walls, and pocket parks (Dennis et al., 2016a). Much interest in CMUGs has stemmed from the potential benefits to be gained through local ecological stewardship (Colding et al., 2006), knowledge exchange (Ersntson et al., 2008; Barthel et al., 2014), cross-scale, participatory environmental decision-making (Ernstson et al., 2010; Andersson et al., 2014; Middle et al., 2014), and local adaptive responses to social-ecological stressors (Dennis et al., 2016a; 2016b). For the most part, studies have focused on organisational structures (Connolly et al., 2013), social networks (Ernstson et al., 2008; 2010), modes of knowledge transfer (Barthel et al., 2010), value perception (Raymond et al., 2009), and spatial distribution (Dennis et al., 2016b). Although these studies together present a sound theoretical argument for CMUGs in promoting urban social-ecological resilience, without evidence of their capacity to maintain or enhance the production of ecosystem services (as the subject of resilience: see Brand and Jax, 2007; Biggs et al., 2012), such a position cannot be conclusively adopted.

Ecosystem service production from collectively managed urban gardens

Social-ecological benefits arising from CMUGs have been described in terms of ecosystem service provision, with microclimate regulation (Cabral et al., 2017), pollination (Speak et al., 2015), food production (Kamiyama et al., 2016), increased well-being (Husk et al., 2013; Wood et al., 2016), and learning benefits (Krasny and Tidball, 2009; Riechers et al., 2016) all being described in the literature.

The therapeutic benefits associated with exposure to nature are well documented (Pretty et al., 2005; 2007; Marselle et al., 2014; Carrus et al., 2015). Specifically, horticulture as a form of physical activity and gardening as a source of social interaction have received much attention on the basis of the well-being benefits derived by individuals (Francis, 1987; Hynes and Howe, 2004; Alaimo et al., 2008; Pudup, 2008) and communities (Okvat and Zautra, 2011; Krasny and Tidball, 2015). Similarly, CMUGs have been highlighted for their considerable and significant contribution to environmental education (Krasny and Tidball, 2009; Barthel et al., 2014) and social learning (Bendt et al., 2013; Krasny et al., 2014). Moreover, there is a recognised synergy between learning and well-being (Waage et al., 2015), and between these factors and connectedness to nature (Olivos and Clayton, 2017), the latter being enhanced by collective environmental stewardship (Andersson et al., 2014).

Although the evidence on a range of ecosystem services provided by such spaces is growing, few studies have explored site-specific trade-offs in service provision. Cabral et al. (2017), for example, provided a detailed assessment of six ecosystem services through site surveys of allotment and community gardens in Leipzig, Germany. Although a comparison was, thereby, allowed between the two types of CMUGs, trade-offs were not explored. Furthermore, the comparability of CMUGs studied was compromised by neglecting to account for site size, thereby precluding a relative evaluation of productivity. Dennis and James (2016a; 2016b) have explored the effect of site management on participation, biodiversity and ecosystem services provision, but failed to address trade-offs between individual services. Similar studies into CMUGs in the form of allotment sites highlight the high performance of the latter compared to municipally managed parks in terms of biodiversity and related ecosystem services (Speak et al., 2015; Borysiak, 2016). Though providing evidence of ecosystem service provision, these studies offer little interpretation of the interaction between services in terms of synergies and trade-offs, nor the effect of scale and design on the latter.

Where trade-offs in ecosystem services have been evaluated, they have often been carried out at the landscape scale, largely overlooking locally important patches of green space. Indicators employed in such assessments assume a large degree of social-ecological consistency across study areas. To date, studies have employed coarse land-use classifications to map ecosystem services in fragmented landscapes (e.g. Larondelle and Haase, 2013; Baro et al., 2016) and applied proxy indicators across distant or contrasting urban areas (Elmqvist et al., 2013; Gómez-Baggethun and Barton, 2013; Larondelle et al., 2014; Alam et al., 2016). Such methods assume that ecosystem service assessment is inherently scalable. Given the known stochasticity of social-ecological systems (Abel et al., 2006; Vellend et al., 2014), the potential for large errors resulting from attempts to transfer assessment values from one spatial or geographical context to another is self-evident. Andersson et al. (2015) demonstrated conceptually that the performance of service-providing units (SPUs) in urban areas depends on both scale and context, though little empirical evidence exists to support this effect at the site level. Greater attention to the effects of scale, and the resulting trade-offs, on the productivity of green spaces in terms of their capacity to produce ecosystem services is, therefore, required.

Thus, if collective approaches to green space management are to be promoted as sources of resilience in social-ecological systems (as in Ernstson et al., 2008; Biggs et al., 2010; Colding and Barthel et al., 2013), an understanding of associated ecosystem service trade-offs and synergies remains a research imperative. A review by Lin et al. (2015) uncovered a need for more detailed research into the biodiversity and production of ecosystem services associated with urban garden sites. Such research can only be accurately conducted at the site-level for which CMUGs provide a useful context given the variability in user participation, access and size (Dennis and James, 2016a), productivity in terms of ecosystem services (Calvet-Mir et al., 2012) and significant levels of biodiversity associated with these spaces (Speak et al., 2015; Borysiak, 2016). In order to address this knowledge gap, a study was conducted to investigate synergies and trade-offs between four key ecosystem services: (1) microclimate regulation; (2) food yield; (3) biodiversity; and (4) learning and well-being, produced by a case study of ten examples of collectively managed urban gardens in Greater Manchester, UK.

Method

Case study sites

Sites were selected from collectively managed pockets of green space found throughout the Greater Manchester conurbation, UK, as identified by Dennis et al. (2016a). All CMUGs were managed by an identifiable, but fluid, community-of-practice made up of local stakeholders. The case study was made up of an established cohort of CMUGs which had formed the basis of previous quantitative research into user participation and its relationship with biodiversity and ecosystem services (Dennis and James, 2016a; 2016b). These were comprised of four types: (1) community gardens (n = 3); (2) community allotments (n = 3); (3) community orchards (n = 2); and (4) pocket parks (n = 2). Each site presented a bottom-up approach to the social-ecological intensification of underused open spaces with food production figuring in the management of all ten examples. Sites were located in areas of above-mean levels of both socio-economic and ecological deprivation for the study area (see Dennis et al., 2016a, 2016b, for more information on the distribution and context of CMUGs throughout the study area). An overview of each type is offered in Table 1.

Table 1 Case study type descriptions

Sites	*Description*
Community gardens (CG)	Multi-use gardens. Varied in terms of size ($500m^2$–$1500m^2$), design and emphasis placed on agriculture, horticulture and social amenities (e.g. shelter/seating)
Community allotments (CA)	Communal plots on established allotment sites under collective management ($600m^2$–$1000m^2$)
Community orchards (CO)	Located within larger green structures (park and recreational land). Principally dedicated to cultivation of soft or hard fruit ($1000m^2$–$2000m^2$)
Pocket parks (PP)	Small (< $300m^2$) sites in urban areas of high surface sealing. Innovative approaches to site greening (e.g.

green roofs/walls with raised bed systems).

Site locations are shown in Figure 1 with details of individual sites presented in Table 2.

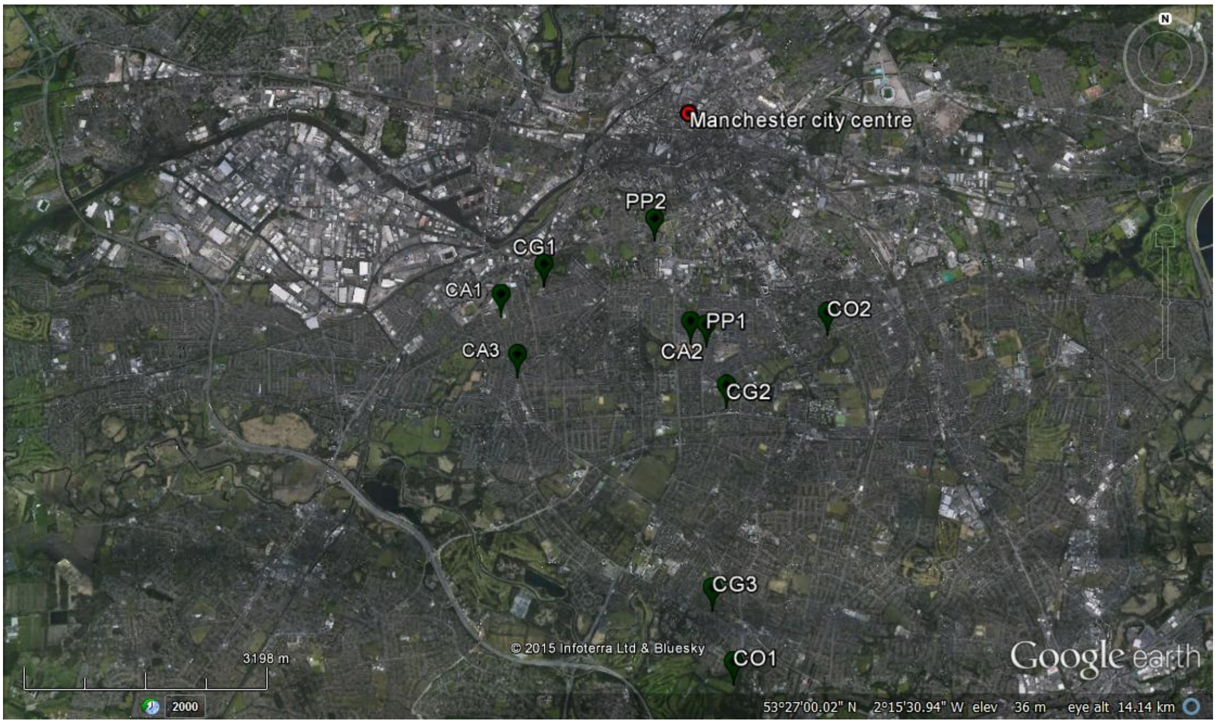


Figure 1 Location of the case study sites

Source: Google Earth 7.0. 2015. *Manchester, 53°27'00.02"N, 2°15'30.94"W, elevation 36m.* [Accessed 2 January 2016]. Available from: http://www.google.com/earth/index.html

Table 2 Case study site descriptions

Site	*Type*	*Main partner organisations*	*Community-of-practice/main users*	*Year established*
CG1	Community garden	Trafford safer stronger communities fund/Trafford Partnership	School and local residents gardening group	2007
CG2	Community garden	City South Housing Association	Local residents and external volunteers	2012
CG3	Community garden	Didsbury Greening and Growing Group	Local residents, Eat Green Community Interest Company	2012
CA1	Community allotment	Trafford Council, Bluesci social enterprise	Local residents and BlueSci service users	2009
CA2	Community allotment	Adactus Housing Association	Local residents and school visits	2011
CA3	Community allotment	Manchester City Council	Local residents and school visits	2009

CO1	Community orchard	Didsbury Dinners community interest company	Local residents	2011
CO2	Community orchard	Manchester City Council/Friends of Birch Fields Park	Local residents and Friends of Birch Fields group	2007
PP1	Pocket park	Manchester City Council/Adactus Housing Association	Cranswick Square Residents' Association	2011
PP2	Pocket park	Self-funded not-for-profit	Community payback groups, schools, local residents and social prescribing	2012

Key: CG = Community Garden; CA = Community Allotment; CO = Community Orchard; PP = Pocket Park

Case study site assessments

At the ten sites, assessments were carried out on four ecosystem services presented in the literature as being of importance to urban environments and their inhabitants. These were:

1. microclimate regulation (Bolund and Hunhammer, 1999; van der Ploeg and de Groot, 2010; UK NEA, 2011; Aubry et al., 2012);
2. food yield (Barthel et al., 2011; UK NEA, 2011; Krasny and Tidball, 2015);
3. biodiversity (Goddard et al., 2010; UK NEA, 2011; Speak et al., 2015);
4. learning and well-being (Hansmann et al., 2007; Krasny and Tidball, 2009; UK NEA, 2011; Bendt et al., 2013; Camps-Calvet et al., 2016).

Data collected from the ecosystem service assessments for each site were computed to produce an area-standardised measure of site productivity per unit area. The latter was used in an analysis of synergies and trade-offs in ecosystem service provision.

Data collection methods

Microclimate regulation

The GI Toolkit, devised by Green Infrastructure North West (2010), was chosen as the method used to quantify microclimate-regulating services at the case study sites. The toolkit is based upon the original Biotope Area Factor (BAF) tool developed for the Berlin Urban Planning Authority (Becker and Mohren, 1990), and subsequent versions, which seek to quantify the *ecological effective* area (EEA) of a given site. The concept of ecological effectiveness is directly related to the provision of regulating ecosystem services (Phillips and Moore, 2012) in that it represents a score derived largely from the presence of permeable and evapotranspiring surfaces. The latter is widely adopted in assessments of climate-regulating processes (e.g. Gill et al., 2007; Schwarz et al., 2011; Gómez-Baggethun and Barton, 2013). The tool has been employed successfully by urban planning departments in Berlin, Hamburg, Malmö, Seoul, Seattle and Southampton (Kruuse, 2011) and its efficacy has been demonstrated in research on urban ecosystem services (Lakes and Kim, 2012). Proportion cover by vegetated surfaces, as a single measure, has been used effectively as a proxy in assessments of microclimate-regulating services by urban gardens (Cabral et al., 2017). The GI Toolkit, however, takes into account eleven discrete surface types and three vertical vegetative features (green walls, shrubs and trees) with scores weighted according to their relative permeability and evapotranspiration potential. Although the assessment is based on the proportion of sites which are determined as ecologically effective, scores over 100% are possible for highly structurally diverse sites. Data were collected for each case study by carrying out detailed surveys of site dimensions and ascribing the corresponding surface type in the GI Toolkit to that observed on-site. Site surveys were conducted in early to late summer (May to September) 2013.

Food yield

The dimensions of each site under cultivation for vegetables, and soft and hard fruit varieties were recorded. For vegetable yields, a proxy was developed based on data from detailed harvest surveys carried out across community gardening sites in Philadelphia, Camden (Penn.) and Trenton (NJ) for the Philadelphia Harvest Report (PHR) by the University of Pennsylvania (Vitiello and Nairn, 2009). This dataset was chosen as the practices of community gardens documented in the surveys reflected the, principally organic, horticultural and agricultural methods adopted at CMUGs in the current study. The proxy was obtained by taking mean yields per unit site area under cultivation at community gardens in the Philadelphia Harvest Report and applying this factor to the ten case study sites. Gardens included in the report were categorised by site area. For all (five) categories of site area less than 2 hectares, the mean site productivity in terms of food yield was equal to 6.93 kg m^{-2} (converted from lbs ft^{-2} in the original report). However, similar data were not available for fruit production associated with examples of CMUGs and, therefore, proxy measures were derived from UK government horticultural statistics (Defra, 2013). In the case of orchards and other sites partially designated to fruit production, projected yields per square metre were calculated from the UK government Basic Horticultural Statistics dataset (Defra, 2013). In cases where fruit production was prominent, yields were calculated according to whether soft or hard fruits were under cultivation. For hard fruit, mean yields for orchard fruit per square metre were calculated at 1.5 kg m^{-2} based on UK commercial mean yields, 2007–2011 (Defra, 2013) and used as a proxy. For soft fruit, a proxy value of 1.39 kg m^{-2} was calculated from national mean soft fruit yields, 2007–2011 (Defra, 2013).

Biodiversity

Quantitative measures of biodiversity as an ecosystem service provided by collectively managed sites, were achieved using an assessment developed by Tzoulas and James (2010) that focuses on structural and biological diversity. In the assessment, the percentage cover of each type of vegetative structure (defined using categories developed by Freeman and Buck (2003)) is estimated using a method adapted from Tandy's Isovist technique (Westmacott and Worthington, 1994). This measure is then combined with the number of genera of vascular plants observed to give a combined score for overall biodiversity. This method is straightforward in approach and provides accurate, comparable biodiversity measures for a variety of green space types. A fuller explanation of the background to the biological surrogates and scales used in the method, as well as a rationale of the scoring system, can be found in Tzoulas and James (2010). In their original assessment design, Tzoulas and James established and surveyed circular sampling points consisting of a minimum of 10% of the total site area. As all case study sites in the study were considerably smaller than 1 hectare, it was possible for them to be assessed in their entirety by using the original visual estimate technique to record vegetative structure from a single vantage point and by subsequently employing line transects to identify and record vascular plant genera. The resulting score provides a proxy for site biodiversity based on the floristic and structural diversity of sites and, as such, is in line with similar biodiversity assessments used in research into urban gardens (e.g. Speak et al., 2015; Borysiak et al., 2016; Cabral et al., 2017). The case study assessments of biodiversity were conducted through single site visits in fair weather conditions during the summer months June to August 2013.

Learning and well-being

Data were gathered based on selected indicators from Natural England's monitoring and evaluation protocols for the socio-cultural benefits that individuals and communities receive from interaction with quality green space. These protocols were prepared as part of the Nature Improvement Area scheme in the UK (Natural England, 2014). The protocols were designed for the assessment of much larger areas of green space and their significance at a regional scale. However, two indicators found under the indicator sub-theme: *Social impacts and well-being* were of direct relevance to the nature of the activities and levels of community participation taking place at the ten case study sites. These were *Volunteer Hours* and *Educational Visits*. These indicators are designed to provide a proxy measure of engagement by user groups and participation in natural resource management. Following the evidence described in the introduction to this paper (e.g. Krasny and Tidball, 2009; Bendt et al., 2013; Andersson et al., 2014; Barthel et al., 2014; Krasny et al., 2014; Olivos and Clayton, 2017), participation in CMUGs comprises a highly effective means to enhance the well-being of urban residents, offering simultaneous benefits by way of learning and well-being.

Information on volunteer hours per month during the growing season (March to October; DECC, 2013) was gathered as a measure of community involvement. Data were also collected, following the rationale of the Natural England protocols, on the number of educational and community events taking place at each site over the course of a year. The latter measure included any events outside regular volunteer-led site management and included schools visits, training workshops (e.g. tree grafting, seed saving, permaculture principles), children's groups, community forums and seasonal celebrations. Values for volunteer hours per month and number of events per year were summed and the resulting score used as a proxy for *learning and well-being*. Data on volunteer hours and events were collected from site gatekeepers via correspondence, or during site visits, and from attendance records (where available), over a period spanning March 2013 to December 2013.

Given that the sites under investigation were managed collectively, volunteer effort can equally be described as an output, in terms of the benefits accrued through participation, as well as an input, as a critical management resource. In the analysis of synergies and trade-offs between services that follows, the opportunity to participate, and, thereby, receive the resulting benefits of participation (i.e. learning and well-being outputs) afforded by CMUGs is the perspective adopted. However, by their nature as collective sites, CMUGs rely heavily on user participation as a principal resource in terms of site management. This reciprocity between engagement and benefit is acknowledged in a Natural England monitoring and evaluation report which presents community involvement both as an "indicator of the contribution volunteers make … and their engagement in the natural environment (and the health and wellbeing benefits from this engagement)" (Natural England, 2014, p. 123). As such, recourse will also be made to the importance of participation from a management perspective where it is warranted in the analysis. For a deeper investigation of the interrelationship between user participation, ecosystem services and their valuation, see Dennis and James (2016b; 2016c).

The site surveys resulted in the collection of a range of data on site characteristics including the proportion of sites dedicated to food cultivation, vegetative cover extent, volunteer hours, levels of access and genera richness, as summarised in Table 3.

Table 3 Summary of site surveys and data collected

	Methods employed and data collected during site surveys		
Assessment	*Indicator*	*Method*	*Data type produced*
Microclimate regulation	Ecologically effective area (EEA)	Detailed survey of surface cover types identified through the GI Toolkit	Score reflecting EEA relative to total site area. Details of site cover by semi-permeable, built and vegetative structures
Food yield	Proportion site area cultivated for food combined with proxy data	Site survey (carried out concurrently with microclimate regulation assessment)	Site area designated to soft and hard fruit, and vegetable cultivation
Biodiversity	Habitat assessment score (Tzoulas and James, 2010)	Structural and floral richness survey	Overall biodiversity score; structural diversity; vascular plant genera richness
Learning and well-being	Volunteer input and community events	Consultation with site gatekeepers and attendance records (where available)	Volunteer hours month^{-1}; number of events year^{-1}

Evaluating synergies and trade-offs

In order to achieve a comparable assessment of ecosystem service provision and identify synergies and trade-offs between specific services, all ecosystem services assessment scores were standardised by area. This allowed a measure of the productivity of sites regardless of site size and addresses a hitherto under-considered mediator in the efficiency of ecosystem service provision. The original assessment scores for the ecologically effective area, biodiversity, food yield, volunteer hours and events were transformed to values 100m^{-2}. To understand the between-services relationships in service provision, the data were investigated, using IBM SPSS.20 for correlations (Pearson's Product Moment and Spearman's Rank), to identify synergies and trade-offs. The rationale was that positively correlated services might be considered as potential ecosystem service "bundles" (i.e. "win-win" scenarios), with negatively correlating services suggesting potential trade-offs ("win-lose" scenarios) in the occurrence of urban ecosystem services provided by collectively managed sites. Equally, service scores which exhibit no level of significant correlation, reasonably imply independence of service provision, with the generation of such services not necessarily affecting the capacity for other services and vice versa. The evaluation of ecosystem service provision from an area-standardised perspective not only rendered service scores comparable but equally provided the opportunity to test the effect of the size of the sites on productivity. This was an important consideration as it allowed for insight into the scalability of ecosystem services. Total site area was, therefore, included in the correlational analysis to test for scale effects on productivity. Between-service relationships were also examined through partial correlation, controlling for site area. Surface sealing extent, an important spatial design consideration affecting ecosystem service provision, was explored for its mediating effects on ecosystem service indicators.

Results

Data derived from the four ecosystem service evaluations are presented in Table 4 as non-standardised values from the original site assessment.

Table 4 Original ecosystem services assessment scores

Site	*Total area (m²)*	*Ecologically effective area (m²)*	*Vegetation cover (m²)*	*Tree cover (m²)*	*Food yield (kg)*	*Area cultivated for food (m²)*	*Biodiversity score**	*Genera present*	*Volunteer hours month⁻¹*	*Yearly events*
CG1	936	665	485	60	129	36	20	84	40	200
CG2	1530	1316	1114	60	555	80	25	107	288	12
CG3	560	554	530	21	485	101	16	52	200	2
CA1	950	703	556	10	2502	403	27	81	220	13
CA2	780	616	518	35	2110	320	24	91	300	48
CA3	630	422	346	39	1104	195	23	96	200	20
CO1	1044	1190	1044	365	390	260	17	34	20	3
CO2	1734	1994	1734	350	806	552	26	68	80	6
PP1	215	133	78	10	125	34	13	60	150	10
PP2	217	130	69	7	199	29	15	55	200	13

*Scores are dimensionless.

Key: CG = Community Garden; CA = Community Allotment; CO = Community Orchard; PP = Pocket Park

With the exception of community gardens, CMUGs of the same type were of comparable size. An increase in size was associated with a corresponding increase in vegetative cover and, therefore, in the ecological effective area according to the GI Toolkit. This pattern was not observed across the other indicators, however. For example, larger sites did not share a correspondingly greater level of participation. Whereas site *CG2*, for example, (a community garden) scored highly on the *volunteer hours and events* indicator, the two other sites in the study with site areas over 1000m² (both community orchards) scored lowest overall in this regard. Community gardens and community orchards differed significantly in terms of access, management (and activities) and location. Importantly, community orchards were publicly accessible areas set within existing urban green space whereas community gardens were all secure (i.e. fenced) with limited and regular access to designated users facilitated by site gatekeepers (Dennis and James, 2016a). As might be expected, allotment sites dedicated the greatest proportion of site area to food cultivation and, therefore, had the highest projected food yield. Pocket parks were characterised by a low ecologically effective area relative to other types, as a result of the high levels of surface sealing which formed the original context of these sites. By contrast, however, the latter achieved high levels of participation (both volunteer hours and events) relative to site size (Table 4). Overall, the observed variance in site area did not correspond to that of the values for service provision scores. Table 5 presents correlations between area-standardised measures of service provision and between services and site area.

Table 5 Correlations between ecosystem services and site size

	Microclimate regulation	*Food yield*	*Learning and well-being*	*Total area*

Biodiversity	Pearson Correlation	-0.745*	0.128	0.961**	-0.870**
	Sig. (2-tailed)	0.013	0.726	0.000	0.001
	N	10	10	10	10
Microclimate regulation	Pearson Correlation		-0.305	-0.766**	0.674*
	Sig. (2-tailed)		0.391	0.010	0.033
	N		10	10	10
Food yield	Pearson Correlation			0.128	-0.206
	Sig. (2-tailed)			0.725	0.569
	N			10	10
Learning and well-being	Pearson Correlation				-0.814**
	Sig. (2-tailed)				0.004
	N				10

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Trade-offs were observed between microclimate regulation and two other services: biodiversity, and learning and well-being; as well as between the latter two services and site area. Biodiversity and learning and well-being exhibited a high degree of synergy ($r^2 = 0.92$). Given that site size was also positively correlated with microclimate regulation, it was clear that site size played a mediating role in site productivity. Table 6 details correlations between the same services controlling for site area.

Table 6 Ecosystem service associations controlling for total site area

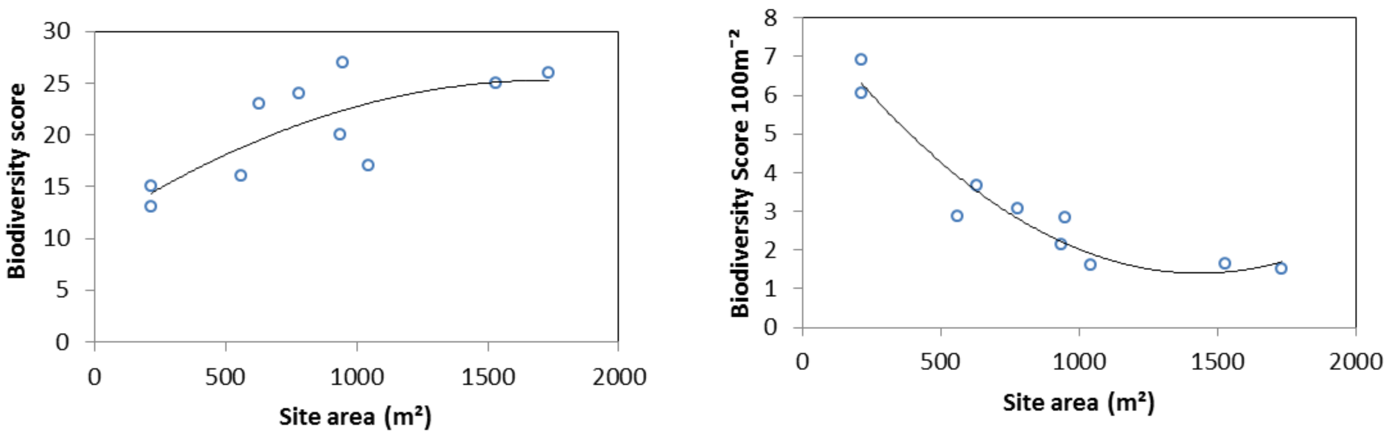
Control variables: total area		*Microclimate regulation*	*Food yield*	*Learning and wellbeing*
Biodiversity	Correlation	-0.436	-0.107	0.883
	Sig. (2-tailed)	0.241	0.784	0.002*
	Df	7	7	7
Microclimate regulation	Correlation		-0.230	-0.506
	Sig. (2-tailed)		0.551	0.164
	Df		7	7
Food yield	Correlation			-0.070
	Sig. (2-tailed)			0.859
	Df			7

* Correlation is significant at the 0.05 level (2-tailed).

Trade-offs highlighted in Table 5 did not demonstrate significance when controlling for site size. The one synergy identified in the data, between biodiversity and learning and well-being, remained significant, albeit with a slightly weaker coefficient, and correlations between food yield and other services remained non-significant. This implies that services related to biodiversity and learning and well-being present a win-win, and that agricultural productivity is largely independent, regardless of site size.

Site area and ecosystem service-related characteristics

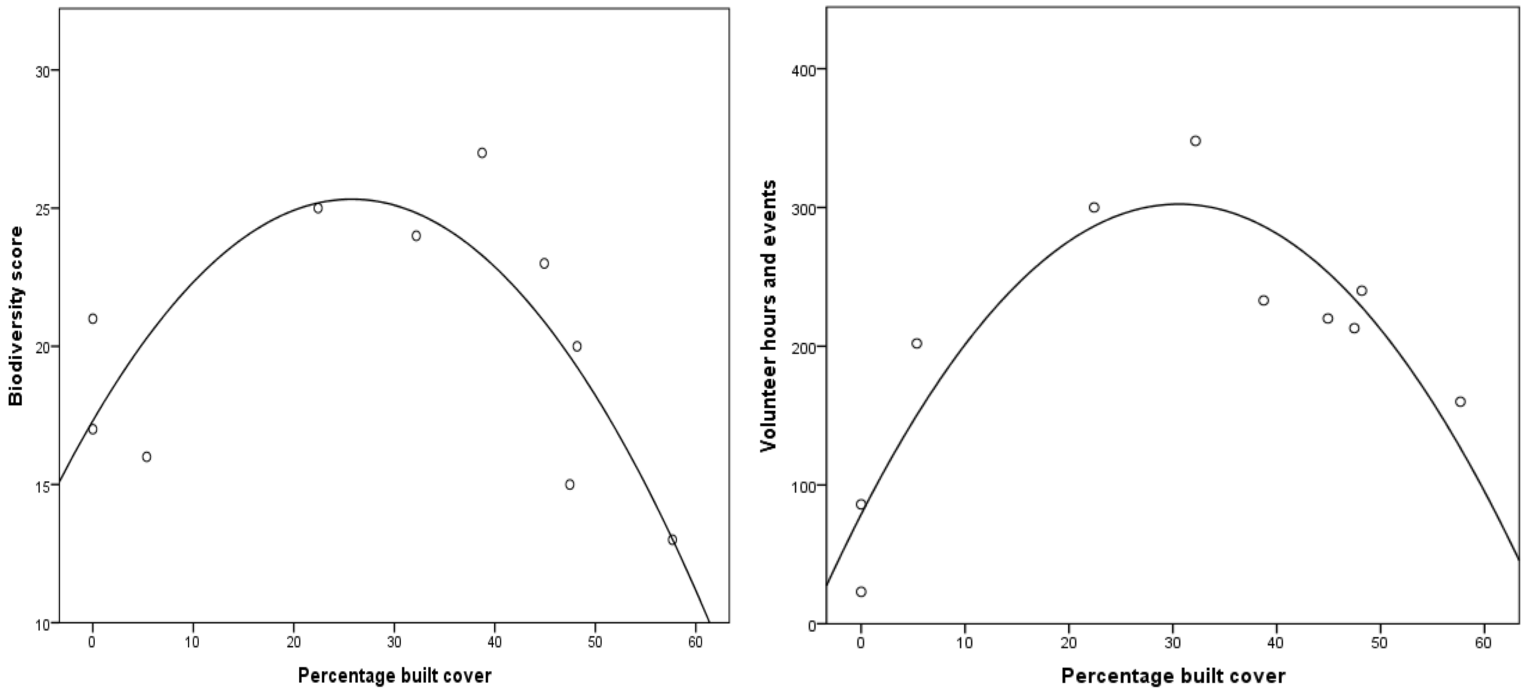
The effect of site area was significant as a mediating factor in establishing trade-offs due to its influence on a range of associated site characteristics. In the case of biodiversity, standardising the assessment score had the effect of reversing the direction of its relationship with site area, as demonstrated in Figure 2.



(a) (b)

Figure 2 Relationship between site area and (a) biodiversity assessment score; R^2 quadratic = 0.60 (*p* = 0.048) and (b) area-standardised biodiversity score; R^2 quadratic = 0.93 (*p* < 0.001)

Although these curves show biodiversity-area relationships which do not diverge from those found in more natural systems (Connor and McCoy, 1979), the definition of *area* in assessments of the latter is generally that of viable habitat for the taxa under consideration. In the context of CMUGs, site area cannot be considered in its entirety as a viable habitat, with significant levels of surface sealing occurring at the majority of sites (Table 4). Percentage surface sealing correlated negatively with site area (Pearson's Product Moment = -0.675; $p = 0.03$) and, not surprisingly, exhibited a strong negative association with microclimate regulation ($R^2 = 0.95$; $p < 0.001$). Cover by built surfaces likewise had a significant impact on biodiversity score and participation (volunteer hours and events) at case study sites. Figures 3a and 3b illustrate the non-linear relationship observed in both cases.



(a) (b)

Figure 3 Relationship between site built cover percentage and (a) genera count; R^2 quadratic = 0.63 (*p* = 0.03) and (b) relationship between volunteer hours and events; R^2 quadratic = 0.83 ($p < 0.001$)

Discussion

According to the statistical analyses, site size was a significant factor in the productivity of collectively managed sites in the study with total site area correlating strongly with all area-standardised measures of service provision other than food yield (Table 5). Trade-offs were observed between microclimate regulation and both biodiversity, and learning and well-being. However, controlling for site area in the correlational analyses (Table 6) demonstrated that trade-offs between services were highly dependent on this site characteristic. The analysis, therefore, demonstrates that there is much to be gained in terms of interpretative power by assessing and comparing ecosystem service provisioning from an area-standardised perspective. Not only does such standardisation permit comparison of sites of varying size, it allows an interrogation of the scalability of ecosystem service productivity. In the current example, productivity appeared not to be up-scalable for two of the ecosystems services examined (biodiversity, and learning and well-being), while microclimate regulation lent itself poorly to downscaling in the case of CMUGs.

Site area, design and ecosystem service provision

Whereas biodiversity generally increased proportionally to site size (Figure 2a), the area-standardised scores (effectively a combined measure incorporating species and structural density), presented a curve describing a diminishing return per unit area (Figure 2b). This suggests that species-area relationships in collectively managed urban green spaces may not differ considerably from those found in natural systems. In this respect, the findings support other observations of increased species richness in larger urban gardens (Smith et al., 2006). Effective returns in terms of the (area-standardised) biodiversity measure were, however, more closely associated with smaller sites (R^2 quadratic = 0.93; $p < 0.001$). The observed effects may be due to management resource factors, with smaller sites likely lending themselves more easily to intensive cultivation and planting regimes. By contrast, increasing site size accompanied lower community involvement per unit area (Table 5). However, site area was not the only significant factor affecting the efficacy of service provision. The proportion of sites subject to surface sealing had an observable effect on participation (Figure 3a), biodiversity score (Figure 3b) and the ecologically effective area (Figure 4). In the case of both biodiversity score and volunteer hours and events, the relationships described in Figures 3a and 3b imply that there is a non-linear relationship between surface sealing extent and site characteristics relevant to ecosystem service provision. Scores for both assessments increased proportional to surface sealing before declining after values of c.40% cover. The highly similar patterns exhibited between both biodiversity and participation with surface sealing extent reinforce the strong synergy between the two former measures highlighted in the correlations in Tables 5 and 6. The analysis points to an increase in volunteer activity and events, facilitated by certain levels of surface sealing (i.e. paving and built structures), but suggests that very highly sealed sites are not effective in delivering comparable levels of participation. Given that CMUGs are, by definition, reliant on such participation for site management, this pattern goes a long way to explaining the similar relationship observed between sealing extent and site biodiversity. Likewise this similarity clarifies the strong synergy between biodiversity and learning and well-being outputs (Tables 5 and 6). The moderately negative correlation between site area and surface sealing also fits with the overall tendency of smaller sites to exhibit greater values for per-unit-area measures of these outputs. These patterns are in line with other observations in studies at urban garden sites, such as Cabral et al. (2016), who demonstrated a positive association between medium-intensity levels of management and floristic biodiversity. The information provided here on the parallel relationship with participation, however, has allowed for a more detailed understanding of such effects.

In contrast to the biodiversity, and learning and well-being assessments, the strong positive association between site size and microclimate regulation suggests that structural elements which contribute to microclimate regulation may be more easily preserved within larger CMUGs. The most salient factor in the assessment tool upon which microclimate regulation was measured was the proportion of vegetative cover at each site. This structural component was more abundant in larger, more naturalistic sites (Table 4). Impervious surface cover at community allotment sites was a reflection of design for agricultural intensification which relies on built amenities such as paths and built structures (e.g. tool sheds). This mirrors characteristics reported in other studies into urban gardens (Calvet-Mir et al., 2012; Camps-Calvet et al., 2016) in which assessments of sites with an emphasis on food production highlighted the provision of largely cultural and provisioning benefits in contrast to regulating services. Community gardens and community orchards, therefore, exhibited a higher proportion of ecologically effective area compared to allotment sites (Table 4), reflecting a greater propensity of surface sealing of the latter as reported elsewhere (Cabral et al., 2016). Although the ecologically effective area was largely derived from the proportion of site area covered by vegetation, this was not the only determining parameter in the GI Toolkit. Other surface cover types such as vertical and raised vegetation, various types of semi-permeable surfacing as well as shrub and tree layers play an important role in the assessment of ecological effectiveness. It is, therefore, possible for sites located almost entirely on impervious surfaces (pocket parks) to increase microclimate-regulating performance through the presence of more improvised, diverse vegetative structures and planting regimes. However, gains in terms of microclimate regulation were associated with greater site size (Table 5), which suggests this service as being, of all services included in this study, that which presents the greatest challenge for small-scale, intensively managed CMUGs to effectively enhance. Moreover, that learning and well-being, and biodiversity benefits exhibited the inverse relationship with site area, and synergy with medium levels of surface sealing (Figure 3), presents a tension in the efficient co-management of these outputs.

The on-the-ground analysis at the case study sites presents the productivity of CMUGs as being highly spatially sensitive, which is a characteristic hitherto largely ignored in the literature. That some ecosystem services, correcting for site area, were produced independently of others suggests the possibility of the effective co-production of services does exist but that managing trade-offs in ecosystem service provision from collectively managed urban gardens is highly scale-dependent. A key finding from this study, therefore, relates to the scalability of ecosystem service production and the observation that, even with relatively small variations in scales of operation, productivity can be seen to be highly responsive. This has implications both for the design of urban green spaces and the methods of research into ecosystem services and their associated trade-offs. To date, such methods have largely failed to acknowledge scale effects in, for example, landscape scale studies into ecosystem service trade-offs (see Haase et al., 2014).

Limitations of the work: context and interpretability

Context is equally as critical as scale in the production, and receipt, of benefits issuing from ecosystem service-providing spaces (Andersson et al., 2015). For example, Dennis et al. (2016a) mapped the distribution of CMUGs in an urban landscape (from which was taken the current study cohort) presenting them as adaptive responses to elevated levels of local social and ecological deprivation. However, the socio-economic characteristics of neighbourhoods containing CMUGs will vary throughout the landscape and, as a result, individual ecosystem services (e.g. food provision, educational opportunities) may take on disproportionate levels of efficacy and demand. In this study, the socio-economic context of sites was not considered as a mediating factor and, therefore, the actual impact of ecosystem service provision at the neighbourhood level cannot be known. Furthermore, given that proxy measures were used, actual receipt of ecosystem services by site users and other local beneficiaries can likewise only be projected. Notwithstanding these shortcomings and the primacy of context in the production and value of ecosystem services, the insights provided here related to site size and management make a significant contribution to the current knowledge of ecosystem service trade-offs issuing from CMUGs.

Although the results reported here demonstrate that productivity, with the exception perhaps of food yield, cannot be considered scalable at sites within the range of 200–2000m^2, it is not clear whether this finding is itself “scalable” to larger green structures in urban areas. Further investigation in this area may be advantageous given the recognition of the benefits of collectively managed urban gardens has resulted in calls for such practices to be integrated into the management of formal public green spaces such as city parks (Middle et al., 2014; Dennis and James, 2017). The potential effect of “scaling-up” CMUGs into larger areas of urban green space is, as yet, unclear but the findings of this study suggest that related ecosystem service provision and the ensuing trade-offs may be highly sensitive to spatial configurations. Nor is it by any means certain that the properties and productivity of CMUGs observed herein are suitable for integration into larger green structures in urban areas. For example, although CMUGs exhibited high species density, this was also associated with relatively high surface sealing and represents a trade-off with other important benefits. The latter relate not only to microclimate regulation, as highlighted here, but also to wider issues such as the provision of habitat for species in larger patches of green infrastructure. Sites included in this study were clearly capable of achieving, even at very small sites with high surface sealing, impressive levels of floristic and structural density. Although such floristic richness may benefit some functional groups (e.g. pollinator species) in urban areas, this does not automatically translate to provision of viable habitat for other taxa which require greater area, stratification and connectivity of structural elements (e.g. birds and mammals). The impact of such spaces may, therefore, lie in their ability to render underused or highly sealed open spaces more ecologically effective, user-oriented and species-rich.

Conclusion

The current study demonstrates the possibility for the co-production of multiple ecosystem services at collectively managed urban gardens, but shows that the achievement of win-win scenarios is highly dependent on spatial considerations. Site size appeared to have a net negative relationship with an area-standardised measure of ecosystem service provision, and further work is necessary to explore the possibility of overcoming spatially derived trade-offs in service provision. Surface sealing also appeared to bear a unimodal mediating influence on participation, microclimate regulation and supporting services. Given that agricultural productivity appeared to be an output that is not significantly modified by site size or by the generation of other services, urban agricultural practices present one avenue of research which may open up possibilities of achieving potential win-win scenarios in ecosystem service provision at a range of scales. More concerted research exploring the relative performance of CMUGs in comparison to, *and situated within*, more naturalistic municipally managed green space would be necessary to fully appreciate the viability of integrating CMUGs, at various scales of operation, into larger green structures within cities. A key focus of such research should be to understand better thresholds and trade-offs in the ability of collectively managed urban gardens to balance microclimate-regulating properties with optimum user participation and habitat for species.

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