Harvesting more than food: Assessing the provision, resource demand and ecosystem service delivery of British allotments

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For Grandma: No gardener has truly left us

whilst her descendants still plant seeds.

Abstract

Interest in urban food cultivation has increased in recent years as attention has turned to its potential to provide sustainable and nutritious food for the increasing global urban population. Alongside this, a growing body of research has begun to address the potential environmental and social benefits that food cultivation in cities could entail. This thesis uses a case study system of allotment gardens in the United Kingdom to investigate, at a nationwide scale, a number of environmental and social features of urban horticulture. It begins with an investigation into land use change throughout the twentieth century, quantifying the loss of allotment land in the latter half of the 1900s, revealing that the most deprived urban areas have experienced eight times the level of allotment land loss as the least deprived, and uncovering that a large extent of former allotment land has the potential suitability for reconversion to use in urban horticulture. Following this, a nationwide field assessment of allotment soil quality is conducted, demonstrating that allotment soils maintain a significantly higher quality than commercial arable and horticultural soils, and producing the first estimate for the contribution of allotment soils to British carbon stocks. The third data chapter assesses the resource demands of allotment gardening with a year-long citizen science project, quantifying the yearly inputs required to cultivate and allotment and assessing where opportunities exist to increase resource use sustainability by better integrating allotments into urban energy flows. These diaries also form the dataset for the following chapter, which identifies the multiplicity of wellbeing benefits that allotment gardeners report to gain from their plots. The final data chapter uses detailed field mapping to reveal the variation in typical structures of allotment gardens, identifying within-plot land uses that contribute not only to food production but also the delivery of other environmental benefits. Finally, a discussion of future research priorities and possibilities are presented along with a summary of key policy messages from the results of the thesis research.

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Declaration

This is an 'alternative format' thesis: each data chapter (Chapters 2 to 6) is presented as a stand-alone research paper. At the time of submission, Chapter 2 has been published in *Landscape and Urban Planning* (doi: 10.1016/j.landurbplan.2020.103803); Chapter 3 has been published in *Science of the Total Environment* (doi: https://doi.org/10.1016/j.scitotenv.2021.146199); Chapter has been published in *Sustainability* (doi: https://doi.org/10.3390/su13052628); Chapter 5 has been published in the *British Food Journal* (doi: https://doi.org/10.1108/BFJ-07-2020-0593); and Chapter 6 has not yet been submitted for review. The published versions of each paper are available as appendices. As such, each chapter has multiple authors listed. My contributions to each one are as follows:

1. Chapter 2

   Design of project, collation and analysis of data, manuscript preparation, editing and submission.

2. Chapter 3

   Design of project, fieldwork, sample preparation, lab analysis, data analysis and statistics, manuscript preparation, editing and submission.

3. Chapters 4 and 5

   Design of project, recruitment of participants, data entry, collation and analysis, manuscript preparation, editing and submission.

4. Chapter 6

   Design of project, fieldwork, data entry, data collation and analysis, manuscript preparation and editing.

Other authors listed in the following chapters contributed as follows:

1. Marta Crispo

Field assistance and assistance with lab analysis, Chapter 3. Field assistance, Chapter 6.

2. Roscoe S. Blevins

Field assistance and assistance with lab analysis, Chapter 3. Field assistance, Chapter 6.

3. Christian J. Reynolds

Assisted with methodological design and manuscript preparation, Chapter 5.

4. Philip H. Warren

Contributed to study design, supervised data collection and analysis, contributed to manuscript preparation and editing, Chapters 2-6.

5. Jill L. Edmondson

Contributed to study design, supervised data collection and analysis, contributed to manuscript preparation and editing, Chapter 2-6.

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Individual chapter reference lists have been removed and collated at the end of the thesis in the interests of brevity; this has involved some small within-text changes to published or submitted manuscripts to ensure referenced works are correct (for example, demarcation of papers published in the same year using letters a / b).

Table of contents

Chapter 1

General introduction

This thesis addresses the growing field of urban horticulture using a series of national-scale studies of allotment gardening in the UK. It is primarily focused on the state and structure of allotment gardens: a land use type predominantly dedicated to the production of fruit and vegetables in urban areas, but also a form of urban greenspace providing social, ecological and health-related services. I investigate the historical land-use change patterns leading to the distribution and extent of allotments in the present day; the quality of allotment soils in comparison to commercial horticulture and their contribution to carbon storage; the resource requirements of allotment gardening; the wellbeing benefits allotment gardeners report to gain from their plot; and the structure of allotments with an emphasis on non-food provisioning features that provide ecosystem services. Firstly, in this chapter, I give an overview of the broad topic of urban horticulture and its particular relevance as a research topic at the present time, as well as identifying the research gaps which are addressed in this thesis.

1. Urbanisation

Urbanisation has now fundamentally transformed the way that global human society functions. The United Nations (UN) estimates that in 2007, for the first time in history, a greater number of people (55% of the world's population) lived in urban areas than rural ones (Ritchie and Roser, 2019). By 2050, the UN forecasts that 68% of the world's population will be urban, a figure that rises to 88% in high-income countries (United Nations, 2019), and in 2019, the urban population of the United Kingdom (UK) was 84% (Statista, 2020). Urbanisation has transformed every aspect of human life, with associated social, economic, and environmental consequences, and is forecast to nearly triple by 2030 on its 2000 areal extent (Seto *et al*., 2012). These transformations have challenges for human society and the wider planetary environment.

The negative environmental impacts of urbanisation are well-documented, from biodiversity loss (Seto *et al*., 2012) to the urban heat island effect (Fokaides *et al*., 2016), and from increased energy emissions (Luederitz *et al*., 2015) to habitat destruction (Liu *et al*, 2016). Socially, urban residents are more likely to suffer mental and physical health problems as a result of disconnection from nature (Wells and Evans, 2003; Soga and Gaston, 2016; Frumkin *et al*., 2017), exposure to air pollution (Vieira *et al*., 2018) and poor nutrition (Warren *et al*., 2015).

However, benefits to human health, biodiversity and ecosystem service provision have also been documented in urban areas (for example: Tratalos *et al*., 2007; Jansson *et al*., 2013; Lin *et al*., 2015; Dickinson *et al*., 2017; Schwartz *et al*., 2017; Setälä *et al*., 2017; Clinton *et al*., 2018). Urbanisation has led to improvements on multiple indices of food security, poverty and levels of deprivation across the globe; urbanisation is one of the strongest indicators of economic development, and countries with urbanisation levels above 60% are predicted to achieve 50% more Millennium Development Goals than those with urbanisation levels below 40% (Zhang, 2016).

Many benefits from urban environments derive from urban green infrastructure or greenspace, where managed or semi-natural green spaces within cities provide positive benefits such as pollinator support (Baldock *et al*., 2015), carbon storage (Morel *et al*., 2015), reduction of the urban heat island effect (Edmondson *et al*., 2016), and benefits to human mental and physical health (Martin *et al*., 2016). However, urban greening in high income countries has also been blamed for negative effects, such as urban "green gentrification" (the process of development of green space and beautification of an area being used as a strategy to encourage new, more affluent, residents, and the investment of capital in the area, or 'the implementation of an environmental planning agenda related to public green spaces that leads to the exclusion of the most economically vulnerable human population while espousing an environmental ethic', Dooling, 2009).

2. Feeding the urban society

The global urban population depends on a complicated and internationalised food system to supply its nutritional needs. This has led to a number of issues in global agriculture, partially due to the increase in urban populations dependent on highly interconnected global food supply chains, but also more generally as a result of farming techniques, population increases, and anthropogenic climate change (Chaudhary *et al*., 2016; Richards *et al*., 2016; Benis and Ferrão, 2017). Worldwide, urban expansion onto agricultural land between 1970 and 2000 resulted in the loss of agricultural land equivalent in size to Denmark, or 43,000 km^2. (Martin *et al*., 2016). Other agricultural issues include soil erosion and desertification (Rosegrant and Cline, 2003), eutrophication of watercourses (Chen *et al*., 2020), loss of biodiversity (Chaudhary *et al*, 2016), failing harvests (Thirtle *et al*., 2004), and an increase in zoonotic diseases from intensive animal agriculture (Jones *et al*., 2013). Agriculture is also an area of key concern in the global climate crisis, contributing 5.8 billion tonnes, or 11.5%, to yearly global greenhouse gas emissions (Ritchie and Roser, 2020), and comprising 10% of the UK's emissions (DEFRA, 2020a). Food production, including agriculture and the international supply chain, is responsible for 26% of global greenhouse gas emissions (Poore and Nemecek, 2018).

Furthermore, access to nutritional and affordable food is a problem for those living in more deprived urban areas. So-called "food deserts", places where no local supermarkets or grocers exist to buy fresh produce from, contribute to health problems (Walker *et al*., 2010). Even where shops do exist, pricing can provide a barrier: one study in Glasgow, UK, found that healthy food cost more when bought from a shop in a deprived area than an affluent one (Cummins and Macintyre, 2002). Such areas are also often more likely to be "food swamps" – areas with a high density of establishments selling food with a poor nutritional profile and a low availability of more nutritionally beneficial food (Cooksey-Stowers *et al*., 2017).

Food security is a multifaceted concept, with conceptual explanations often taking as their starting point the World Food Summit definition that "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). Conceptual frameworks of food security tend to have four key pillars, according to the FAO: availability, access, utilisation and stability (Devereaux *et al.*, 2020). Urbanisation and the international food system affects all of these in regard to the food security of urban residents.

Overall, dependency on a globalised food supply chain leaves city residents vulnerable to shocks in the system. This is most evident in price volatility: the global food market is vulnerable to fossil fuel price fluctuations due to transportation fuel reliance and fuel-dependent agricultural machinery (Lee, 2012; Wiskerke and Viljoen, 2012). Food products also continue to rise in price at the consumer end, demonstrated by the continuing upward trend of the UN Food and Agriculture Organisation price index as of August 2020 (FAO, 2020a), and successive spikes in the price of food and non-alcoholic beverages in the UK since 2007 (DEFRA, 2020b).

The demand that growing urbanisation places on food production can be further illustrated through the concept of 'foodprints', "the environmental footprint of urban food demand" (Goldstein *et al*., 2016a). London, which as of August 2020 has a population of 9 million, requires the equivalent land area of 40% of the UK's agricultural land in order to feed itself (Eigenbrod and Gruda, 2015). In practice, food imports mean that actual land requirement in the UK is less than this. The UK imports 45% of its food (DEFRA, 2020a), a figure which rises to 77% when only fruit and vegetables are considered (Benton *et al*., 2017). In the light of these figures, which are demonstrative of the globalised food situation in the global North[1], and the above identified threats to the current global food system, a large and increasing amount of literature has examined localising the food chain to provide resilience against coming

[1] "Global North" and "Global South" are terms commonly used in comparative studies of urban agriculture (e.g.: Taylor and Lovell, 2014; Morgan, 2015; Opitz *et al.*, 2016). Therefore, for consistency I have used these terms here to apply to countries that formerly would have been referred to as "developed" or "developing", prior to the move away from such terms with their unequal economic and colonial overtones. However, there is a growing debate in the academic literature regarding the terms global north and global south being also outdated, and not accurate for conveying the global situation, as well as being founded in colonial perspectives (Schneider, 2017). Further to this, it is difficult to accurately capture urban agriculture as taking specific forms in some countries compared to others; different urban environments, which can vary within and between countries, have different forms of urban agriculture that are typical for them.

uncertainties (e.g. Barthel and Isendahl, 2013; Taylor and Lovell, 2014; Morgan, 2015; Barthel *et al*., 2015; Eigenbrod and Gruda, 2015).

3. Global urban agriculture

One focus of increasing urban and food system sustainability in recent years has been urban agriculture (UA), which is increasingly viewed by international bodies such as the Intergovernmental Panel on Climate Change as a key facet of ensuring future food security (Mbow *et al*., 2019). Defining UA can present a challenge, but definitions tend to agree that UA consists of food production within an urban area primarily focused on the supply of food to that locality. Goldstein *et al*. (2016a) have proposed a taxonomy of UA to facilitate comparison of types and a further taxonomy for "local food" was proposed by Eriksen (2013). Much UA activity is informal and opportunistic (de Graaf, 2012), casting doubt on the usefulness of describing UA as an industry (as has been done by e.g. van der Schans and Wiskerke, 2012; Eigenbrod and Gruda, 2015). Indeed, the very term 'urban' is contested in regard to UA, as what constitutes urban land can be defined in numerous ways, such as through using population density thresholds, proportion of building cover, or legal and jurisdictional boundaries (Badami and Ramankutty, 2015).

The majority of the studies in the following sections focus on urban horticulture rather than UA as a whole. This is a key distinction that of importance throughout this thesis. UA is wide-ranging and includes all agricultural production taking place within cities, which in some places includes livestock farming (Omudu and Amuta, 2007; Katongole *et al*., 2012; Lupindu *et al*., 2012) and the production of cereal crops (Mkwambisi *et al*., 2011; Safi *et al*., 2011). Urban horticulture, however, is of more relevance particularly in cities in the global North and refers to horticultural production of fruit and vegetables. This thesis uses an understanding of urban horticulture that also precludes non soil-based food production, limiting the definition to traditional horticulture, such as garden, allotment and community garden-based cultivation (as opposed to, for example, hydroponic systems). However, a broad overview of UA is also important to consider here.

Urban agriculture has been practiced internationally throughout urban history (Isendahl and Smith, 2013; Barthel and Isendahl, 2013); it is presently estimated to engage 800 million people worldwide and provide 15-20% of the world's food (Lorenz, 2015). Participation globally is also increasing, with one estimate calculating an increase of 30% in the past 30 years, although this mirrors a similar increase in the proportion of the world's population living in urban areas (Wiskerke and Viljoen, 2012; Lin *et al*., 2015). Exact numbers however remain uncertain, in part due to the wide variety of types of UA practiced across the world. A number of reviews of UA have been published in recent years as the topic gains increasing attention across a range of academic disciplines (e.g. Guitart *et al*., 2012; Mok *et al*., 2014; Taylor and Lovell, 2014; Warren *et al*., 2015; Eigenbrod and Gruda, 2015; Lwasa *et al*., 2015; Aerts *et al*., 2016; Goldstein *et al*., 2016a; Opitz *et al*., 2016; Russo *et al*., 2017; Siegner *et al*., 2018), each focusing on a slightly different aspect of UA.

The variety of global forms of UA (for example: allotments, community gardens, city farms, aquaponics, prison gardens, rooftop gardens, etc.) mirrors the variety of motivations and purpose of UA globally. For example, 60% of household budget in Kinshasa, DRC, is spent on food compared to 9-15% across the UK, suggesting that subsistence plays a much smaller role in the global North in terms of rationale for participation in UA (Caputo, 2012). UA in the global South is more of an everyday occurrence: in Dar es Salaam in 1999, 70% of milk consumed was produced within urban boundaries and 74% of urban dwellers kept livestock (Lwasa *et al*., 2015). In the global North, motivations for UA participation also include issues not directly related to food security, such as community, education, health, leisure, climate change mitigation and the desire to spend time outdoors (Caputo, 2012; Taylor and Lovell, 2014; Lorenz, 2015; Lwasa *et al*., 2015; see 1.5. below). Comparative analysis of a dataset of 15 developing countries found that whilst food insecurity reduction from urban agriculture was limited, dietary indicators from participants were better than the general population and it also provided an income source (Zezza and Tasciotti, 2010).

4. Estimating potential food production

A growing body of research has begun to address perhaps the first and most obvious question regarding UA: that of the potential contribution it could make to urban food supply. Modelling of different scenarios has begun to uncover the potential of UA to meet cities' food needs, more accurately assessing the potential land available. Previous assertions that UA presents extremely limited potential to meaningfully contribute to food supply (e.g. Martin *et al*., 2016) are challenged by these new studies. For example, a case study of Sheffield, UK (Edmondson *et al*., 2020a) found that 15% of the population's annual fruit and vegetable needs (on a "five-a-day" diet) could be met by current levels of allotment cultivation and 10% cultivation of home gardens and other suitable additional land; and 122% could be met if all available land, including urban grey space suitable for non-soil based UA, was cultivated. Another study, in Sydney, Australia (Mcdougall *et al*., 2020), estimated that between 15% and 34% of the city's fruit and vegetable needs could be met with varying levels of cultivation of vacant lots and gardens for food production. Estimates of production levels in three English towns found that current production could supply the population with one month's fruit and vegetables, and under an expanded UA scenario, 198 days could be supplied (Grafius *et al*., 2020).

Prior to these more recent studies, one of the primary limitations of assessing the food production potential of UA was a lack of real data regarding yields, with estimates often taking those from commercial horticulture as a stand-in. The huge variety of types of UA make quantification difficult, especially with regard to home gardens which present an access problem for research (Galluzzi *et al*., 2010; Taylor and Lovell, 2014). There is a paucity of quantitative evidence of yields of UA (Goldstein *et al*., 2016b) and one attempt to do so concluded that baselines were too uncertain for any real predictions (Lee, 2012). However, recently, citizen science methodologies involving the self-reporting of yields by own-growers have provided a promising avenue to more accurately assess food production potential in future research (Edmondson *et al*., 2019; Edmondson *et al*., 2020b).

Previous positive outlooks include studies that have shown high yields, such as Hong Kong meeting 45% of its own vegetable supply (Doron, 2005); a prediction that Detroit could supply 31% of its own fruit and vegetables (Beniston and Lal, 2012); a prediction that Bologna could supply 77% of vegetable needs from rooftop gardens alone (Orsini *et al*., 2014); the estimated UA production of Havana in 1996 reaching 138 million kg of produce (Altieri *et al*., 1999); the suggestion that Cleveland could meet 100% of its fresh produce needs (Grewal and Grewal, 2012); and mean yields in urban farms in Sydney reporting twice the typical yields of commercial Australian farms (Mcdougall *et al*., 2019). The food provision potential of UA is greater when only fruits and vegetables are considered; there is a general agreement in the literature that there is less potential to grow crops requiring much larger tracts of land, such as grains, in urban areas (Lovell, 2010; Eigenbrod and Gruda, 2015). With such a consideration, it was found that UA practitioners could be self-sufficient in their cultivated crops at harvest time, but not all year round (Kortright and Wakefield, 2011). In general, performance of UA is particularly notable when produce with a high yield per unit area such as tomatoes are grown (Goldstein *et al*., 2016b).

Whilst most of the focus of research has been on quantifying outputs, that is, yield, there is much less information on the net balance between inputs and outputs in UA. One study found that over five years, yields from UA did not surpass inputs when all inputs and outputs were converted to a common unit of solar energy (Beck *et al*., 2001); another study found low levels of crop yields meant UA had no significant impact on reducing a city's foodshed, although this used only three case study growing areas in a single city (Martin *et al*., 2016); and a third claimed that 75% of food insecure households engaging in UA remained food insecure (Warren *et al*., 2015). Goldstein *et al*. (2016b) have claimed that UA has the potential to be more environmentally damaging than conventional agriculture (in high energy input situations such as the greenhouse production of tomatoes which was studied in New York City and Boston), similarly to Edwards-Jones' (2010) claim that localising the food chain would cause an increase in emissions, although this claim is not supported by the majority of other studies (e.g. Kulak *et al*., 2013).

Further to this, other potential negative consequences may exist with UA. Trade-offs in ecosystem services may exist when agriculture takes place in cities (Wilhelm and Smith, 2017). Some of the main potential negative consequences in the global North concern the safety of food produced in environments where pollution is an issue, with the potential for contamination from both airborne and soil-based sources (Russo *et al.*, 2017). In the global South, potential negative effects include the dominance of the use of wastewater for UA where no other water sources are available, which increases the risk of water-transmitted diseases such as *E. coli*; levels of heavy metal contamination in excess of health guidelines; air pollution; and heavy use of pesticides (de Bon *et al.*, 2010). However, there is a growing body of research on the environmental and social benefits UA can provide through ecosystem services, which will now be explored in more detail.

5. Ecosystem service provision

In addition to the key question of how much food urban agriculture can produce, as noted above, it is also important to understand the role played by green space areas used for soil-based UA in providing other ecosystem services in urban areas. There is a wide body of literature on the ecosystem service provision of urban greenspace overall; however here the focus, in the interests of brevity, will be specifically on UA in the global North (due to the difference in forms UA takes globally and the distinction between global North and South as discussed above).

5.1. Social and cultural ecosystem services

Health benefits are one of the main social and cultural services discussed in the literature. Physical health benefits of urban agriculture can include increased fresh fruit and vegetable consumption (Howe and Wheeler, 1999; Eigenbrod and Gruda, 2015; Church *et al*., 2015; Warren *et al*., 2015; Martin *et al*., 2016): participation in UA is associated with higher fruit and vegetable consumption (Barnidge *et al*., 2013), which has been quantified as 225% of the fruit and vegetable intake of non-gardeners (Litt *et al*., 2011). UA also improves mental health by reducing stress (Nordh *et al*., 2016), an effect which even extends to passers-by (Brown and Jameton, 2000), and people who grow their own food were found to be happier than the general population on average across fifteen European countries (Church *et al*., 2015). Species richness increases the psychological benefits of urban greenspace, of which UA is a part, (Fuller *et al*., 2007), so the diversity of forms and crop types in UA has the potential to support this. UA participants also report feelings of agency and empowerment (Crouch and Ward, 1997; Clavin, 2011; White, 2011; Wiltshire and Geoghegan, 2012; Taylor and Lovell, 2014; Church *et al*., 2015), including personal independence for the elderly (Church *et al*., 2015). However, negative health consequences of UA have also been discussed, for example the global challenge of ensuring that urban pollution does not contaminate soils and crops and cause negative health consequences due to the consumption of pathogens and heavy metals (de Bon et al., 2010; Russo *et al.,* 2017).

UA also provides opportunities to build social capital and enhance community cohesion (Crouch and Ward, 1997; Church *et al*., 2015; Speak *et al*., 2015; Martin *et al*., 2016); the social interaction found between volunteers and neighbouring plot-holders provides an atmosphere of care (Nordh *et al*., 2016). Community resilience is enhanced (Witshire and Geoghegan, 2012) through the development of social connections and social movements (Barthel *et al*., 2015). Rationale for the development of UA is often a reduction in economic hardship (Mees and Stone, 2012), and UA has been found to provide economic resilience for participants throughout the EU – with the notable exception of the UK (Church *et al*., 2015). Economic benefits also include job creation (Eigenbrod and Gruda, 2015), urban regeneration (Howe and Wheeler, 1999; Martin *et al*. 2016), crime reduction (Howe and Wheeler, 1999), and overcoming socio-economic inequalities, especially dietary ones (Levidow and Psarikidou, 2012). There have also been two very recent studies investigating UA during the coronavirus crisis of 2020, both of which emphasise the potential of UA to advance food and nutritional security and provide community-level resilience against future shocks of a similar nature (Lal, 2020; Pulighe and Lupia, 2020). However, UA in the global North also contributes to the risk of 'green gentrification', which can have unintended consequences of widening inequalities and driving lower-income communities from their local area as rent prices increase (Dooling, 2009; Cole *et al.*, 2017; Alkon and Cadji, 2018; Maia *et al.*, 2020).

Finally, one of the key social and cultural ecosystem services of UA is that of education and skills development. This has been described as the "best" ecosystem service of UA (Martin *et al*., 2016). Education, whether formal or informal, skills- or theory-based, is emphasised by many of the studies (Howe and Wheeler, 1999; Barthel *et al*., 2010; Galluzzi *et al*., 2010; Clavin, 2011; Kortwright and Wakefield, 2011; Taylor and Lovell, 2014; Speak *et al*., 2015; Church *et al*,. 2015; Barthel *et al*., 2015; Lin *et al*., 2015; Lorenz, 2015; Martin *et al*., 2016; Gregory *et al*., 2016). UA sites have been defined as "communities of practice" where knowledge transmission and exchange takes place in an equal and accessible environment, and is therefore a key site of environmental education for the urban population (Taylor and Lovell, 2014). Developing skills of gardeners has the potential of knock-on benefits to other ecosystem services, as more knowledgeable gardeners tend to be more productive growers, manage their soils more sustainably, and are better able to adapt to climatic shocks such as droughts (CoDyre *et al*., 2015; Egerer *et al*., 2020).

5.2. Support for pollinators and biodiversity

In general, urban greenspaces are important sites for the support of pollinators in the urban environment (Potter and LeBuhn, 2015; Baldock *et al*., 2015; Lin *et al*., 2015; Langellotto *et al*., 2018): UA, as part of the urban greenspace network, contributes to this. In the UK, allotment holders were interested in increasing pollinator provision on site (Speak *et al*., 2015), but allotment cultivation guidelines do not specifically encourage pollinator support within the land required to be under cultivation. In Stockholm such legislation does exist and was found to increase pollinator-friendly planting in allotments (Barthel *et al*., 2010). Even without planting specifically aimed at encouraging pollinators, the diversity and abundance of flowering plants found on UA sites provides a prolonged nectar supply season, increasing support and abundance of pollinators (Hennig and Ghazoul, 2012; Lin *et al*., 2015). Pollination is important for maximising crop yields: tomatoes pollinated by wild pollinators in urban agricultural settings in San Francisco outperformed controls consistently, producing higher yields (Potter and LeBuhn, 2015). Indeed, allotments have been found to be the key form of urban greenspace outside of home gardens for supporting pollinator diversity, and contribute disproportionately to urban pollinator community support compared to their areal extent (Baldock *et al*., 2019).

Many studies emphasise the importance of home gardens for the conservation of urban biodiversity (e.g. Tratalos *et al*., 2007; Loram *et al*., 2008; Davies *et al*., 2009; Goddard *et al*., 2010; Sperling and Lortie, 2010). Urban agricultural sites are less well-studied in terms of general biodiversity than specifically in terms of pollinators. Speak *et al*. (2015) found that allotments in Manchester, UK, and Poznań, Poland, had the potential for high biodiversity, with Poznań allotments providing particularly high plant species richness and conservation of threatened species. In Bologna, it was predicted that creating green corridors through rooftop planting could result in 94 km of corridor space for biodiversity (Orsini *et al*., 2014). Lin *et al*. (2015) also emphasise the biodiversity potential of urban agriculture across five types of UA site and suggest that high biodiversity in a UA system enhances the provisioning of other ecosystem services across the entire urban area.

5.3. Soils

Urban soils present unique challenges, such as the relative difficulty of distinguishing horizons due to historical disturbance (De Kimpe and Morel, 2000); lack of data regarding biogeochemical cycles (Lorenz and Lal, 2009); difference in pedogenesis from non-urban areas (Beniston and Lal, 2012); leaching (Lorenz, 2015); contamination (Beniston and Lal, 2012; Kim *et al*., 2014; Taylor and Lovell, 2014; Eigenbrod and Gruda, 2015); and unique forms of degradation due to anthropogenic waste objects (Pavao-Zuckerman, 2008). Urban soils have often been considered to be compacted (Pavao-Zuckerman, 2008; Beniston and Lal, 2012; Lin *et al*., 2015), however some recent studies have found that the situation is not as serious as has been assumed, and that compaction where it occurs is localised and infrequent (Edmondson *et al*., 2011; Devigne *et al*., 2016). Soils are an important indicator of ecosystem services and provide fertility, filtration, structure, climate regulation, flood mitigation, air pollution immobilisation and biodiversity conservation (Dominati *et al*., 2010; Edmondson *et al*., 2012; Rawlins *et al*., 2013). Maintenance of soil structure and quality is important not only agriculturally and environmentally, but also economically: total costs of soil degradation in England and Wales are estimated to cost the British economy £1.2 bn per year (Graves *et al*., 2015).

Urban agriculture provides a means to address several negative conditions of urban soils (Beniston and Lal, 2012). Edmondson *et al*. (2014a) found that UA maintains the high soil quality seen in urban greenspace, and it has been suggested that the sustainable management of urban soils has the potential to improve UA yields (Beniston and Lal, 2012). Organic agricultural practices (Lorenz, 2015), minimal tillage and cover cropping (Lorenz and Lal, 2009; Taylor and Lovell, 2014; Lorenz, 2015; Gregory *et al*., 2016), harvesting and recycling rainwater (Beniston and Lal, 2012), application of biochar (Ghosh *et al*., 2012) and addition of organic matter (Beniston and Lal, 2012) are some of the management practices that can increase the quality of urban soils and their function as a reservoir for biodiversity (De Kimpe and Morel, 2000; Beniston and Lal, 2012; Lorenz, 2015). Many of these practices are already common amongst UA practitioners which explains the results of Edmondson *et al*. (2014a) who reported high soil quality on allotments. However, importing organic matter, such as peat, may have negative environmental consequences for the ecosystem in the areas from which this material is sourced (Boldrin *et al*., 2009). With regard to soil contamination, adverse health effects have been contested (Leake *et al*., 2009; Mees and Stone, 2012) and risk perception may be a more limiting factor than risk itself (Wortman and Lovell, 2013), but contamination does have the potential to limit yields and land availability for UA (Sharma *et al*., 2015; Entwistle *et al*., 2019). However, site-specificity is a recognised barrier to drawing far-reaching conclusions about the benefits of UA to urban soils (Altieri *et al*., 1999; Pavao-Zuckerman, 2008; Bretzel *et al*., 2016), and one study in California found that soil properties in community gardens varied according to the demographics of the area (Egerer *et al*., 2018). Comparative soil health indicators and nematode analysis have been used in predicting lettuce (Knight *et al*., 2013) and tomato (Reeves *et al*., 2014) productivity.

Several studies have investigated the concentrations and stocks of soil organic carbon (SOC) in urban greenspace, although research specifically about UA is limited. Edmondson *et al*. (2012) found that SOC storage in urban areas was far in excess of the UK carbon inventory estimates, higher than in arable soils, and that urban greenspace, of which UA is a component, contributed the largest proportion of SOC to the total group. This was further shown in a study of allotment soils (Edmondson *et al*., 2014a) which found 32% higher SOC concentrations in allotment soils compared to arable fields. Carbon storage helps meet global climate obligations (Davies *et al*., 2011) and there is potential to increase this through a thorough investigation into which UA crops and plants are best for the goal (Lin *et al*., 2015). Whilst some aspects of the measurement of SOC sequestration dynamics are still in development (Stockmann *et al*., 2013), there is general consensus that management practices that reduce soil disturbance and maximise vegetation cover are key in ensuring maximum SOC storage (Lorenz and Lal, 2009; Lal, 2010; Lwasa *et al*., 2015; Lorenz and Lal, 2015). Further to this, SOC levels and quality in the rhizosphere directly impact the ability of the soil to provide ecosystem services (Lal, 2010), and therefore effective delivery of UA services depends in large part on effective management and care of soil. Above-ground carbon storage is also a consideration, such as in trees (Davies *et al*., 2011; Speak *et al*., 2015).

5.4. Other potential benefits

A further service of UA is the conservation of genetic resources. Growing heritage or heirloom varieties maintains genetic diversity (Galluzzi *et al*., 2010; Speak *et al*., 2015) and seed saving and sharing are often practiced on UA sites (Eigenbrod and Gruda, 2015) – 56% of allotment gardeners in Stockholm shared seeds with neighbours (Barthel *et al*., 2010). The value of agro-biodiversity conservation is recognised throughout the developed world as demonstrated through the numerous organisations established to actively conserve agricultural genetic resources (see list in Galluzzi *et al*., 2010).

UA has also been found to have a number of regulating effects on the local environment. These include urban cooling and moderation of the urban heat island effect by trees, shrubs, and green roofs (Orberndorfer *et al*., 2007; Lovell, 2010; Lin *et al*., 2015; Mancebo, 2018); improvement of water quality and tempering of stormwater runoff (Lin *et al*., 2015; Goldstein *et al*., 2016b; Gittleman *et al*., 2016; Grard *et al*., 2017); harvesting and reuse of water reducing demands on municipal water systems (Coutts *et al*., 2013; Lorenz, 2015); air quality improvement (Lin *et al*., 2015); wind protection (Lovell, 2010); and shade provision (Lovell, 2010). Finally, UA has been studied for its potential to prevent the degradation of biodiverse systems through the expansion of agriculture, and Wilhem *et al*. (2018) estimated that expansion of UA instead of rural agriculture could spare a land area twice the size of Massachusetts (or 5,474,600 hectares).

Quantification of multiple ecosystem service provision by UA is in its infancy; to date there has been just one study attempting to do this (Clinton *et al*., 2018). This study produced a global annual estimate of 100 - 180 million tonnes of food production, 14 - 15 billion kilowatt hours of energy savings, 100000 – 170000 tonnes of nitrogen sequestration, and 45 – 57 billion cubic metres of storm water runoff avoidance from UA. Overall, the individual studies in this section support these findings, suggesting that potential benefits to human and wider planetary health from UA are extensive.

6. Challenges facing urban agricultural expansion

UA expansion, particularly in the global North, currently faces a number of challenges. This section is limited to studies in the global North as those of most cultural relevance for this thesis, involving challenges to UA expansion in, for example, the UK, Europe and the USA. Foremost amongst these is land availability, and pressure on urban land from developers. Urban sprawl impacts land used for peri-urban agriculture (Mok *et al*., 2014), and land availability in denser urban areas is similarly under pressure from development (Levidow and Psarikidou, 2012). In Leeds, UK, allotment area declined from 162 to 17 hectares between 1948 and 1963 as urbanisation increased (Crouch and Ward, 1997) and similar declines were also found throughout the rest of the UK, as well as in Europe (Spilková and Vágner, 2016).

Part of the reason that UA particularly suffers from development pressure seems to be limited consideration or understanding by town planners; numerous authors have cited the lack of institutional support (e.g. Lovell, 2010; Caputo, 2012; Clark and Nicholas, 2013; Mok *et al*., 2014; Cohen and Reynolds, 2015). However, interest in UA is increasing. City Food Strategies are becoming more commonplace, for example in London, Milan, and Toronto; and the American Planning Association recently recognised the importance of integrating UA into policy (although recognition is not the same as practice). As of 2020, the Milan Urban Food Policy Pact has 2010 signatory urban areas globally (Milan Urban Food Policy Pact, 2020), and in the UK, 52 towns and cities are members of the Sustainable Food Places network (Sustainable Food Places, 2020). Interest from architects (Nasr and Kamisar, 2012) has influenced this policy shift, including with the concept of 'Continuously Productive Urban Landscapes' (CPULs), where UA is intensively developed as a key part of urban greenspace (Bohn and Viljoen, 2011). However, Cohen (2012) points out that policy rarely becomes reality unless numerous conditions come together to create the 'right time' for change, and it is recognised that pressure on policymakers must be retained for change to occur (Derkzen and Morgan, 2012). Cuba is the historical example given by most advocates of integrating UA into planning, as it has had an Urban Agriculture Department in the Ministry of Agriculture since the 1990s (Altieri *et al*., 1999). However, there are barriers to integrating UA into policy, not least its informal nature which resists top-down organisation (de Graaf, 2012), legal questions regarding the use of vacant plots and suchlike in UA practice (Warren *et al*. 2015), and concerns about environmental hazards (Lin *et al*., 2017).

Another challenge to expansion of UA regards practicalities concerning human involvement. These take a number of forms. More apartment living means fewer private growing spaces, which presents a problem in terms of land access for food growing (CoDyre *et al*., 2015; Nordh *et al*., 2016). A lack of expertise amongst home growers prevents optimal use of space for cultivation (Lorenz, 2015; Martin *et al*., 2016) and there are financial barriers to training and education (Brown and Jameton, 2000; de Graaf, 2012). This is further accentuated by questions regarding the long term profitability of UA (Caputo, 2012; Wiltshire and Geoghegan, 2012; Wortman and

Lovell, 2013; Warren *et al*., 2015) which is related to uncertainty regarding actual longevity of many UA ventures, particularly more informal or non-profit ones (Levidow and Psarikidou, 2012). Limited participation rates also contribute to this (Derkzen and Morgan, 2012), and reliance on voluntary labour means workforce capacity fluctuates (Wiltshire and Geoghegan, 2012). However, increasing consumer interest in local food supply chains may increase commercial viability of UA (Aubry and Kebir, 2013).

Questions also remain about how UA fits into the material and energy flows of cities. There are currently limited data available to quantify resource demand implications directly associated with UA systems, and the literature is not yet sufficiently comprehensive to make conclusive claims on benefits and trade-offs (Mohareb *et al*., 2017). UA takes many different forms, and this heterogeneity results in a concurrent heterogeneity of lifecycle energy and resource demands (Goldstein *et al*., 2016a). UA has been found to offer the potential for "urban symbiosis" through rainwater harvesting and flood mitigation (Pataki *et al*., 2011; Gondhalekar and Ramsauer, 2016; Maye, 2019), diversion of waste streams to reuse in UA (Buechler *et al*., 2006; Bahers and Giacchè, 2019; Maye, 2019), and use of waste energy from heating buildings to power greenhouses (Goldstein *et al*., 2016b). However, opportunities come with constraints, and trade-offs have been found to exist, for example in wastewater treatment and reuse for UA purposes (Miller-Robbie *et al*., 2017).

The technological focus of much energy flow research (e.g. "smart cities", as discussed in Maye, 2019) means that those studies that have been conducted on life cycle approaches to urban agriculture have tended to focus on, for example, vertical farming, soil-less systems, and rooftop greenhouse growing (Sanyé-Mengual *et al*., 2015; Maye, 2019). Traditional soil-based horticulture has been neglected (with the exception of one LCA study undertaken by Kulak *et al*., 2013), despite occupying the greatest amount of land and having the longest tradition, history, and participation levels of UA (although arguably less commercial potential). There is a need for energy systems approaches to understand the whole variety of UA forms, and include economic and social dimensions previously overlooked (Petit-Boix *et al*., 2017).

The site-specificity of research into UA is noted by a number of researchers (Guitart *et al*., 2012; Mok *et al*., 2014; Goldstein *et al*., 2016a). Whilst there is research that addresses questions from a global perspective (Mok *et al*., 2014; Lorenz and Lal, 2015) or by continent – in Europe (Church *et al*., 2015), North America (Beck, 2001; Beniston and Lal, 2012; Wartman and Lovell, 2013; Goldstein *et al*., 2016b), and Africa (Crush *et al*., 2011, Lwaza *et al*. 2015) – it is more common to find research that only addresses one or two cities (Altieri *et al*., 1999; Howe and Wheeler, 1999; Barthel *et al*., 2010; Kremer and DeLiberty, 2011; Peters *et al*., 2011; Kortright and Wakefield, 2011; Moreau *et al*., 2012; Mees and Stone, 2012; Denny, 2012; De Graaf, 2012; Jansma *et al*., 2012; Levidow and Psarikidou, 2012; Taylor and Lovell, 2012; Barnidge *et al*,. 2013; Edmondson *et al*., 2014a; Speak *et al*., 2015; Borysiak *et al*., 2016; Nordh *et al*., 2016; Benis and Ferrão, 2017– for example). This makes comparative conclusions difficult to draw as research methods and sample sizes vary considerably between studies. Furthermore, UA is practiced differently depending on the country; for example, Norwegian allotments (Nordh *et al*., 2016) are often primarily ornamental and sites of family vacations, very different to British allotments (e.g. Edmondson *et al*., 2014a) which are non-residential growing spaces. Comparative studies tend to focus on a single ecosystem service (e.g. Church *et al*., 2015). Site-specificity has also been highlighted as a potential issue in drawing firm conclusions regarding the ecosystem service provision potential of UA. This has been recognised by Altieri *et al*. (1999), Pavao-Zuckerman *et al*. (2008) and Borysiak *et al*. (2016).

7. Thesis case study system

This thesis uses allotment gardens as a case study system for investigation – i.e. the focus is on non-commercial, soil-based, urban horticulture. Allotments are a common feature of urban land in many countries, primarily in Europe, where they have a history stretching back to the nineteenth century. The purpose of allotments varies between countries, with some primarily dedicated to recreation and relaxation, and others primarily for food production. In the UK, allotments are legally required to be primarily used for the purposes of food production, with the majority of local guidelines stating that 75% of an allotment plot must be cultivated for such purposes. They are typically 250 m^2 parcels of land, or ‘plots’, which are rented either from private landowners or, more commonly, from local councils. Plots are grouped together to form larger sites which vary in size, often providing communal facilities such as toilets, parking and social spaces.

The history of allotments in the UK began over two hundred years ago and has been researched in great detail by Acton (2011, 2015) and Crouch and Ward (1997). The following brief history is based on their research. By the late 1800s, there were nearly 250,000 allotments in England, in both rural and urban areas, typically rented by working- and middle-class male gardeners. In 1907, the Smallholdings and Allotments Act codified the responsibility of local authorities to provide allotments to members of the public in their areas to meet demand. Demand for allotments grew throughout the early twentieth century, including through a popular scheme to provide allotments for unemployed people, and by the outbreak of the Second World War, there were 720,000 allotments in the UK. During the Second World War, increasing unreliability of international food imports led to an explosion in allotment gardening, heavily encouraged by the Dig For Victory campaign launched by the government, encouraging people to grow their own food as rationing became increasingly stringent as the war went on. By 1942, there were almost 1.5 million allotments in the UK. Alongside home gardens, these allotments produced an estimated 18% of Britain’s fruit and vegetables (by value) during the Second World War (DEFRA, 2017). However, after rationing ended in the mid-1950s, demand for allotments decreased, pressure on urban land for development grew, and many sites were closed in the latter half of the twentieth century. By 1997, there were fewer than 300,000 allotment plots in the country. Demand has increased since the turn of the century as interest in ‘grow-your-own’ food practices escalates, along with rising popularity of organic food consumption, and growing concerns about climate change and embedded greenhouse gas emissions of commercial food. In 2020, allotment waiting lists grew up to 300% during the UK’s coronavirus lockdown (Smithers, 2020).

8. Thesis aims, objectives and outline

8.1. Objectives

The overall aim of this thesis is to gain a greater understanding of allotment gardens and their place in the urban system as a form of urban horticulture. This is done by assessing historical context, resource demands, and ecosystem service provision. The objectives of this study are:

1. To identify the historical context leading to current structure and provision of allotments.

    - Have former allotment gardens all become part of the urban built infrastructure, or do opportunities exist to utilise former allotments in future urban horticulture?

    - Has the pattern of allotment land closures varied demographically within cities?

2. To discern the resource demands of allotment gardening based on typical management practices across the year.

    - To what extent are the resources used by allotment gardeners sustainable?

    - Where do opportunities exist to integrate the resource demands of allotments within the flows of materials in the wider urban system?

    - Do certain management practices contribute to higher levels of soil quality?

3. To assess the ecosystem service provision of allotments, with a particular focus on soil, and understand the contribution of allotment soils to national carbon storage.

    - Do allotment soils maintain high levels of soil quality, and how does this compare to commercial horticultural soils?

- To what extent do allotments contribute to national soil carbon stocks?
- How do the structure and features of the non-crop production areas of allotments contribute to the delivery of ecosystem services?
- How do allotment gardeners self-report physical or mental wellbeing benefits of allotment gardening?

8.2. Thesis outline

I begin (Chapter 2) with an investigation into the historical change in land provision for urban horticulture in ten case study cities, using GIS and historical Ordnance Survey maps to quantify the loss of allotment provision throughout the twentieth century. In doing this, I uncover that much former allotment land now exists as greenspace, rather than the urban built environment, which we analyse to quantify the amount of land possibly available in cities for reconversion to allotment gardens. I also use the Indicies of Multiple Deprivation to reveal that the most deprived urban areas have been hit the hardest by allotment closures, and thus the restoration of former allotment sites could be particularly important for food insecure communities. [Objective 1]

Chapter 3 investigates the role of soils and soil management in allotment gardening. Fieldwork conducted in ten cities across the UK demonstrate that allotment soils maintain a consistently higher level of quality than surrounding arable land, demonstrating their role in contributing to carbon storage and associated ecosystem services. I investigate soil management practices, revealing that allotment gardeners consistently practice composting, manure addition, and other techniques which contribute to the maintenance of soil quality and provision of sustainable soils for food growing. This research enables me to present the first nationwide estimation of the contribution of allotment soils to British carbon storage, revealing that they contribute disproportionately relative to their land cover area. [Objectives 2 and 3]

Chapters 4 and 5 widen the investigation into sustainability of allotment practices, using data from a year-long citizen science survey investigating the activities that allotment gardeners undertake. For the first time, my data reveals how much time allotment gardeners spend outside, with associated wellbeing benefits, and how much time commitment the average gardener needs to cultivate a plot for a year. I also reveal the required water, compost, and other additions that a plot requires throughout a year and demonstrate the extent to which these resources are recycled (e.g. rainwater harvesting; food waste composting), and where possibilities exist for expanding the sustainability of resource use on allotments. Qualitative information from this project also demonstrates that allotments give people wide-ranging personal wellbeing benefits, from mental health improvements due to spending time outside and connecting with wildlife, to the social capital of allotments and networks of community support and food sharing that informally exist in these sites. [Objectives 2 and 3]

Chapter 6 uses field-based mapping of allotment plots to demonstrate the non-food related ecosystem service provision that allotment gardeners partake in, assessing the structure of plots to estimate the contribution of allotment gardens to environmentally beneficial land cover types such as ponds and spontaneous flora. I show that despite high levels of variation between plots, allotment gardeners are not only using their land for growing food for personal provision, but also create valuable areas for wildlife that across an entire country represent a substantial contribution to the urban green infrastructure network, maintaining and conserving biodiversity in urban areas. [Objective 3]

Chapter 2

Urban food cultivation in the United Kingdom: Quantifying loss of allotment land and identifying potential for restoration

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Abstract

Urban horticulture contributes to food security and human wellbeing and is associated with a wide range of environmental benefits. In the United Kingdom, a substantial proportion of urban horticulture occurs in allotment gardens, and these are a historically significant part of the landscape. However, allotment land provision has declined significantly since its mid-twentieth century peak. Here, we examine the magnitude and nature of this decline using a GIS analysis of historical Ordnance Survey maps covering ten British urban areas from the beginning of the twentieth century to the present. We find there has been a 65% decline in allotment land from its peak to 2016, a pattern also reflected in per capita provision, which declined by 62%, demonstrating a long-term trend across the case study areas, and the loss of food provisioning land for an average of 6% of the urban population. We also show that the most at-risk areas for food insecurity have faced eight times the level of allotment closures than the least deprived areas. Assessing subsequent land-use of former allotments, we show that 47% of allotment land is now part of the urban built infrastructure, and 25% is other forms of urban greenspace. Restoration of these greenspace sites to allotments has the potential to meet up to 100% of the current levels of demand for new allotments by residents of our case study areas. Our results demonstrate that whilst a significant amount of urban horticultural land has been lost, opportunities for restoration exist on a substantial scale.

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1. Introduction

The global urban population has increased significantly in past decades and forecasts predict this trend will continue. According to the United Nations, by 2050 68% of the global population will be urban residents, a figure rising to 90% in the United Kingdom (United Nations, 2019). Impacts of urbanisation on food systems, and food security, can occur at local, national and international levels. Urban areas, which are forecast to increase in global land cover by 1.2 million km^2 by 2030 compared to the turn of the century (Seto *et al*., 2012), often expand into agricultural land (Martin *et al*., 2016), itself a limited resource facing increasing problems of soil degradation (Graves *et al.*, 2015; Lal, 2015). The density of urban populations also means that the agricultural land requirements of cities are vastly greater than their areal extent (Eigenbrod and Gruda, 2015). This creates an inherent reliance on food imports for urban populations, with associated risks for food security. This is a growing issue of concern in the global North where, for example, undernourishment affects 2.5% of the British population, and 11.1% of American households experienced food insecurity (an inability to access sufficient, safe and nutritious food; taking the internationally accepted definition of food security from the Food and Agriculture Organisation, 2006) at some point during 2018 (Food and Agriculture Organisation, 2017; Coleman-Jensen *et al*., 2019).

Against this background, researchers and policymakers have shown a renewed interest in the potential contribution to food supply which can be made by food grown in urban areas, or urban agriculture (Grewal and Grewal, 2012; Taylor and Lovell, 2014; Horst *et al*., 2017; Edmondson *et al*., 2019).. It is estimated that 25-30% of urban residents participate in urban agriculture to some degree (Orisini *et al*., 2013), although this varies in form and prevalence across the world. Urban agriculture is practiced not only for food security, but also for leisure, wellbeing and mental health (Blair *et al*., 1991; Andersson *et al*., 2007). A growing body of research supports this, demonstrating that urban agriculture can provide multiple benefits which go beyond food provision. These include providing cultural ecosystem services (Webber *et al*., 2015; Robert and Yengué, 2017; Langemeyer *et al*., 2018) and benefits to human health through supporting exercise and healthy diets (Altieri *et al*., 1999; Leake *et al*., 2009; Zezza and Tasciotti, 2010; McClintock *et al*., 2013). Further to this, urban agriculture can also help to enhance biodiversity (Lin *et al*., 2015; Speak *et al*., 2015; Aerts *et al*., 2016; Borysiak *et al*., 2017); increase food system resilience to international economic or climatic shocks (Goldstein *et al*., 2016b; Seguí *et al*., 2017); reduce food miles and waste (Howe and Wheeler, 1999; Lovell, 2010); support plant genetic diversity (Barthel *et al*., 2010; Eigenbrod and Gruda, 2015); mitigate urban heat island effects (Orbendorfer *et al*., 2007; Lovell, 2010; Lin *et al*., 2015); regulate stormwater runoff (Coutts *et al*., 2012; Lin *et al*., 2015; Goldstein *et al*., 2016b); and maintain soil carbon stocks and other aspects of soil quality (Edmondson *et al*., 2014a; Lorenz 2015). In the global South, urban agriculture traditionally contributes primarily to food security and poverty alleviation (Zezza and Tasciotti, 2010). In the global North, whilst motivations for participation are more likely to be recreational (Mok *et al*., 2014), urban agricultural participation and access to food growing space has been shown to have important potential for the alleviation not only of food insecurity in low income communities but empowerment, education and improvement in quality of life (Travaline and Hunold, 2010; Milbourne, 2012; Carney *et al*., 2012; Poulsen *et al*., 2014, & Horst *et al*., 2017).

In the global North, urban food production is practiced in a variety of forms, predominantly focusing on fruit and vegetable production, or urban horticulture (Orsini *et al*., 2013). For example: allotments (see below; Crouch and Ward, 1997; Acton, 2011; Edmondson *et al*., 2014a); private domestic gardens (Foster *et al*., 2017); community gardens (Kulak *et al*., 2013; Martin *et al*., 2016); and commercial market gardens (Kulak *et al*., 2013; Schmutz *et al*., 2018).

Allotment sites are 'small parcels of rented land, in rural and urban locations, used for growing fruits and vegetables for personal consumption' (Acton, 2015). Allotments form a large proportion of the area of urban horticultural land across Europe (Speak *et al.*, 2015) and their use varies, but in the United Kingdom they are almost wholly dedicated to food production, with plot tenancy dependent on maintaining a minimum cultivation level, typically between two-thirds and three-quarters of the area of the plot. Typically, an individual allotment garden is a plot of land around 250 m^2 rented from a local council in a larger allotment site comprising anything from fewer than ten to over two hundred individual plots. There are around 333,000 allotment plots in the United Kingdom (Campbell and Campbell, 2013) covering 135 km^2 of land. As demand for allotments fluctuated throughout the twentieth century, many sites were closed, particularly in the decades following the Second World War, and, nationally, levels of provision fell from an estimated 1,400,000 plots during the war to 300,000 in 2009 (Crouch and Ward, 1997; Acton, 2015). However, whilst general estimates can be made of the overall national trend across this period, the available data are limited, both temporally and spatially, and as a result we have little understanding of precisely when and where these closures occurred, or the subsequent fate of the land.

There have been multiple drivers for allotment closures over the twentieth century, including post-war prosperity and the rise of convenience food leading to a decrease in demand for food growing areas; and pressures from urban development taking precedence over allotments in land use allocation (Acton, 2011). Whilst some closures have been generally accepted by tenants and local residents, others have been contested. Recent examples in Bristol (Morris, 2015) and Watford (Siddique and Topping, 2016) demonstrate a tension that exists between the legal obligation of councils to provide allotments sufficient to meet demand and planners' needs to prioritise or consider other forms of urban infrastructure. Over the past twenty years, a cultural revival in interest in "grow your own" food practices, has led to an increase in demand for allotments. For example, in England demand rose from fewer than ten people waiting per one hundred plots in 1996, to more than fifty per one hundred plots in 2013 (Campbell and Campbell, 2013), and increased up to 300% during the 2020 coronavirus lockdown (Smithers, 2020).

The consequences of loss of allotments for the full range of ecosystem service provision depends not just on the extent of allotment loss, but also on what happens to the land afterwards. This may also be an important determinant of the scope to reinstate allotment provision, in response to new demand, in the future, as well as contributing to addressing food insecurity in cities through the provision of growing space. Understanding the extent of allotment closures over the course of the twentieth century, and the subsequent fate of allotment sites, would help us understand both historical changes in urban food production and other ecosystem services, and help to inform future decisions about allotment provision where demand necessitates their expansion. Here, we use historical maps to quantify the change in allotment provision, in relation to population, for ten cities across the United Kingdom over periods of between 50 and 100 years. We analyse change in allotment provision over time, identify what former allotment sites have now become, identify the potential for former sites to be re-converted to allotment usage to help meet waiting list demand, and examine the potential impact of closures on food security, discussing how this has affected the food provision capacity of the most food insecure urban areas.

2. Methods

2.1. Case study areas

We selected ten case study urban areas, geographically distributed across mainland Great Britain: Bristol, Glasgow, Leicester, Liverpool, Milton Keynes, Newcastle, Nottingham, Sheffield, Southampton and Swansea. These cover a range of population sizes and densities, demographics, and land-use histories (Figure 1; Table 1). With one exception all are major British cities, which have been substantial urban settlements with significant industrial or maritime activity for at least the last 150-200 years. Milton Keynes is the exception, being a new town created in a previously non-urban location in 1967. We analysed all case study areas according to their 2016 administrative boundaries to ensure a consistent geographical area of investigation across the time period studied. Population data were taken from the 2011 census, the closest census year to that for which the boundary data could be obtained.

Table 1. Case study areas listed in declining order of population size according to 2011 United Kingdom census data, as well as administrative area in hectares (Office for National Statistics; National Records of Scotland, 2016), and availability of Ordnance Survey historical maps.

Case study area	**2011 UK census population**	**Administrative area (hectares)**	**Decades for which mapping was available**
Glasgow	593,245	20,956	1940, 1950, 1960, 1970, 1980, 2016
Sheffield	552,698	36,793	1910, 1930, 1940, 1950, 1980, 2016
Liverpool	466,415	13,353	1930, 1950, 1960, 1970, 2016
Bristol	428,234	11,223	1920, 1940, 1950, 1970, 1980, 2016
Leicester	329,839	7,331	1910, 1940, 1950, 1960, 1970, 1980, 2016
Nottingham	305,680	7,461	1910, 1940, 1950, 1960, 1970, 2016
Newcastle	280,177	11,510	1920, 1940, 1950, 1960, 1970, 1980, 2016
Milton Keynes	248,821	30,863	1950, 1980, 2016
Swansea	239,023	42,120	1960, 1970, 1980, 2016
Southampton	236,882	5,639	1930, 1960, 1970, 1990, 2016

Figure 1. Locations of case study areas within the United Kingdom. From North to South: Glasgow, Newcastle, Liverpool, Sheffield, Leicester, Nottingham, Milton Keynes, Swansea, Bristol and Southampton.

2.2. Historical and present-day mapping of allotment provision

The Ordnance Survey (OS) is the United Kingdom's national mapping agency, and has been surveying and producing printed maps of the entire country, at a range of scales, since 1791, with complete coverage first completed in 1870 (Owen *et al.*, 1992). For urban areas OS mapping is available at larger scales, with delineation of buildings, and distinctions made among a range of land covers. For each urban area, we obtained digital scans of historical Ordnance Survey maps from EDINA Digimap (https://digimap.edina.ac.uk) in the form of georeferenced raster "tiles" (see Supplementary Material for a full reference list of maps used in this paper). For the identification of allotments, a scale of 1:10,000 or 1:10,560 such as the National Grid or County Series mapping produced by OS is fine scale enough for areas of allotment land to be delineated on the map tiles. The time periods for which maps were available at this resolution varied between case study areas, but for all areas we were able to generate data for at least three, and up to seven, different time points, hereafter referred to by the decade during which the maps used were published for all historical maps, and by 2016 for the present-day map (Table 1). The present-day map used was the OS “VectorMap” layer of October 2016.

Allotment areas were digitised as polygons for each land parcel labelled as “Allotment Gardens” or “Allot. Gdns” on the original maps. Despite stylistic changes in mapping over the twentieth century, labelling of allotments remained consistent enabling unambiguous identification of allotments for all decades studied. Where uncertainty arose, the previous decade’s and next decade’s maps were checked to ensure consistency throughout a time period, ensuring no allotments “disappeared” for a decade only to reappear ten years later; if this was the case, continuous existence of the site was assumed. For 2016, the OS mapping was validated by cross-checking the GIS polygon data with aerial images and information provided online by local councils. To account for population variation, both over time and between cities, the absolute change in total allotment area over time was converted to change in per capita provision over time using census data for the nearest decade to when mapping occurred (the British population census occurs decennially).

The typical allotment was originally designed as such to be large enough to feed a family of four on fruit and vegetables for a year (National Society of Allotment and Leisure Gardeners Ltd., 2012). Recent research in Leicester, one of our case study cities, found that the actual current productive capacity of an allotment is around 1.8 kg m^{-2} $year^{-2}$, or a “five-a-day” provision of fruit and vegetables for about four people (Edmondson *et al.*, 2020b). We used these figures, along with the typical allotment plot size of 250 m^2 with 18% of total site area used for infrastructure rather than food production (Edmondson *et al.*, 2020b), to calculate how the productive capacity of allotments have changed, and the change in the number of people that could be fed with current provision levels compared to those of the decade of peak provision.

2.3. Land use change and waiting list demand

For a subset of five case study cities (Bristol, Glasgow, Leicester, Newcastle and Southampton; which maintained our geographic range throughout the country), the digitised layer of polygons for all allotment sites that had been closed at some point throughout the twentieth century was overlaid on the Ordnance Survey VectorMap (2016) backdrop mapping. Sites were then characterised according to their 2016 land use as greenspace or built environment, and greenspace areas were further categorised to type (park, nature reserve, cemetery, scrub, etc.) using Google Earth to ensure accuracy of this fine detail categorisation. Where a former allotment site had multiple 2016 uses, polygons were split to reflect this.

In order to calculate the potential of former allotment land to meet current waiting list demand, waiting list data was obtained from Campbell and Campbell (2011) for four of the five case study areas: Bristol, Leicester, Newcastle, and Southampton (with waiting list data for Glasgow unavailable). We followed an approach developed by Grafius *et al*. (2019), originally for the identification of potential biofuel production sites, which has been adapted by Edmondson *et al*. (2020a) for use in urban horticulture. This applies a spatial restriction criteria to land parcels to identify their suitability for a purpose and excludes, for example, sites of Special Scientific Interest, nature reserves, buildings, ancient woodlands, sites inaccessible by vehicle, and playing fields or sports grounds (see Supplementary Material). We then applied a further allotment-specific spatial restriction: the site had to be large enough to have four full-size allotments plus infrastructure. Anything below this was deemed too small to be considered a viable site. The potential number of plots was then expressed as a percentage of the total numbers on the waiting list to analyse the extent to which demand could be met by the reconversion of former allotment land which met the criteria above. We used the above data on allotment productivity to calculate the number of people that could be fed through land reconversion.

2.4. Socio-demographic correlates of allotment site closures

The English and Scottish Indices of Multiple Deprivation (IMD) measure relative deprivation for small areas of the United Kingdom, known as Lower Level Super Output Areas (LLSOA), with a mean population of 1500 people per area. We used this data to determine the current deprivation levels of areas in which allotment sites had been closed for our subset of five case study cities to quantify how much allotment land had been closed in each current IMD decile, on a scale of 1 being the most deprived areas to 10 being the least deprived. Whilst deprivation patterns in the UK have not necessarily stayed completely static over time, given recent sharp increases in inequality, and de-industrialisation in the 1970s and 1980s, we made the assumption that, in the majority of cases, a previous allotment closure in a current deprivation category would also have been in a similarly deprived area at the time it took place. This may have led to incorrect IMD categories for the area of allotment closure at the particular time that the allotment closed; however, current access to allotment land is of more importance in this paper, so the present-day IMD was more explanatory for our findings and the present-day consequences of allotment closures than the historic IMD category.

Where a land parcel overlapped a LLSOA border, we used the IMD decile in which most of the land parcel lay. Smith *et al*. (2018) found a strong positive correlation (Spearman rank correlation 0.929, p<0.01) between IMD level and risk of food insecurity (defined by Smith *et al.* as the inability to acquire or consume an adequate quality or sufficient quantity of food) based on the identification of at-risk household types from the Department for Environment, Food and Rural Affairs. In England; this was the first estimate of food security risk, as data regarding household food insecurity is not routinely collected in the UK. Whilst this single study would become more robust with further research into the explicit links between urban horticulture and food insecurity, as an initial investigation this suggests that the IMD can provide a good index of potential food insecurity, allowing us to test whether changes in access to food growing space as a result of allotment land closures impacts disproportionately on the most food insecure communities in our case study cities. We combined this data with the spatial restriction criteria outlined above to show which IMD categories would benefit most from a conversion of former allotment land back to allotments.

3. Results

3.1. Change in allotment provision over time

The spatial distribution, area, and changes through time in allotment provision are illustrated for a single urban area, Leicester, in Figure 2. Patterns for other locations are broadly similar. Absolute allotment land provision varied between our case study sites, as would be expected from the variation in size of the urban areas themselves, but there are also marked differences in per capita provision suggesting that variation does not simply reflect population size (Figure 3). The main trend through time is a major decline since peak allotment provision in the 1950s (Figures 2 and 3; see also Supplementary Material Figures 1-9). This trend was found in all areas studied: whilst the decade of absolute peak provision and peak provision per capita varied somewhat, each case study area had reached its peak provision on both counts by 1960. For every city both absolute and per capita provision in 2016 was lower than that for the preceding date with available data. This is also reflected in the net change on a decade-to-decade basis (see Supplementary Material Figure 10), which demonstrates the greatest loss of allotment land between the 1950s and 1970s, followed by a more gradual decline to 2016.

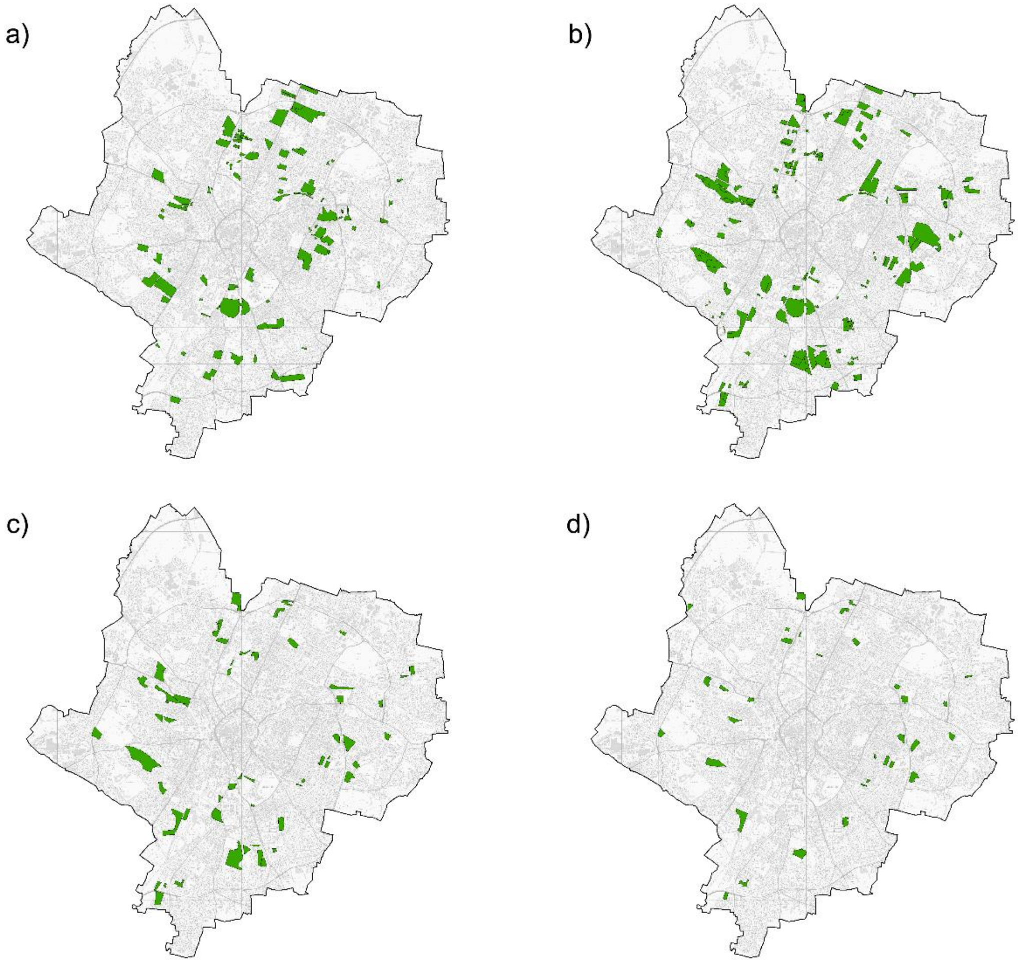

Figure 2. Change in allotment land provision in Leicester, United Kingdom, over the twentieth century: a) 1910, b) 1950, c) 1970, d) 2016.

From the early twentieth century to 2016, the mean decline in allotment land area experienced from peak provision to 2016 was 65% of total area (s.e. = 4%) and the mean decline experienced in provision per capita was 62% of total area (s.e. = 7%). This demonstrates a comparable percentage decline between locations despite variation in absolute levels of decline expressed in terms of hectares lost. For every city except Newcastle and Sheffield, allotment provision per capita in 2016 is less than it was in the first decade for which historical maps were available (Newcastle had particularly low provision prior to the 1950s, where in one decade provision increased from 0.6 m^2 per capita to 4.5 m^2 per capita, and Sheffield had low levels of provision at 1.3 m^2 per capita in the 1910s which had dramatically increased to 7.9 m^2 per capita in the 1930s). In the case of Milton Keynes, the high levels of provision per capita in the 1950s is due to low population prior to the creation of the town, and the existence of large rural allotment sites which subsequently became urban sites within Milton Keynes when the population density rose dramatically following the town's creation (Figure 3).

Changes from the decade of peak provision to current levels have impacted on the number of people citywide able to be fed from a city's allotment land. Using population levels from the most recent UK census (2011, see Table 1), loss of food provision ranged from provision for 0.7% of the population of Swansea to 13.8% of the population of Leicester, with the mean loss at 4.7% (s.e.= 1.1). Regarding total loss of yields, this ranged from 241 tonnes of food production per year in Swansea (1.28 kg per person on 2011 population levels) to 6,700 tonnes per year in Leicester (25.9 kg per person), with a mean of 2,500 tonnes (s.e. = 628).

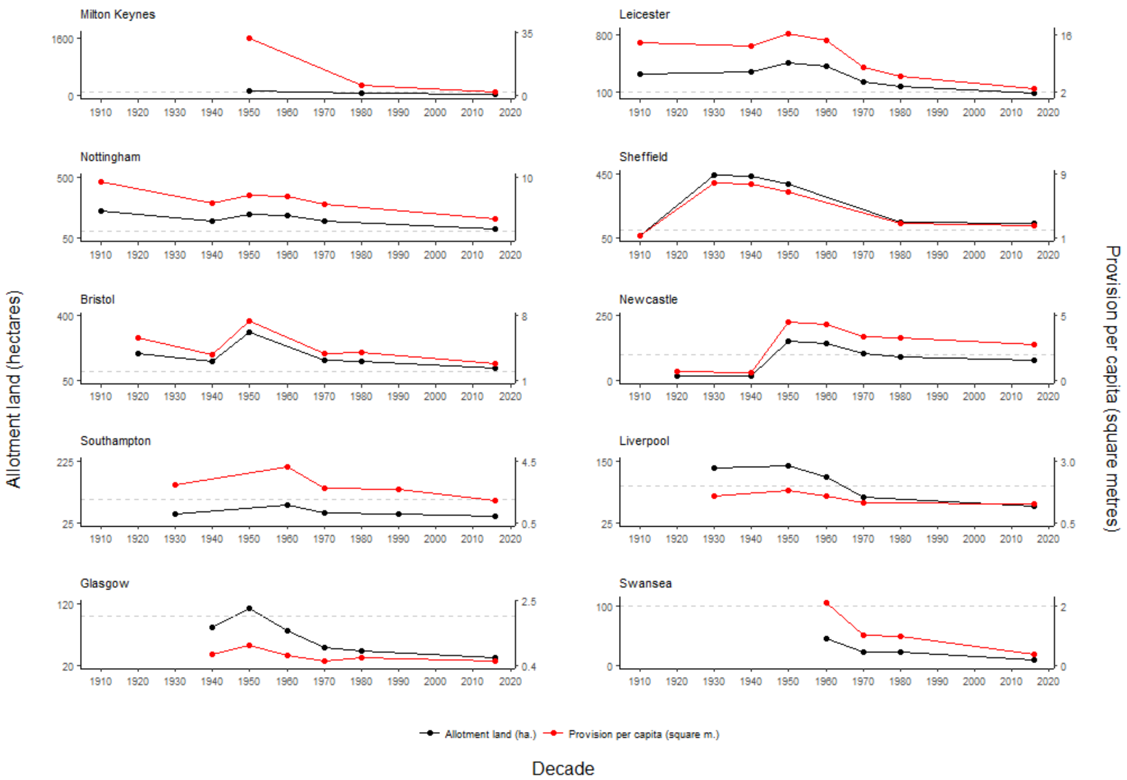

Figure 3. Plots showing the trend in allotment land provision for ten urban areas in the United Kingdom, both in absolute provision per hectares, and in per capita provision accounting for population change over the twentieth century and to 2016. Urban areas are arranged in declining order of peak total provision. Provision in hectares is shown in black, and provision per capita in red. The grey, dashed line indicates 100 hectares and 2 m^2 per capita to allow comparison between plots, as the scale of allotment provision varies between urban areas.

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3.2. Land use change

For our subset of five case study cities, by 2016 of all areas that were recorded as allotments in the historical data, just 26.7% (s.e. = 12.6%) was still allotment land, while 47.9% (s.e. = 14.2%) had become built infrastructure and 25.3% (s.e. = 6.7%) was other types of greenspace (Figures 4 and 5). Of the former allotment land that remained as greenspace, 75.7% (s.e. = 18%) was suitable for reconversion to agricultural cultivation based on our spatial restriction criteria, with a range from 57.2% in Bristol to 100% in Southampton (Figure 6). This gave, over the five cities, 365 hectares remaining as allotment land, 914 hectares converted to built infrastructure, and 458 hectares of greenspace of which 307 hectares were suitable for reconversion.

This represents a substantial increase in the potential number of city residents able to be fed by a reconversion of former allotment land to agriculture. With every plot providing for four people, as detailed above, an extra 14,107 people (3.27% of the 2011 population) per year could be fed in Bristol; 4,521 (0.76%) in Glasgow; 14,462 (4.38%) in Leicester; 4,260 (1.52%) in Newcastle; and 3,037 (1.28%) in Southampton.

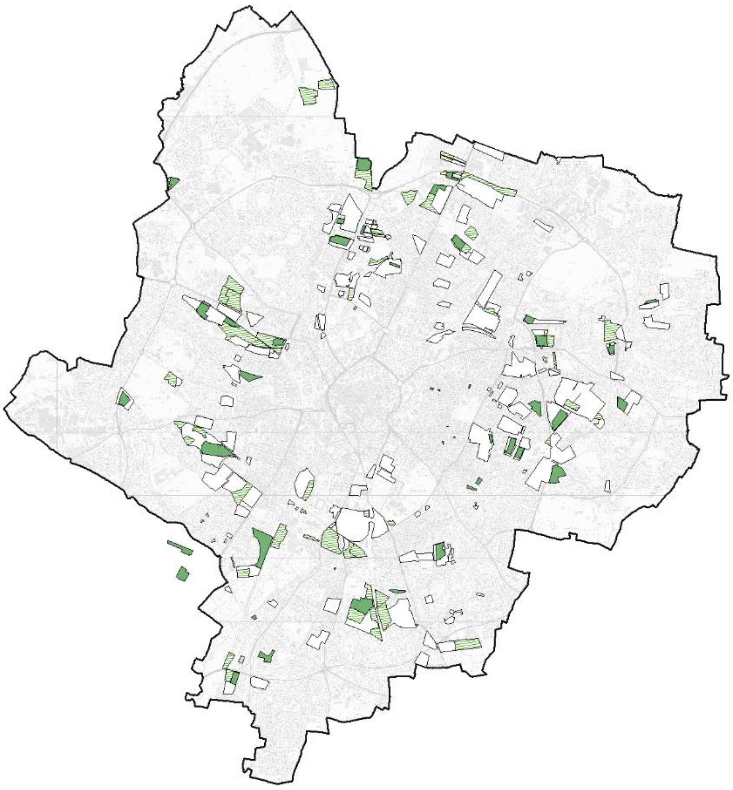

Figure 4. Current (2016) land uses of sites in Leicester which were allotments during the twentieth century. Solid fill indicates allotments, hollow is built infrastructure, and hatched is greenspace.

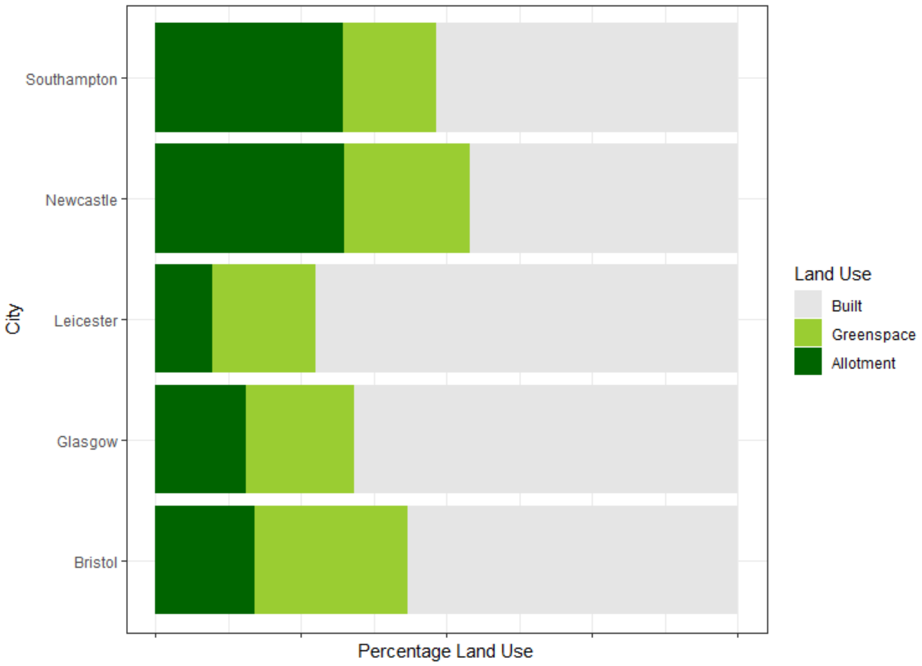

Figure 5. Proportional land-use change of different types in twentieth-century allotment sites for five urban areas in the United Kingdom. Dark green indicates sites still in use as allotments in 2016; light green indicates sites converted to other forms of greenspace; and grey indicates sites converted to the built urban environment.

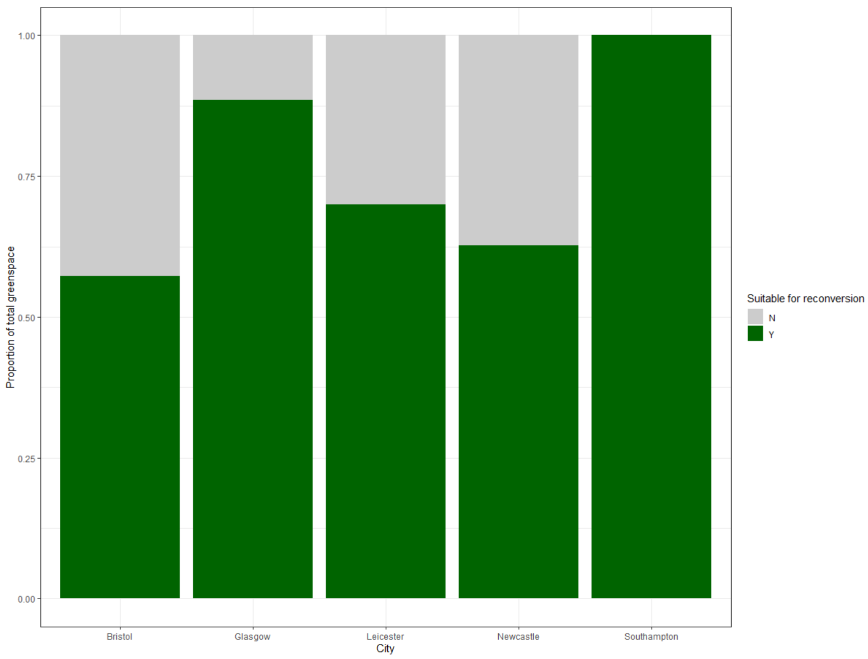

Figure 6. The proportion of former allotment greenspace with potential suitability for reconversion to use as food production for five urban areas in the United Kingdom based on spatial restriction criteria. Green indicates suitability; grey is unsuitable land.

3.3. Waiting list demand

For the cities for which waiting list data was available (Southampton, Newcastle, Leicester and Sheffield), all except Southampton would, in principle, be able to fully meet current demand by restoring suitable greenspace sites which were formerly allotments to their prior use. Of these cities, Newcastle would need to convert 75.1% of this land, Bristol would need 41.8%, and Leicester would need 6.6%. In Southampton, a full restoration of all suitable former allotment sites would meet 55.4% of waiting list demand.

3.4. Socio-demographic trends

Across the five cities, the more deprived IMD deciles experienced greater absolute allotment land loss than the least deprived deciles (Figure 7; Table 2). This suggests that the most food insecure areas are also those that have, historically, lost the greatest amount of allotment land. For all five cities, despite variation in the absolute levels of loss within each decile within the cities, deciles 1-4 (the most deprived) faced substantially greater levels of allotment loss than the more affluent areas. Many of the more deprived areas in cities contain land changed from use as allotments to commercial and industrial buildings; in more affluent areas, which tended to be primarily residential, such land use change was rare.

When applying the spatial restriction criteria to discover where former allotment greenspace has the potential for reconversion to use as allotments, almost half of suitable land occurs in IMD deciles 1 and 2, the most deprived areas (Figure 8). This suggests that the most food insecure communities stand to gain the greatest benefit from a restoration of former allotment land in terms of providing access to food growing space where it has historically been lost. Using the above measures of potential people fed from restoration of land, over four times as many people in IMD decile 5 and below would be fed on a five a day diet as in the upper deciles with a full restoration of potentially suitable former allotment land.

Table 2. Occurrences of allotment closures throughout the twentieth century to 2016 for five British cities, arranged by Index of Multiple Deprivation decile, where 1 is most deprived and 10 is least deprived.

IMD Decile	**Area closed (hectares)**	**Percent of total closed area in this IMD**	**Percent of total former and current allotment land in this IMD**
1	253.28	18.45	21.33
2	239.02	17.41	18.45
3	214.25	15.61	10.87
4	236.08	17.20	15.39
5	165.26	12.04	16.08
6	50.41	3.67	3.60
7	100.96	7.36	3.96
8	53.77	3.92	2.66
9	29.26	2.13	2.19
10	30.26	2.20	3.55

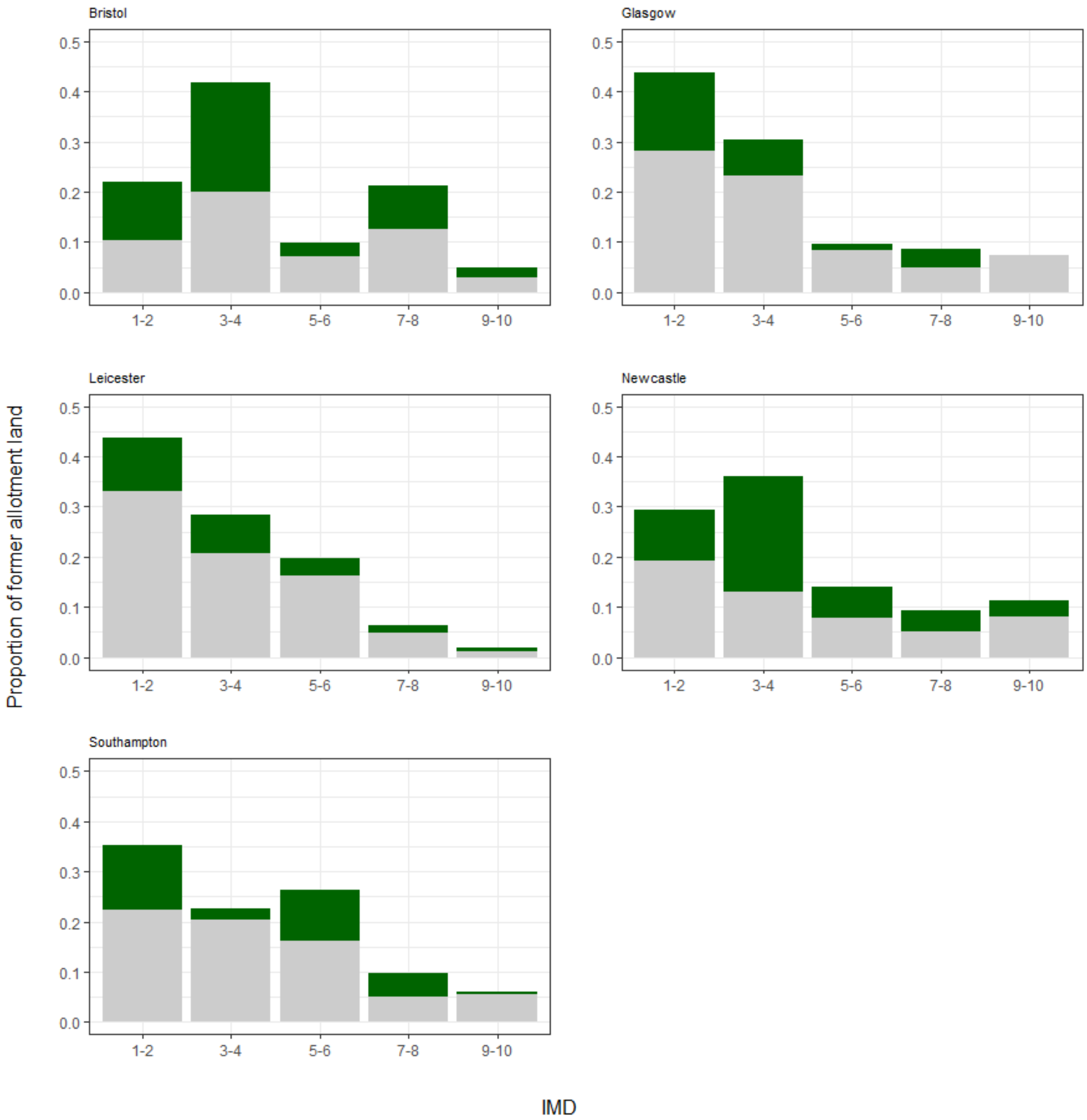

Figure 7. Allotment closures throughout the twentieth century to 2016 in different Index of Multiple Deprivation deciles for five urban areas in the United Kingdom. Grey indicates sites closed that are now part of the built environment; green indicates sites closed that remain as greenspace.

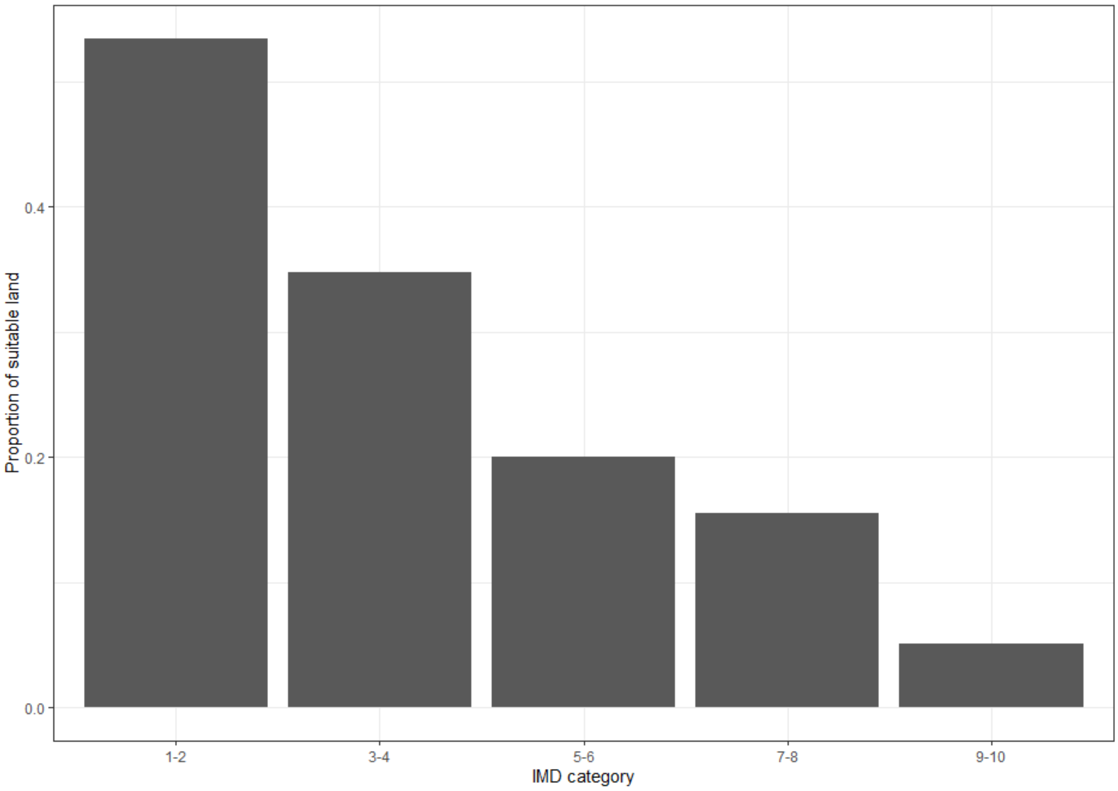

Figure 8. Proportion of land suitable for reconversion to allotment gardening purposes, categorised by Index of Multiple Deprivation, for five urban areas in the United Kingdom.

4. Discussion

Our results demonstrate a large loss of allotment provision in the United Kingdom from its mid-twentieth century levels of peak provision: a decline by almost two-thirds in both absolute land area and land area per capita. The fact that there has been a decline in the amount of allotment land available to be cultivated on a nationwide scale has previously been reported in aggregate by major works on the subject's history (Crouch and Ward, 1997; Acton, 2015). Our city by city analysis demonstrates how this overall change is realised on the ground. Despite the variation in absolute provision of allotments, we see similar trends, country-wide, of mid-century increase to peak provision in the immediate post-Second World War period, following rationing and the Dig For Victory campaign, to a decline throughout the second half of the century resulting in the lowest recorded levels of provision occurring in 2016. This supports the nationwide general historical trend identified by Crouch and Ward (1997) and Acton (2011). In terms of the number of people that own-growing on allotments could provide fruit and vegetables for, our analysis shows that there has been a substantial loss in the capacity of urban allotments to feed a city's population on their "five a day" fruit and vegetable diet, and a substantial overall loss in yield in absolute and per capita kilograms of fruit and vegetables produced each year. A continuation of this downward trend is increasingly at odds with the public desire for access to allotments, as evidenced by waiting lists. From 2004, waiting list numbers began to rise across the UK following a resurgence in interest in allotment gardening, and national demand continues to be high (Acton, 2011; Campbell and Campbell, 2013); however, we have demonstrated that reconversion of suitable former allotment land to urban horticulture would be sufficient to meet waiting list demand in four of our five case study sites.

Our results also demonstrate that areas that are in the lowest (most deprived) deciles for deprivation, and as a result are at the greatest risk of food insecurity (Smith *et al*. 2018), have faced the highest levels of allotment closure throughout the twentieth century to 2016. However, further research is needed into food insecurity, urban horticultural land access, and the relationship between IMD and food insecurity risk, beyond this initial study. Whilst reasons for site closures vary, the cumulative effect is that access to food growing space is more limited in areas where the need is potentially greatest. Food security has not been found to be a primary concern of allotment gardeners, who tend to discuss own-growing in terms of the social and cultural ecosystem services it provides (Acton, 2011); however the potential contribution to food security own-growing can and does make is well-documented, if not conclusively quantified, by a growing body of literature (Orsini *et al*., 2013; Mok *et al.*, 2014; Badami and Ramankutty, 2015; Eigenbrod and Gruda, 2015; Opitz *et al*., 2016). An increase in access to food growing space in more deprived areas could play a significant role in reducing food insecurity in vulnerable communities, and concurrently contributing associated wellbeing and health benefits.

Whilst the primary pressure on urban land comes from the development of the built environment, our results suggest that a substantial area of land formerly used as allotment gardens has not been developed for this purpose but now comprises other forms of urban greenspace, from unused or vacant land through to school playing fields and nature reserves. Whilst we have demonstrated that the amount of former allotment greenspace is, in the majority of cases, sufficient, or nearly so, to meet current waiting list demand, the heterogeneity of types of greenspace land cover on former allotment sites provides a significant caveat. It is clearly not the case that all former allotment land could, or should, be converted back to its use for food growing. In many cases the current land use is also of high value in either a social or environmental capacity, and waiting list demand may be spatially variant within cities such that past allotment locations are no longer the best places for future provision. What the results do demonstrate is that not all former allotment land has been converted to land uses now unsuitable for urban horticulture. Our method, using the spatial restriction criteria developed by Grafius *et al*. (2019), along with further restrictions to identify viable allotment sites, easily identifies cases where land could be at least considered for such a purpose, with the added benefit that former use as allotments suggests potential suitability (e.g. soil quality) for the same purpose. As allotment waiting list numbers continue to rise, and urban food security maintains its status as a pressing issue, the identification of land parcels suitable for urban horticulture, in any of its forms, is of great importance. Higher spatial resolution data on waiting list numbers and trends in site closures within a city would enable investigation into the optimum locations for the creation of new sites to meet waiting list demands.

The method we have used here provides a simple technique for the identification of land parcels formerly in use as urban horticulture and suitable for reconversion to such a purpose. Whilst there are some limitations with the use of LLSOA areas (primarily, people travelling across LLSOA boundaries to access an allotment site in a different IMD decile), the trends we found were consistent across the UK, suggesting the robustness of the approach. The specific issue of allotments and their closures may be unique to the United Kingdom, but urban land across the world faces the challenges of being a limited resource, subject to demands for housing, transport, and other infrastructure, with which the use of urban land for food production and delivery of associated ecosystem services must compete. The extent to which waiting list demand could be met – in four fifths of cases, completely – by reconverting former land proves the surprising extent to which this land exists, and such a result seems likely to hold for other similar urban areas in the global North. In the future, issues of access to land for food production, as well as those of food justice and inequalities of resources (financial and time-related) to engage in food growing must also be considered by any project, in the public sector or in civil society, looking to expand the availability of urban horticultural land (Siegner *et al*., 2018).

5. Conclusions

Current research into urban horticulture focuses on the current ability and capacity of urban horticultural land to provide urban ecosystem services and food for urban residents. However setting current provision into its historical context, as we have done here, is a key part of building the bigger picture of urban horticulture, demonstrating the scale of past food growing space in cities and the long-term trends in such space, and illustrating the consequences of site closures in the face of competing demands on urban land and food security issues faced by deprived communities. This investigation is an important first step in the identification of areas where food growing projects, and not just allotments, have the potential to be successful based on historical land use, and present-day need for access to food growing spaces for deprived communities. With the increasing urbanisation of populations, feeding urban communities equitably and sustainably is a pressing question. Our findings strengthen the case for retaining those sites that remain today, and increasing the distribution of urban horticultural land across all deciles of urban deprivation or affluence to ensure access to food growing spaces, and their associated environmental and health benefits, for all.

Chapter 3

A nationwide assessment of urban horticultural soil quality and its contribution to carbon storage

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Abstract

1. As participation in urban horticulture grows, understanding the quality of urban horticultural soils is of increasing importance. Until now, case studies of individual cities or gardens have limited the potential of such studies to draw generalised conclusions.

2. In this paper, we present the first national scale assessment of soil quality in allotments, a dominant form of urban horticulture in the United Kingdom. We sampled soils in 200 allotments in 10 urban areas across Great Britain. We assessed a range of soil quality indicators (carbon and nitrogen concentration, C:N ratio, bulk density, carbon density, pH) comparing them to the quality of soils in rural arable and horticultural land.

3. We found that allotment gardeners consistently employ management practices conducive to high soil quality such as composting. Allotment soil quality differed significantly between soil types sampled but in general soils were of a high quality as indicated by low bulk density (0.92 g cm^{-3} – national median) and high soil organic carbon concentration and density (58.2 mg g^{-1} and 58.1 mg cm^{-3} respectively - national median).

4. *Synthesis and applications:* This national-scale study provides compelling evidence that small-scale urban horticultural production, unlike conventional arable and horticulture, does not degrade soil quality. Urban horticultural land is a vital part of the urban landscape with effectively functioning soils that should be protected. As the public demand for urban horticultural land rises and policy-makers from local to trans-national levels of governance advocate for urban food production for sustainability and for improved health and wellbeing, our findings demonstrate that land assigned to urban horticulture can protect or enhance the valuable ecosystem services provided by soils in cities and towns where the majority of the global population live.

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1. Introduction

A growing global urban population has brought with it increasing concern about issues of urban sustainability and food security. Recent research attention has turned to possibilities presented by urban horticulture (UH) to contribute to meeting the nutritional demands of urban residents, predicted to comprise over two-thirds of the global population by 2050 (United Nations, 2019). Urban horticulture is increasingly viewed by international organisations as a facet of ensuring future food security (Mbow *et al*., 2018), and studies have demonstrated that it has the potential to provide at least 15%, and up to 122%, of a city's residents with fruit and vegetables if all available land was cultivated (Edmondson *et al*., 2020a; Mcdougall, Rader, & Kristiansen, 2020), or thirty days of provision for a city's residents at current levels of cultivation (Grafius *et al*., 2020).

In addition to providing fruit and vegetables to urban residents, UH is important for ecosystem service provision (Speak, Mizgajski, & Borysiak, 2015; Church, Mitchell, Ravenscroft & Stapleton, 2015; Goldstein, Hauschild, Fernández & Birkved, 2016a; Benis & Ferao, 2017), including services supported by UH soils (Beniston & Lal, 2012; Rawlins, Harris, Price & Bartlett, 2013; Edmondson, Davies, Gaston & Leake, 2014a; Lorenz, 2015; Gregory, Leslie, & Drinkwater, 2016; Tresch *et al*., 2018). Soils are the foundation for many ecosystem services, but globally face challenges from degradation, land-use change and climate change (Wiskerke & Viljoen, 2012; Eingenbrod & Gruda, 2015). The traditional assumption that urban soils are of poor quality, storing limited or no organic carbon (OC) has been overturned by research demonstrating that they contain nationally important stocks of soil organic carbon (Pouyat, Yesilonis & Nowak, 2006; Edmondson, Davies, McHugh, Gaston & Leake, 2012; Edmondson, Davies, McCormack, Gaston & Leake, 2014b). In addition, urban greenspace soils contribute to runoff and flood control, mitigate the urban heat island effect, support biodiversity, and improve air quality (Morel, Chenu & Lorenz, 2015; Mbow *et al*., 2018). However, there is a poor understanding of this functionality in soils managed for UH. Soil organic carbon (SOC) is a good indicator of soil quality, being positively associated with water and nutrient holding capacity, and negatively associated with soil compaction (Franzluebbers, 2002; Edmondson *et al*., 2014b). It is also positively associated with crop yields and ecosystem service delivery (Lal, 2010; Powlson *et al*., 2011). Globally, soil degradation and land-use change have released ~78 Gt SOC into the atmosphere, and changes in SOC concentration are a major contributor to greenhouse gas emissions (Lal, 2004; Emmett *et al*., 2010; Batjes, 2014). However, national SOC inventories do not, typically, account for urban SOC stocks (Bradley *et al*., 2005; de Brogniez *et al*., 2015).

Previous research has found that good soil management is key for the improvement of UH soils to increase yields as well as maximise ecosystem service provision (for example: Edmondson *et al*., 2014a; Lorenz, 2015; Eigenbrod & Gruda, 2015, Tresch *et al*., 2018). However, guidelines on best practice have not yet been developed as research addressing the influence of management on urban horticultural soil quality is still relatively young (Lorenz, 2018). Many common practices such as composting and manure addition contribute to improving UH soils (Edmondson *et al*., 2014a); however, unsustainable practices such as high peat input gardening are also common, and contribute to environmental degradation of the land from which the peat is sourced as well as broader negative climatic impacts (Boldrin *et al*., 2009). Knowing what management practices gardeners undertake, and how this influences soil quality, is key to educate prospective and current gardeners on the best ways to sustainable manage their UH activities for soil quality (Lorenz, 2018). However, urban soils are particularly heterogeneous with a large degree of spatial variability (Lal, 2018), and different underlying soil types can have significantly different properties (Wilson, Koen, Barnes, Ghosh & King, 2011). Case studies in individual cities, which form the bulk of previous research into UH soil quality, whilst presenting some common findings, need corroborating with a nationwide understanding.

In the UK, allotment gardening is the predominant land-use devoted to UH (Crouch & Ward, 1997; Acton, 2015). Allotment plots are rented land parcels for the purpose of food production, usually around 250 m^2, and form part of larger sites comprised of a varying number of plots. Current UK provision of allotment plots does not meet demand: there are approximately 330,000 allotment plots, covering 135 km^2, however, there were 100,000 people on waiting lists in the last decade (Campbell & Campbell, 2013), and demand for plots is rising (Dobson, Edmondson & Warren, 2020) particularly in response to the Covid-19 pandemic (Smithers, 2020). Previous research on allotment soils in Leicester, UK, found they had a 32% higher SOC concentration than in regional arable soils (Edmondson *et al*., 2014a), suggesting that UH occurs without the degradation of soils seen in conventional agricultural systems.

In this paper, we establish the first nationwide assessment of soil quality on allotment gardens. As well as investigating SOC density and SOC concentration, which as detailed above is one of the primary indicators of overall soil health (Franzluebbers, 2002), we also look at other soil quality indicators associated with the provision of regulating and supporting ecosystem services in the soil (Dominati, Patterson & Mackay, 2010). These are bulk density (BD), a key measure of soil compaction (Emmett *et al*., 2010); soil total nitrogen (N) concentration and the C:N ratio (an important control of soil nutrient cycling; Powlson *et al*., 2011); pH; and water holding capacity (WHC). We undertake a questionnaire with plotholders to determine soil management practices and investigate whether these have a significant influence on soil quality. For each of our study cities, we investigate SOC concentration in comparison to their surrounding arable and horticultural rural land, allowing us to compare the quality of UH soils to overall arable and horticultural soil quality in the UK.

2. Methods

2.1. Site selection

We selected ten case study urban areas, geographically distributed across Great Britain: Bristol (B), Cardiff (CA), Edinburgh (ED), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO) (Figure 1). Each urban area was split into four quadrants with an allotment site selected for field sampling randomly from each quadrant in a Geographic Information System (ArcGIS 10.4.1.; Supplementary Information S1 for sites). Within each allotment site five allotment plots were selected for soil sampling. Soils were sampled in 200 allotment plots in 40 sites over the 2017-2018 growing seasons. In addition, for each plot, a map was produced detailing all features present, e.g. cropped areas, grass, impermeable surface, greenhouses.

Figure 1. Location of study cities: Edinburgh (ED), Newcastle (NE), Leeds (LD), Liverpool (LV), Nottingham (NO), Leicester (LE), Milton Keynes (MK), Cardiff (CA), Bristol (B), and Southampton (SO).

The general soil type of each site was identified using the NatMap Vector "soilscapes" dataset (National Soil Resources Institute, 2001). Edinburgh sites had no available soil type data. Ten soil types were sampled from the remaining nine urban areas: freely draining floodplain soils (FDFS), freely draining lime rich loamy soils (FSLLS), freely draining slightly acid loamy soils (FSALS), freely draining slightly acid sandy soils (FDSASS), lime rich loamy and clayey soils with impeded drainage (LLCSID), loamy and clayey floodplain soils with naturally high groundwater (LCFNHG), loamy and clayey soils of coastal flats with naturally high groundwater (LCCNHG), slightly acid loamy and clayey soils with impeded drainage (SALCSID), slowly permeable seasonally wet acid loamy and clayey soils (SPSWALC), and slowly permeable seasonally wet slightly acid but base rich loamy and clayey soils (SPSWABLC; Figure 2).

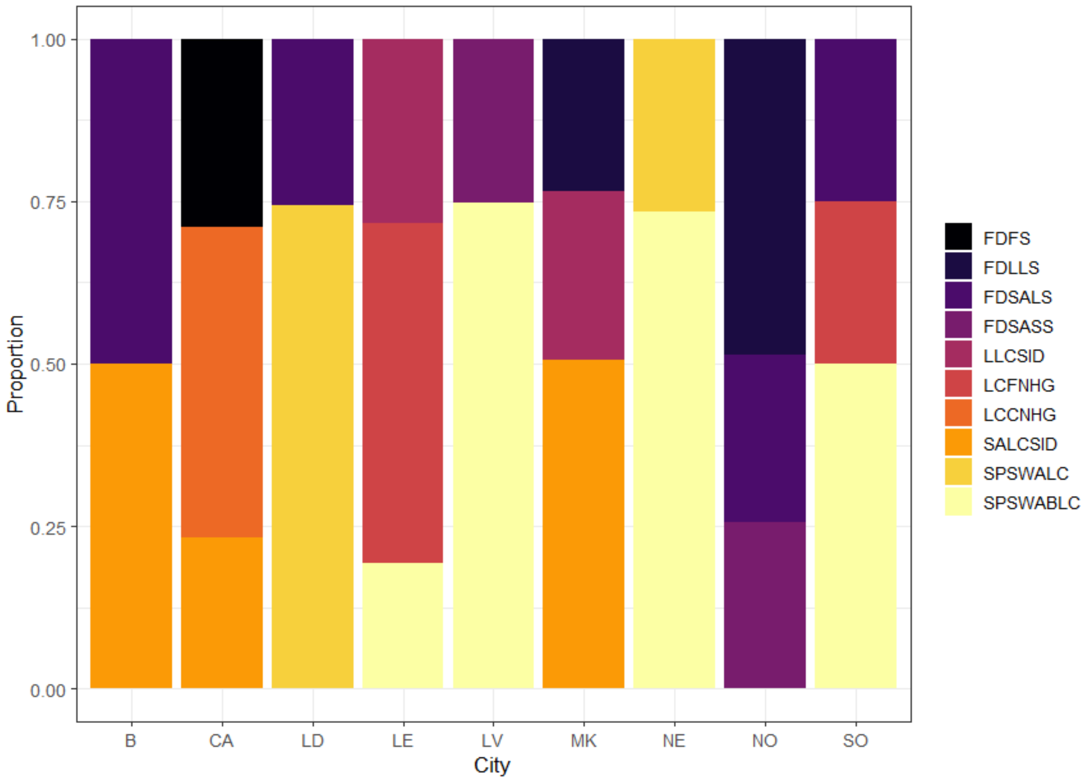

Figure 2. Distribution of soil types on allotments in case study urban areas (n = 20 per urban area): Bristol (B), Cardiff (CA), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO).

2.2. Soil sampling methods

At each allotment plot (n = 200), soil was sampled under one perennial and one annual crop. In plots where there were only annuals or perennials then soils were sampled beneath two different annual or perennial crops (Supplementary Information S2). Soils were sampled using two methods. Firstly, in duplicate at two depth increments (0-10 cm and 10-20 cm) using a specialist bulk density corer (Eijkelkamp Ring Kit C; Edmondson *et al*., 2012). Secondly, triplicate auger samples were taken to 20 cm depth. In total, 1600 soil core samples and 1200 soil auger samples were taken: eight cores per plot and six auger samples per plot (hence, forty cores and thirty augers per site; one hundred and sixty cores and one hundred and twenty augers per city).

2.3. Soil analysis

Soil samples were dried at 105°C for 24 hours, weighed, ball-milled to homogenise and passed through a 1mm sieve (Edmondson *et al* 2012). Material >1mm was weighed and removed from soil total weight; this material was then volumetrically measured using water displacement and the volume removed from total volume to calculate soil BD (g cm^{-3}). Inorganic carbon was removed from samples with 5M HCl, and analysed for SOC and N in an elemental analyser (Vario EL Cube; Isoprime, Germany). SOC density (mg cm^{-3}) was calculated individual samples using SOC concentration (mg g^{-1}) and BD prior to the removal of the volume of >1mm material (g cm^{-3}) (Edmondson *et al*., 2012).

Auger samples were air dried and analysed for water holding capacity (WHC) and pH. Soil pH was determined in 1:10 (v:w) ratio with 0.01 M $CaCl_2$ suspension (Houba, Temminghoff & van Vark, 2000). Prior to WHC analysis, auger samples were passed through a 9 mm sieve. 50 g of soil was saturated and the weight of water held after 30 minutes was used to determine WHC as a % of soil weight.

2.4. Soil management questionnaire

Questionnaires were conducted with 184 of the 200 allotment plotholders on whose plots soil samples were taken. Participants were asked a variety of questions related to plot and soil management practices, such as organic growing, manure use, winter coverings, and composting of plot waste (Supplementary Information S3). However, the full diversity of possible plot management practices undertaken over the course of a year could not be captured with this simple questionnaire.

2.5. Agricultural soil carbon concentration

LandCover Map 2015 (Rowland *et al*., 2017) was used to identify areas of arable and horticultural land surrounding each urban area. Ten locations were selected at random (in ArcGIS 10.4.1; for Cardiff and Liverpool, only nine were available) within this agricultural land surrounding each urban area. At each location (n = 88) a topsoil organic carbon value was extracted from NatMap Vector (National Soils Resources Institute 2001). This was not possible in Edinburgh as NapMap Vector does not extend into Scotland.

2.6. Statistical analysis

Statistical analysis was conducted in R version 4.0.0. (R Core Team, 2020; see Supplementary Information S4 for a full list of R packages used). The mean of the two replicated samples was taken for each allotment plot, to give one result per plot depth per crop type (annual or perennial), except for pH and WHC, where only one depth was sampled.

We examined the influence of soil type, crop type and depth (for pH and WHC, depth was excluded) on our measured soil quality indicators. Data were transformed where necessary to improve the fit to assumptions of normality (tested using Shapiro-Wilk tests), and linear mixed effects models were built to include the influence of city or allotment site as random effects using the R package *lme4* (Bates, Maechler, Bolker & Walker, 2015). Using Akaike's information criteria (AIC) values and 95% confidence intervals, the most parsimonious model for each variable was built. The package *lmerTest* (Kuznetsova, Brockhoff & Christensen, 2017) was used to generate *p*-values for the models using Satterthwaite's approximation.

Linear mixed effects models were also used to investigate the influence of management practices on soil quality. We built models for organic / non-organic gardening, use of winter cover, use of manure, use of compost, organic fertiliser use and nonorganic fertiliser using the methodology above to create the most parsimonious model for each management variable.

A paired-sample t-test was used to analyse differences between allotment and arable and horticultural SOC concentration.

3. Results

3.1. Allotment soil quality

Overall, the median properties of allotment soils were BD of 0.92 g cm^{-3} (0.22-1.52 g cm^{-3} range); SOC density of 58.1 mg cm^{-3} (16.7-191.8 mg cm^{-3} range); SOC concentration of 58.2 mg g^{-1} (14.0 to 305.6 mg g^{-1} range); N concentration of 3.7 mg g^{-1} (0.75-7.95 mg g^{-1} range); C:N ratio of 16.0 (7.0-40.0 range); pH of 6.5 (4.8 to 7.2 range), and WHC of 71.8% (44.6 to 105.7% range). Most soil properties varied by urban area (Figure 3). The greatest SOC density, SOC concentration, C:N ratios and WHC were found in Cardiff; Leicester had the lowest SOC density and WHC. Milton Keynes had the lowest SOC concentration and C:N ratio, and the highest BD. pH was lowest in Edinburgh (Figure 3).

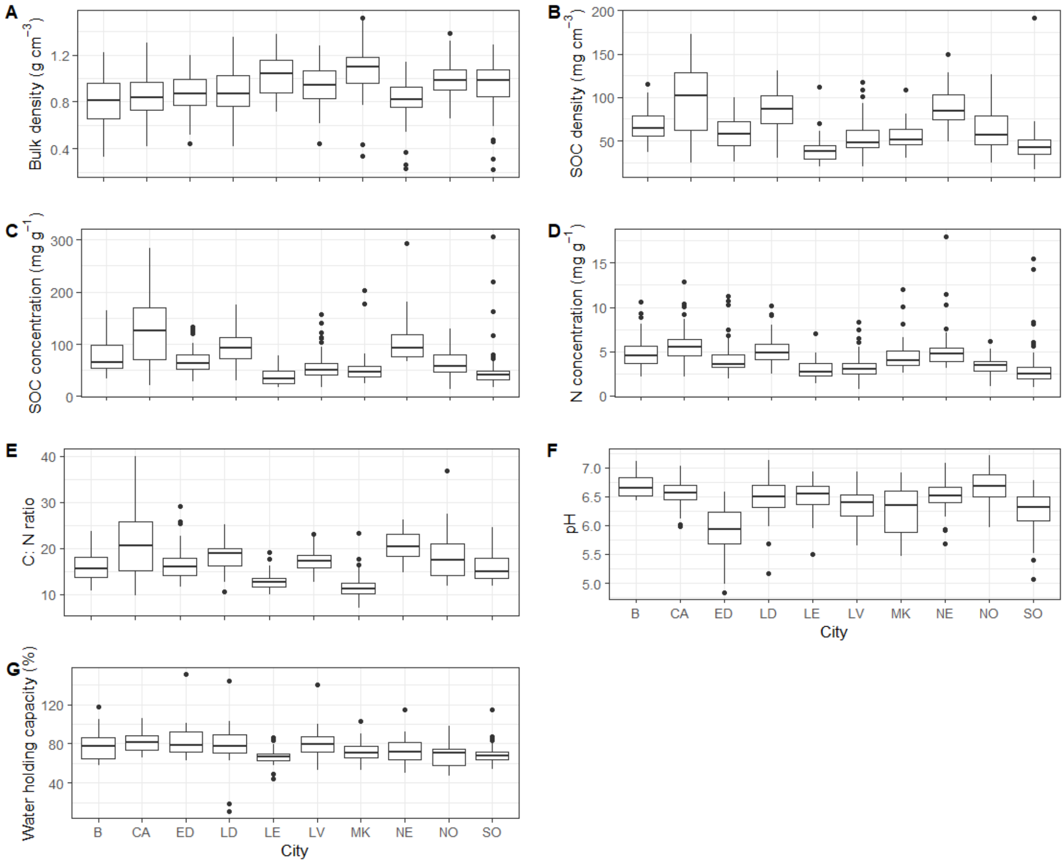

Figure 3. Soil quality indicators on allotments sampled in ten British urban areas: Bristol (B), Cardiff (CA), Edinburgh (ED), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO). **A**: Bulk density, **B**: SOC density; **C:** OC concentration; **D:** N concentration; **E**: C:N ratio; **F:** pH; and **G:** water holding capacity.

For all soil properties measured the most parsimonious models included depth (where applicable), crop type, and soil type, except for N concentration where no fixed effects were included (Table 1). Soil type significantly affected SOC density (df = 9, 566.4, F = 2.1, p = 0.027), C:N ratio (df = 9, 603.7, F = 2.0, p = 0.034), and WHC (df = 9, 184.8, F = 5.4, p < 0.0001) (Figure 4). There was a significant interaction effect between crop type and soil type on pH (df = 9, 92.5, F = 2.7, p = 0.005). Depth did not influence any soil property, and crop type only influenced pH. Soil type was the most important factor effecting soil properties (Figure 4; Table 1). When plot management practices were included, there was no improvement in model performance, suggesting that there were no significant effects of management on soil quality (Supplementary Information S5).

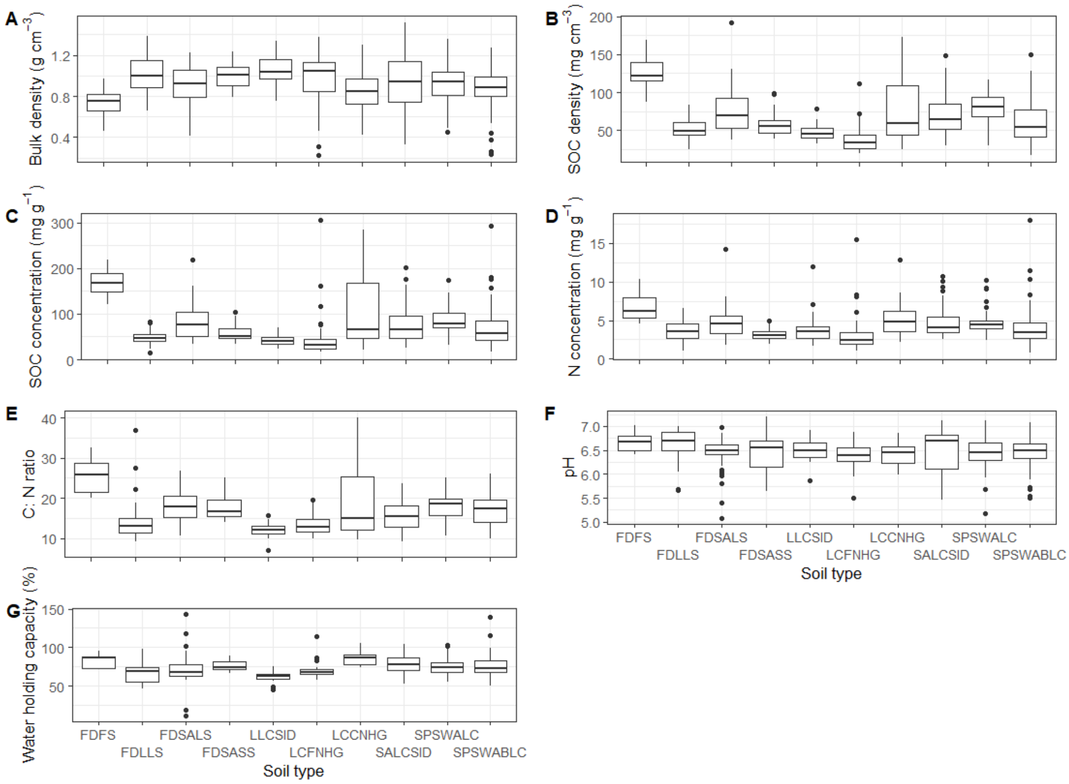

Figure 4. Soil quality indicators on allotments according to soil type: **A**: Bulk density, **B**: SOC density; **C:** OC concentration; **D:** N concentration; **E**: C:N ratio; **F:** pH; and **G:** water holding capacity.

Table 1 (following page). Soil quality indicators on allotments analysed using linear mixed effects models, showing transformations applied to the data; the model terms (fixed and random effects) included that created the most parsimonious model for each variable; and the results of type III analysis of variance on each of the fixed terms in each model. For N concentration, no analysis was performed as the model was most parsimonious without any fixed effects.

Variable	Transformation	Fixed effects	Random effects	Results	Annual / perennial	Depth category	Soil type	Crop type : depth	Crop type : soil type	Depth : soil type	Crop type : depth : soil type
Bulk density	None	Crop type, depth, soil type	City	F	$_{1,595.8}$ = 0.55	$_{1,596.0}$ = 0.93	$_{9,601.4}$ = 1.80	$_{1,595.78}$ = 0.09	$_{9,595.81}$ = 0.55	$_{9,595.96}$ = 0.74	$_{9,595.82}$ = 0.41
				p	0.81	0.34	0.07	0.76	0.83	0.67	0.93
SOC density	Log	Crop type, depth, soil type	City	F	$_{1,560.88}$ = 1.52	$_{1,560.95}$ = 0.47	$_{9,566.37}$ = 2.11	$_{1,560.89}$ = 1.78	$_{9,560.89}$ = 0.50	$_{9,560.98}$ = 0.54	$_{9,560.91}$ = 0.39
				p	0.22	0.49	**0.03**	0.18	0.87	0.85	0.94
SOC concentration	Log	Crop type, depth, soil type	Site	F	$_{1,598.91}$ = 0.02	$_{1,598.93}$ = 2.13	$_{9,604.71}$ = 0.86	$_{1,598.9}$ = 0.21	$_{9,598.92}$ = 0.43	$_{9,598.95}$ = 0.43	$_{9,598.91}$ = 0.26
				p	0.90	0.14	0.56	0.65	0.92	0.99	0.98
N concentration	Square-root	None	City & site	F	-	-	-	-	-	-	-
				p	-	-	-	-	-	-	-
C : N	Log	Crop type, depth, soil type	City	F	$_{1,598.98}$ = 0.43	$_{1,598.98}$ = 0.00	$_{9,603.72}$ = 2.03	$_{1,598.96}$ = 0.12	$_{9,598.97}$ = 0.48	$_{9,598.99}$ = 0.16	$_{9,598.97}$ = 0.26
				p	0.51	0.99	**0.03**	0.72	0.89	0.99	0.98
pH	Exponential	Crop type, soil type	City & site	F	$_{1,293.05}$ = 3.17	-	$_{9,22.50}$ = 0.96	-	$_{9,292.49}$ = 2.67	-	-
				p	0.07	-	0.50	-	**0.005**	-	-
Water holding capacity	Log	Crop type, soil type	City	F	$_{1,295.46}$ = 0.65	-	$_{9,184.82}$ =5.39	-	$_{7,295.64}$ = 0.20	-	-

3.2.Allotment soil management

Plotholders had managed their plots for a median length of 7 years, ranging from two weeks, to 61 years. Previous growing experience prior to taking on their allotment ranged from none to a lifetime of growing, but the majority (76%) had no experience of growing food before taking up their plot. When a plotholder's previous experience was added to the length of their plot occupancy, plotholder median food growing experience increased to 11 years.

Forty-three percent of respondents self-reported growing organically, 43% grew mostly organically, and 13% were non-organic. Fifty-four percent of questionnaire respondents used winter covering on their beds, most commonly black plastic, Geotex membrane and green manure. The most common soil additions were garden waste compost (92%) and manure (82%) with addition of other material less common (Table 2).

Table 2. Inputs to allotment plots by survey respondents.

Additions to plot	Yes %	No %
Home kitchen waste compost	67	33
Compost from allotment organic matter waste	92	8
Purchased compost	69	31
Other compost*	33	67
Manure	82	18
Fertiliser (organic)	38	62
Fertiliser (non-organic)	27	73

* For example: cardboard, livestock straw, ash.

3.3. Organic carbon in allotment soils compared to arable and horticultural soils

Median SOC concentration in arable and horticultural soils was 23.5 mg g^{-1}, compared to 58.15 mg g^{-1} for allotment soils across Great Britain. Allotment SOC concentration was significantly higher than that of arable or horticultural soil from the surrounding region ($t = 7.80$, $df = 8$, $p < 0.0001$, Figure 5).

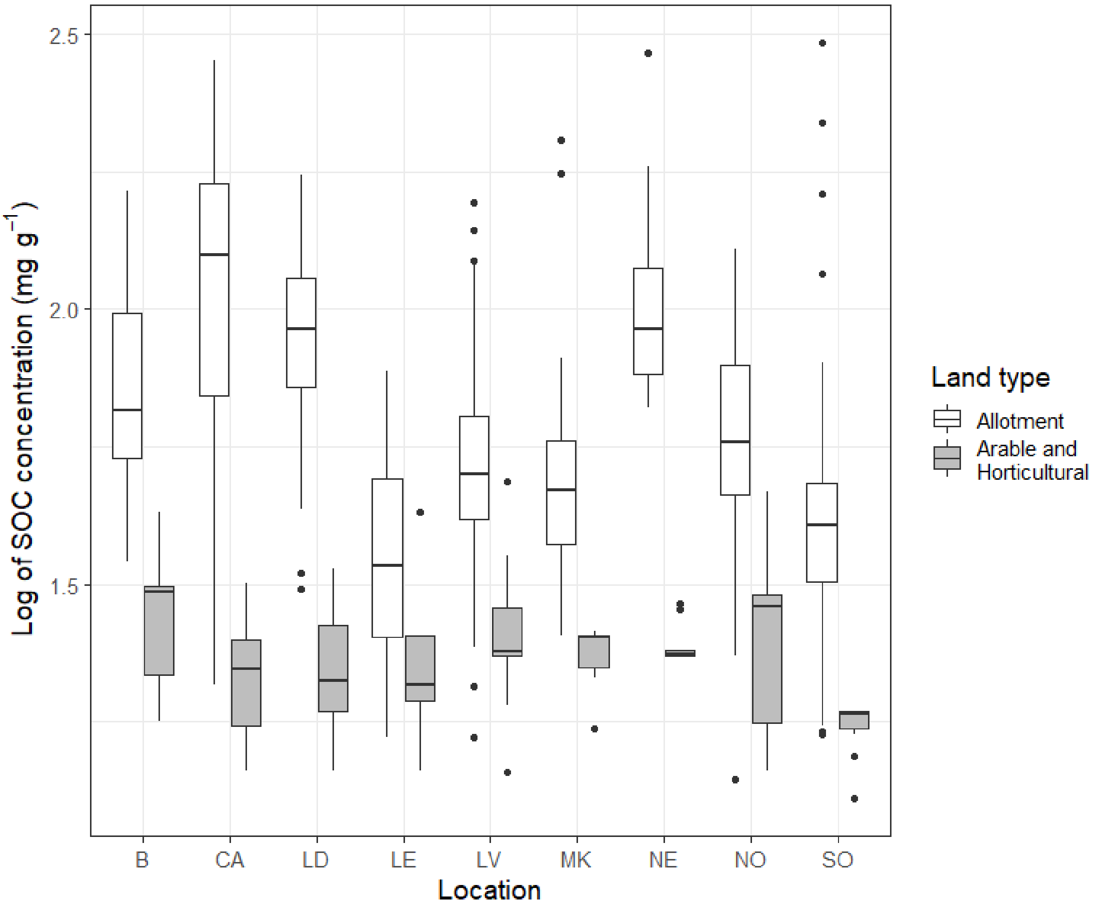

Figure 5. Soil organic carbon concentration in topsoil (0-20cm) in allotments within cities, and arable and horticultural land surrounding each urban area: Bristol (B), Cardiff (CA), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO), and Southampton (SO).

4. Discussion

Previously, site-specificity of research limited our understanding of the nature and properties of UH soils (Borysiak, Mizgajski & Speak, 2016). Here, using data at a national scale, we can assess overall properties of allotment soils, and compare their SOC concentrations with those of arable and horticultural land. We find that UH soils in allotments maintain levels of SOC across Great Britain that are significantly higher than those found arable and horticultural soil.

Soil organic carbon is one of the most important overall indicators of soil health (Franzluebbers, 2002). The most recent Countryside Survey, a national-scale survey that includes measures of soil health across Great Britain (Emmett *et al*., 2010; no estimates of variation were given for this or the following figures drawn from this reference), found that average SOC concentration for arable and horticultural land was 30.7 mg g^{-1}. This is higher than the 23.5 mg g^{-1} we found, but still substantially lower than the average allotment SOC concentration of 58.2 mg g^{-1}. Allotment SOC concentrations from our field data were similar to improved grassland, which had an SOC concentration of 56.9 g kg^{-1} (Emmett *et al*., 2010).

Bulk density on allotments was 0.92 g cm^{-3}, compared to 1.23 g cm^{-3} for arable and horticultural soil reported nationally (Emmett *et al*., 2010). This is lower than the BD reported for allotments in a case-study in Leicester (Edmondson *et al*, 2014a); however, our values for Leicester were consistent with this study. Bulk density is typically negatively correlated with SOC and provides a proxy measure for soil compaction with higher bulk density values indicating more compacted soils (Edmondson *et al*., 2011). Compaction has negative impacts for erosion and flood mitigation, as well as impeding plant growth (Edmondson *et al*., 2011). We found lower pH on allotments than those reported in the Countryside Survey from arable and horticultural soils (6.5 vs. 7.2; Emmett *et al*., 2010). For horticultural production, a pH of 6.5 is ideal, allowing optimum earthworm activity and nutrient availability (Royal Horticultural Society, 2020). Total nitrogen concentration was higher on allotments than in arable and horticultural soils (3.7 mg g^{-1} vs. 2.5 mg g^{-1}; Emmett *et al*., 2010), and C:N ratio was also higher (16.0 vs. 11.3; Emmett *et al*., 2010). The higher C:N ratio is linked to reduced N leaching and maintaining good levels of nutrient cycling, which is also supported by higher WHC (Dominati *et al.*, 2010; Robinson *et al*., 2013). Overall C:N ratios in this study of ten cities were slightly higher than those reported on allotments in Leicester but were consistent with the soils in that urban area (Edmondson *et al*., 2014a).

Overall, management practices undertaken by allotment gardeners mirror those recommended for the maintenance of soil health and organic matter (Lorenz & Lal, 2009; Lorenz, 2015; Gregory *et al*., 2016). However, our analyses did not reveal any consistent findings regarding the influence of soil management techniques on soil quality. There are a number of possible reasons for this. Firstly, our questionnaires with plotholders asked them about whole-plot management; the management of the specific crops sampled may have varied. This means that the management practices detailed in the questionnaire responses may not have directly related to the soils which were sampled; the way in which allotment plots were sampled was, therefore, inappropriate for assessing the impact of soil management (as it was primarily designed to assess overall soil quality). Further to this, long-term management of soils has substantial impacts on their qualities (Lorenz, 2015). Previous tenants on the same plot may have managed their soil differently, which would affect those plots where tenancy had only recently been undertaken. Finally, allotment soils were in consistently good health, giving limited scope for variations in management revealed by the questionnaire responses to produce significant variation in the soil quality.

Recently, the potential of UH to provide food for city residents has also been demonstrated to exceed past expectations. Current levels of cultivation on allotments have been estimated to provide 3.3% of a city's population with their daily fruit and vegetables, with the potential to increase this to as much as 3.8% if more land was cultivated (Edmondson *et al*., 2020b). Two studies on wider urban horticultural potential, in Sheffield, UK (Edmondson *et al*., 2020a), and Sydney, Australia (Mcdougall *et al*., 2020) both found the possibility to grow at least 15% of the study city's fruit and vegetable supply on potentially available land, with the former showing that if 100% of this was cultivated, 122% of the population could be fed on their recommended daily fruit and vegetable intake. As this expanding body of research on yields feeds into policies for scaling up urban horticultural production, our findings provide promising empirical evidence to demonstrate that such upscaling would also improve other soil-based ecosystem services (such as climate change mitigation, flood mitigation, filtration, and biodiversity conservation; Dominati *et al*., 2010; Edmondson *et al*., 2012; Rawlins *et al*., 2013) alongside food provision.

We found a consistently significant impact of soil type on soil properties, underscoring the need for nationwide approaches to truly understand the properties of urban soils. In future research, biological indicators would provide a further lens through which to examine urban horticultural soil quality, as demonstrated by Zhang (2019); bacterial community composition is an important indicator of ecosystem health. However, the potential dis-services of allotment soils are also in need of further research. This includes issues such as heavy metal contamination and the bio-availability of soil heavy metals; as well as any potential for NPK accumulation (Lorenz, 2018). Adverse health effects of UH through soil contamination have been contested (Leake, Adam-Bradford & Rigby, 2009; Mees & Stone, 2012), but further research is necessary in this area. Indeed, one paper found that risk perception may be a more limiting factor than risk itself in UH, so continued education of its multiplicity of benefits and potential ecosystem services is important (Wortman & Lovell, 2013). Opportunities also exist in future research to investigate the potential for the required inputs (e.g. water) for UH to be sourced from within the urban system, utilising waste energy to improve sustainability (Kumar & Hundal, 2016; Mcdougall *et al*., 2020). In general, further research directions should focus on continuing to improve our understanding of the factors driving the maintenance of high soil quality levels in UH at national scales, and further investigate possible areas where trade-offs exist between different ecosystem services, leading to an understanding of the best way to practice UH that delivers the maximum benefits for both human wellbeing and ecosystem health.

5. Conclusions

This research has demonstrated that urban horticultural soils are of a consistently high quality, for the first time expanding case study locations to a national scale. Our findings add to the evidence base that UH maintains considerably higher levels of SOC than arable and rural horticultural soils, and performs better on other soil quality indicators as well. We have also demonstrated that management practices on allotments follow techniques conducive to sustainable crop productivity as well as ecological health. Overall, our findings suggest a potential for valuable ecosystem service provision by UH soils beyond that of just food production. This further contributes to a growing evidence base of the value of UH.

Chapter 4

Assessing the resource requirements of urban horticulture: A citizen science approach

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Abstract

Interest in urban food production is growing, and recent research has highlighted its potential to increase food security and reduce the environmental impact of food production through the expansion of urban horticulture. However, the resource demands of urban horticulture are poorly understood. Here, we use allotment gardens in the United Kingdom to investigate the resource demands of urban horticultural production across the country. We conducted a nationwide citizen science project using year-long allotment 'diaries' with allotment gardeners (n = 163). We analysed a variety of resources: transportation; time; water use; inputs of compost, manure and topsoil; and inputs of fertilisers, pest control and weed control. We found that, overall, an allotment demands 87 annual visits, travelling 139 km to and from the plot; 7 fertiliser additions; 4 pest control additions; and 2 weed control additions. On average, each kilogram of food produced used 0.4 hours' labour, 16.9 litres of water, 0.2 litres of topsoil, 2.2 litres of manure, and 1.9 litres of compost. We also identified opportunities that exist to increase the sustainability of resource use, noting that 91% of water use was from mains water supply rather than harvesting rainwater; and that 16% of compost was shop-bought. As interest in urban horticultural production grows, and policymakers build urban horticultural spaces into future sustainable cities, it is of key importance that this is done in a way that minimises resource requirements, and we demonstrate here that avenues exist for the diversion of municipal compostable waste and household-level city food waste for this purpose.

Acknowledgements

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1. Introduction

The urban population of the world is rising, and is predicted to continue to do so over the next few decades (United Nations, 2019). Increasing urban populations highlight the need to understand and plan for the issues underpinning the sustainability of urban systems. Food is one of these. Cities are dependent on international food supply chains, which are vulnerable to shocks in the global system such as the 2020 coronavirus pandemic and the 2008-9 food price crisis (FAO, 2020a; FAO, 2020b). In many cities across the world there is developing interest in the potential of urban horticulture (UH) to build resilience to such shocks, as well as improving the environmental footprint of their food consumption and creating opportunities for other social and environmental benefits associated with UH (Benis and Ferrão, 2016). Research into mechanisms and opportunities for upscaling the amount of food production taking place within city limits has recently found promising results regarding potential food provisioning (Edmondson *et al*., 2020a; Mcdougall *et al*., 2020). Some cities already produce a large proportion of their fruit and vegetable needs within the city limits; for example, Shanghai produces 60% of the vegetables consumed by its residents (Lovell, 2010). Many other cities now include some reference to UH within their sustainability planning, and networks of cities interested in scaling up urban food production are increasingly popular: the Milan Urban Food Policy Pact has 210 city signatories (Milan Urban Food Policy Pact, 2020), and the UK's Sustainable Food Cities network has 52 (Sustainable Food Places, 2020). There is also a large body of research demonstrating that UH can provide co-benefits alongside food production, such as improved health and wellbeing and the delivery of ecosystem services (McClintock *et al*., 2013; Lin *et al*., 2015; Speak *et al*., 2015; Webber *et al*., 2015; Borysiak *et al*., 2017).

An underlying assumption of the above research, and general increase in interest in UH in cities in the global North, is that UH offers a more sustainable form of fruit and vegetable production than conventional horticulture. However, there is very little empirical evidence to date to examine this claim. The nature of much UH activity, which takes place informally, at small scales, and in different settings, means that the energy and resource flows associated with it have not commonly been integrated into citywide systems thinking (Maye, 2019). There are many forms of UH with correspondingly varied resource demands (Goldstein *et al*., 2016a). What we do know about resource demand is limited to very few analyses, such as Life Cycle Analysis (LCA) on integrated urban farms, soil-less systems or rooftops (Kulak *et al*., 2013; Sanyé-Mengual *et al*., 2015; Maye, 2019); however, most UH is small-scale, soil-based, activity, and has received little attention from this point of view.

In this paper, we investigate the year-round resource demands of allotment gardening in the UK. Allotments are the most significant form of UH in the UK (Crouch and Ward, 1997; Acton, 2015), and also form a large proportion of UH land across the European continent (Speak *et al*., 2015). Allotment 'plots', typically 250 m^2 land parcels, are rented by individuals or families from local councils or private landowners, and plots are grouped together on larger sites comprising anything from fewer than ten to over one hundred plots. There are around 330,000 allotments plots in the UK (Campbell and Campbell, 2013), and allotment sites as a whole use 82% of their land for plots, with the remaining used for associated infrastructure such as vehicle access (Edmondson *et al*., 2020b). Recent research has demonstrated that allotment gardening has the potential to be a highly productive form of UH, with one case study analysis finding that it could provide fruit and vegetables for 3% of a city's population despite allotments covering less than 1.5% of the city's area (Edmondson *et al*., 2020b). Demand for allotments is rising (Dobson *et al*., 2020), with an average of 52 people on waiting lists for every 100 plots in the UK (Campbell and Campbell, 2013), although evidence suggests that the Covid-19 pandemic is further increasing demand for growing space (Niala, 2020). It is therefore timely to develop our understanding of what the associated resource costs of allotment gardening are, both with regard to assessing the sustainability of this form of UH, and identifying opportunities for “urban symbiosis” (Maye, 2019), so future developments of UH land can be integrated into cities in a way that enhances the sustainability of resource use.

There are a number of ways in which integration of UH might contribute to enhanced urban sustainability. Increasing kitchen waste compost for use in UH and redirecting excess rainfall for growing purposes could not only lead to a reduction in greenhouse gas emissions but also a reduction in costs associated with landfill management, water demand and flood mitigation (Grewal and Grewal, 2012; Petit-Boix *et al*., 2017). According to the United States Environmental Protection Agency (2020), 28% of household waste sent to landfill is potentially compostable. On average, over 16 kg of vegetables are wasted per year per capita across the world (Chen *et al*., 2020). Producing food locally, and composting waste, has the potential to reduce overall food waste as well as lower the emissions associated with food spoilage occurring during transportation (Grewal and Grewal, 2012; Sanyé-Mengual *et al*., 2015; Chen *et al*., 2020). The built infrastructure of urban environments also provides considerable potential for rainwater harvesting; it is estimated that Munich could save 26% of its current freshwater supply by harvesting rainwater (Gondhalekar and Ramsauer, 2016). If this were integrated into UH, better management of rainwater run-off and a reduction in demand on the water supply could benefit both UH and the overall fabric of an urban area. There is widespread agreement that development and protection of urban green infrastructure, including UH, can contribute to sustainability of urban systems, for example through the mitigation of the urban heat island effect (Pataki *et al*., 2011; Petit-Boix *et al*., 2017). There is also some evidence that greenhouse gas emissions reductions from expanding UH are greater than the sequestration potential of other urban greenspaces, based on Life Cycle Assessment results (Kulak *et al*., 2013).

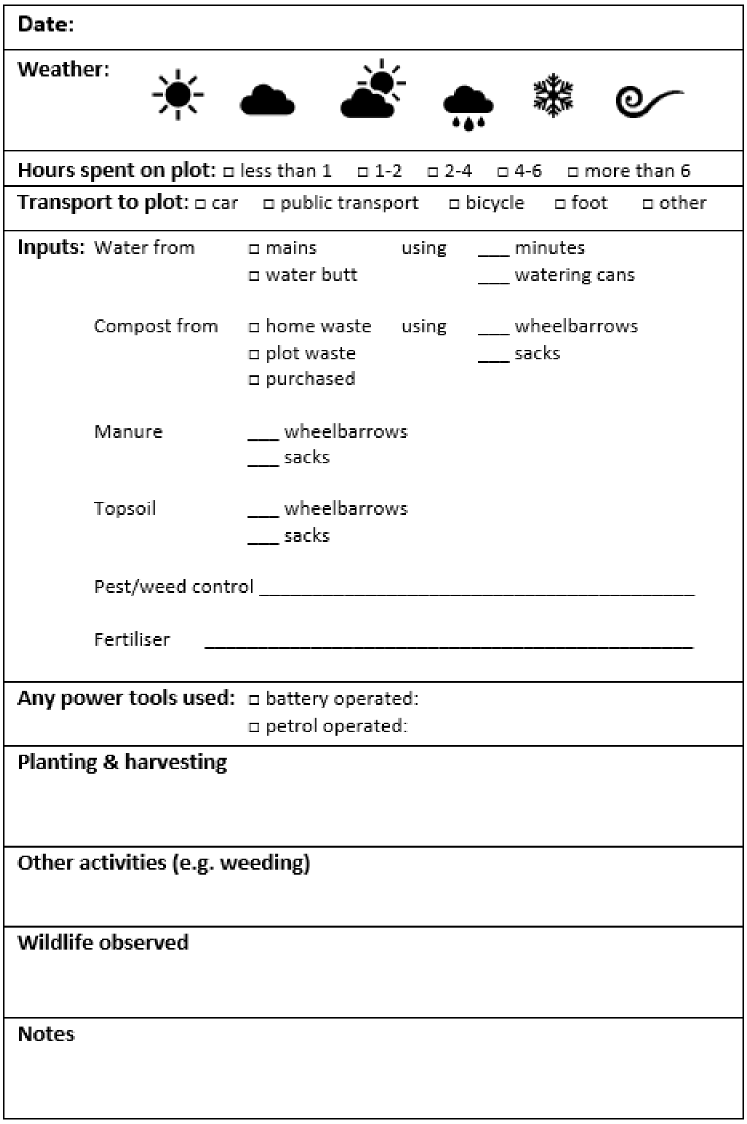
We know from previous research that allotment gardeners tend to use management practices conducive to the maintenance of highly productive soils; 75% of respondents to Edmondson *et al*. (2014a) added manure, 95% composted on their plot, and commercial composts and organic fertilisers were also used. However, the challenge remains to quantify these resources as well as investigate their origins, and there has been no research to date quantifying other resource demands of allotment gardening, such as transportation, time commitments and water use. In light of this, it is clearly important to compile an evidence base of the resource demands of UH.

Here, we use a year-long citizen science project, with allotment gardener participants from England and Wales, to establish the resource use requirements of urban horticulture annually. Our approach follows the Ten Principles of Citizen Science (Robinson *et al.*, 2018), involving active participation of members of the public in scientific data collection to generate new knowledge to answer previously unanswered research questions. This is an ideal methodological form to answer questions such as those regarding resource use on allotments: allotments are heterogeneous and small-scale land parcels, and alternative methodologies, for example LCA (above) would require much more detailed investigation of a far small sample size. Without prior understanding that the selected study gardens were representative, an LCA runs the risk of not capturing the typical allotment. The citizen science approach allowed us to go beyond a small number of case studies (e.g. Kulak *et al*., 2013), and to gather data from across the country, providing good representation of allotment practices overall, as well as demonstrating the variations that exist among gardeners' practices. This has enabled a first understanding of the resource costs associated with allotment gardening, in addition to current levels of resource recycling. However, in order for the data collection to not be overly onerous for the citizen scientist participants, some level of detail that would be captured in, e.g. an LCA, was necessarily sacrificed. We have also identified the opportunities to further increase the sustainability of allotment gardening through increasing the amount of waste and renewable resources used in this form of UH, illustrating the potential for integration of UH into whole-system flows of food, energy and water to contribute to the sustainability of urban areas as a whole.

2. Methods

Citizen science participants, all of whom were allotment gardeners, were recruited through online advertising: Facebook, the MYHarvest website (https://www.myharvest.org.uk), and the National Allotment Society. Recruitment was also done in print in the Royal Horticultural Society magazine, and through posters attached to allotment site gates, which were posted to any volunteer who expressed an interest in recruiting other members of their allotment site. In total, 437 participants were recruited with a geographical spread across England, Wales, Scotland and Northern Ireland. However, due to the nature of advertisement through channels likely to be followed by enthusiastic gardeners, and the time commitment involved in diary-keeping, this approach biased selection towards gardeners who already spend a lot of their mental and physical energy and time on their allotments; it is unlikely we managed to recruit and retain any gardeners for whom it is a lesser hobby.

Volunteers were sent an allotment “diary”, with a separate page to fill out for each allotment visit (Figure 1). They were asked to fill their diary out each time they visited their allotment, for a full year, with participant recruitment and therefore start date spanning December 2017 to March 2018. Participants were also asked a number of general questions about their allotment, including length of tenancy, whether they grew organically, use of peat free compost, number of people working on the plot, and yearly rent prices (Supplementary Information 1).



Date:

Weather:

Hours spent on plot: □ less than 1 □ 1-2 □ 2-4 □ 4-6 □ more than 6

Transport to plot: □ car □ public transport □ bicycle □ foot □ other

Inputs: Water from □ mains □ water butt using ___ minutes ___ watering cans

Compost from □ home waste □ plot waste □ purchased using ___ wheelbarrows ___ sacks

Manure ___ wheelbarrows ___ sacks

Topsoil ___ wheelbarrows ___ sacks

Pest/weed control ___________________________

Fertiliser ___________________________

Any power tools used: □ battery operated: □ petrol operated:

Planting & harvesting

Other activities (e.g. weeding)

Wildlife observed

Notes

Figure 1. Recording sheet for participants in the allotment diary project. Copies of the same sheet were filled out every time gardeners visited their allotment over the course of a year.

On each allotment visit, participants recorded the activities they undertook. This included: the date; the weather; the method of transport used to get to the allotment; how long they spent on their plot; quantification of water use from the mains or from water butts (rain water containers) in number of watering cans, or minutes of hosepipe time; compost, manure and topsoil additions (in number of wheelbarrows or sacks used); any use of fertilisers, pesticides or weedkillers; planting, harvesting and other activities; wildlife observation; and any other comments they felt they wanted to share. For the purposes of this paper, we focus on the resource inputs recorded by participants.

This includes transportation, number of hours spent on the plot, water, compost, topsoil, manure, and other additions.

At the end of the year, participants were sent a stamped addressed envelope to return their diary pages. The returned diary pages were then scanned (so that originals could be returned to those who had requested this) and data were extracted. The mid-point of each option for the number of hours spent on the plot was taken to analyse total and average time spent working on the allotment (for example, 1-2 hours was entered as 1.5, and 2-4 hours was entered as 3). Google Maps was used to work out the distance from a participant's house to their plot. Specific parts of data had to be discounted from some participants, for example two of the participants who did not record any water use for an entire year.

As is typically the case with citizen science initiatives, we had to compromise between the detail of information people were asked to supply, and the willingness of participants to record information on every visit for an entire year. We therefore adopted a system of quantifying many aspects of resource use in simple, and easily recorded, forms, accepting some sacrifice of precision in individual estimates. We surveyed volunteers from the MYHarvest citizen science project (https://www.myharvest.org.uk) to estimate typical sizes of watering cans. From 207 respondents who told us the size of their watering can, the median (9 litres) was used. Average sizes of wheelbarrows and compost sacks (where participants had not quantified this themselves) were estimated by sampling popular items on garden centre websites. Probable hosepipe flow, in litres per minute, was estimated using information from Swanhose (Swan Products Ltd., 2020). Pesticide, fertiliser and weedkiller use was unquantified beyond whether it had been used on a visit or not, but participants were asked to name the type or brand of each of these inputs when they used them.

We calculated our estimates for the average yearly resource requirements of allotment gardening by using the typical allotment plot size of 250 m^2, as our citizen scientists were not required to measure their particular allotments (due to the balance of collecting important data whilst not asking too much of the participants' labour). Not all of an allotment is cultivated for food production, with a proportion being impermeable surface such as paths and sheds, and a proportion being permeable uncultivated surfaces such as grass areas. The intensity with which each area is managed varies and the food production areas can be assumed to use the majority of resources, but time is also taken to manage the overall allotment and spend time in relaxation. Differentiation of different time use types like this were not analysed due to the need to not provide participants with an overly onerous task when filling out their diary each day. It is unlikely that a gardener would have only food growing area and no other type of land use on their allotment; therefore, we have chosen to treat the plot as a whole rather than divided into individual land use types.

3. Results

One hundred and sixty-three participants (37%) returned their diaries, detailing a total of 14,992 individual allotment visits. Most returns were from England, despite a wider geographical spread of initial participants, which reflects the proportional spread of the initial recruitment (Figure 2). All diaries returned covered a full twelve-month period, apart from one which spanned February to October only due to health reasons, and this was excluded from estimates of year-round inputs but included when analysing on a month-by-month basis. A further two returned diaries were immediately excluded from our analyses due to incompleteness.

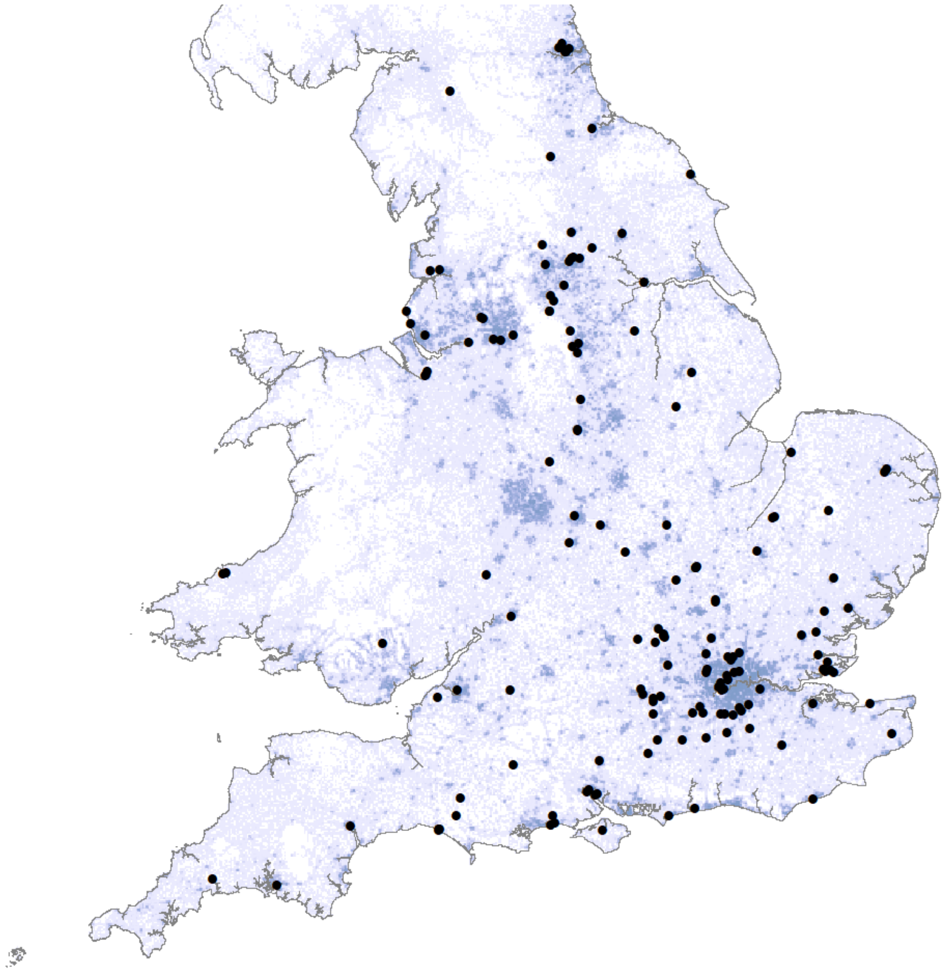


Figure 2. Distribution of allotment diary participants across England and Wales (black dots), and population density (blue shading, Reis *et al.*, 2017).

3.1. General characteristics of allotment gardeners

Participants' homes were between 0 (an allotment backing on to a residential property) and 9.2 km away from their allotment plots; however, the distribution of distances was skewed and the median distance that people lived from their plot was 1.6 km. Participants had worked their plot a median of 6 years, with a range from zero years (one person who was a new tenant on their plot) to 47 years. Of participants who answered the question of whether they cultivated organically (n = 159), 88 (55%) did, 45 (28%) grew mostly organically, and 26 (16%) did not. Most participants worked their allotment alone, with 97 (61%) being the sole worker on their plot, 61 (38%)

sharing the work with one other person, and one respondent having two additional co-workers. The median yearly rent for an allotment was £37, with rent ranging from £0 (two participants) to £280 (a site in London). Overall, only 7% of respondents paid over £100 a year.

3.2. Time commitment

We included 161 diaries in our analysis of time commitment. The median number of hours spent on the allotment over the course of a year was 150 (with a range from 22 to 647.5 hours), with a median of 87 visits. The total number of visits across the year ranged from 30 to 204. The median visit length was 1.5 hours. In winter (December, January and February), 30% of time spent on the plot and 26% of visits to the plot took place; in spring (March, April and May), 39% of time and 42% of visits took place; in summer (June, July and August), 21% of time and 21% of visits took place; and in autumn (September, October and November), 10% of time and 12% of visits took place. The time spent visiting was greatest in May and June, but the largest number of visits was in July. There was no statistically significant correlation between the total number of visits made over the course of a year and the distance people lived from their allotment (Kendall's tau, tau = -0.01, Z = -0.20, $p = 0.84$).

3.3. Transportation

Transportation to the allotment was split between bicycle, car, foot, public transport, and "other" (which included one motorcycle journey, and the rest of unknown type), and 158 diaries were included in this analysis. In total, 56% of journeys were made by car, 36% by foot, 8% by bicycle, 0.4% by public transport, and 0.05% by "other". The typical distance travelled differed significantly between different forms of transport (Kruskal-Wallis test, H = 32.8, df = 4, $p < 0.0001$). The median car journey length was 1.6 km, and the distribution of car journey lengths was strongly skewed due to people who lived unusually far from their allotment plots (see 3.1.). The median walking journey distance was 1 km, and the median bicycle journey distance was 1.3 km.

Ninety-five percent of walking journeys were under 2.1 km (according to Google Maps, this is around half an hour of walking time). Walking and cycling was most popular if people lived less than 5 km from their allotment (n = 141); over 5 km, most people were dependent on car travel (n = 17), with the maximum walking journey length being 8.0 km and the maximum cycling journey length 4.2 km, but the maximum car journey length 9.2 km (Figure 3).

3.4. Water use

Water use was highly variable amongst the 149 participants included in this analysis and ranged from 288 litres over the course of the year to 120,013 litres. The median annual water use on an allotment was 7595 litres, and the data were heavily skewed towards people who used a substantially greater amount of water on their plot. The median annual amount of water used from water butts (which also included other non-mains sources of water, such as river water) was 486 litres, and the median amount of water used from the mains was 5993 litres (Figure 4).

The types and total amounts of water used varied by month (Figure 4). Overall, 13.2% of water use occurred in spring, 80.8% in summer, 5.7% in autumn and 0.1% in winter. In spring, 11.8% of mains and 26.6% of water butt water was used; in summer, 82.4% of mains and 65.5% of water butt water was used; in autumn, 5.7% of mains and 7.0% of water butt water was used; and in winter, 0% of mains and 0.4% of water butt water was used. There was a peak in the use of water butt water in May followed by a decline in June and none used in July, and a corresponding increase in the amount of mains water used in June and especially in July as a result; water butts provide a limited storage for water, and dry conditions meant that they were used up before the peak of the summer. The small increase in water butt water usage in the autumn can be interpreted as people going back to using water butt water once rain had replenished supplies.

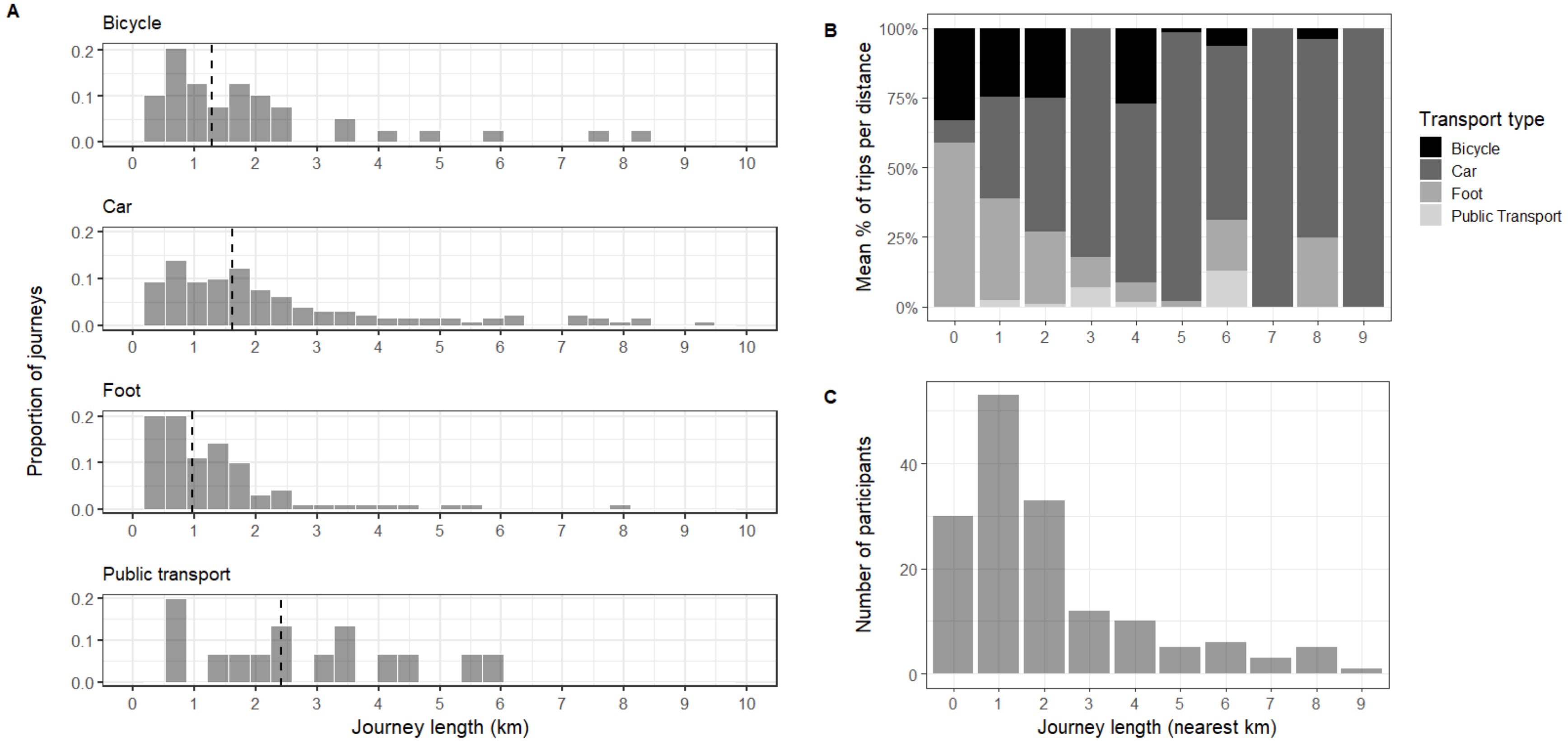


Figure 3. Graphs showing variation in use of different transport models and distances travelled from home to plot by allotment gardeners (n = 158). **A**: Distribution of journey lengths for each transportation type (bicycle, car, foot and public transport); **B:** Distribution of transportation type for each km travelled; **C:** Distribution of distances travelled by participants, not split by transport type.

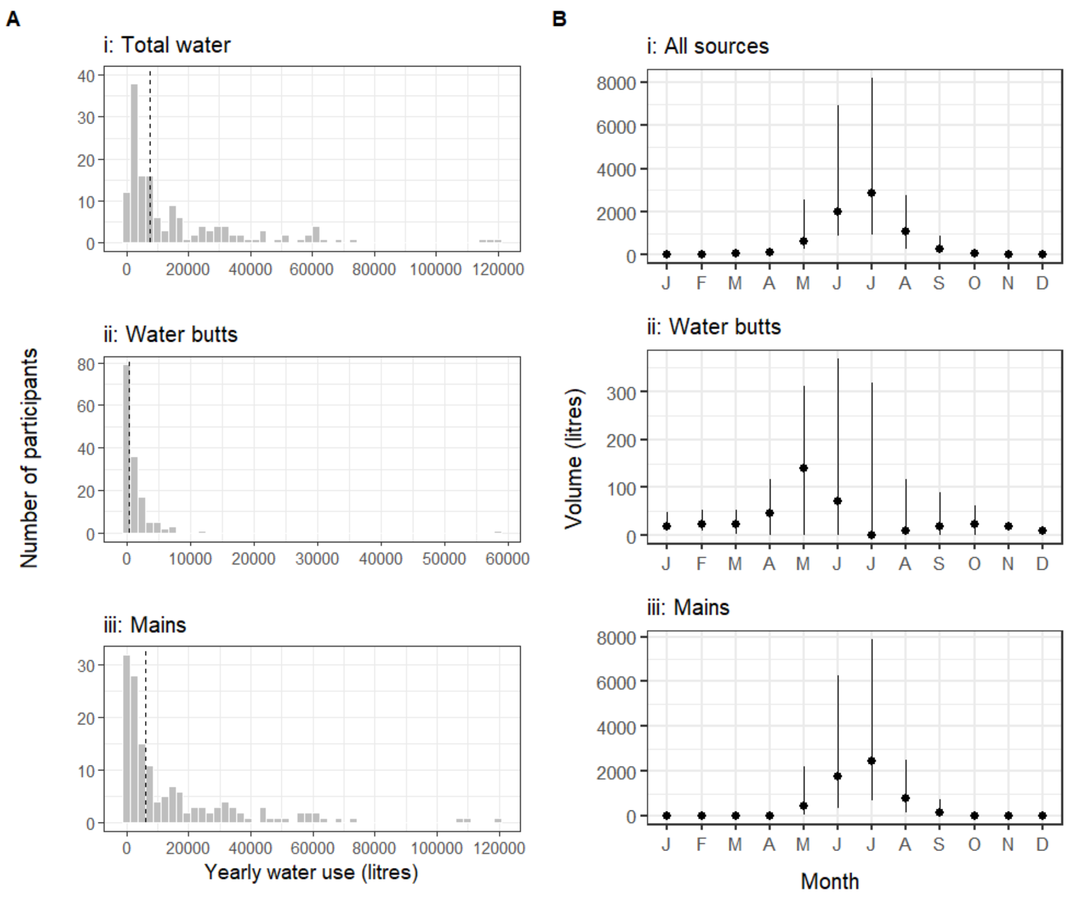


Figure 4. Water use by allotment gardeners (n = 149) over the course of a year. **A**: Total water use, water from water butts, and water from mains supply. Dashed lines indicate the median water use, for (i) 7595 litres; (ii) 486 litres; and (iii) 5993 litres. **B**: Monthly median (points) and interquartile ranges (lines) of litres of water used on allotments from water butts, mains water, and all sources.

3.5. Compost, manure and topsoil

One hundred and thirty-three (86%) participants added compost to their plot; 110 (71%) added manure, and 26 (17%) added topsoil. The median total annual amount of compost, manure and topsoil added to an allotment plot was 1575 litres. The median amount of compost per year added by people who used compost was 850 litres; the median use of manure by manure users was 992 litres; and the median use of topsoil by topsoil users was 85 litres (Figure 5). However, when considering all participants (n =

155 for this analysis) rather than just those using each of these inputs, the median amount of compost was 688 litres; manure was 275 litres and topsoil was 0 litres. We asked participants to disclose the origins of the compost they used: council waste comprised 5.3% of the total volume of compost applied by all our participants, home food waste 23.8%, plot waste 54.6%, and purchased compost 16.1%. Therefore, 83.9% of compost used by volume was recycled material, whether from the home, garden or local council. Many respondents used a mixture of sources for their compost, and overall 76 (49%) participants brought home waste to their plot to compost, 92 (59%) purchased compost, and 94 (61%) composted plot waste. Of participants who answered the general question regarding whether they used peat free compost (n = 156), 92 (59%) only used peat-free, 12 (8%) used mostly peat-free and 52 (33%) did not use peat-free compost. Levels of compost, manure and topsoil all varied throughout the year, as demonstrated in Figure 5 showing monthly variation for people using each of these inputs.

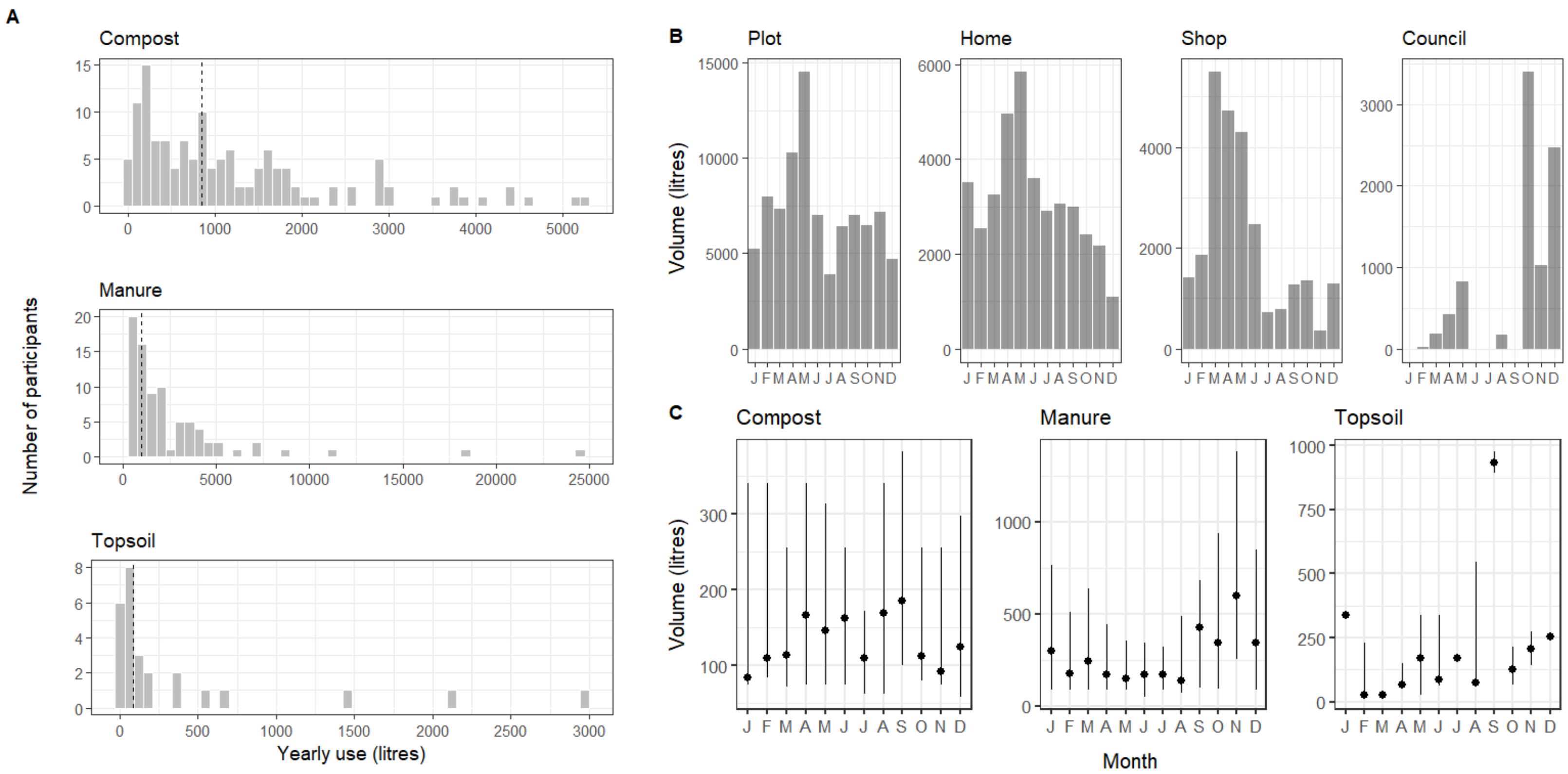


Figure 5. Use of compost, manure and topsoil by allotment gardeners (n = 155). **A:** Distribution of yearly use (litres) of compost, manure and topsoil with dashed lines indicating the median use of each resource. **B**: Monthly total use of compost split by source (plot, home, shop or council). **C**: Monthly median (points) and interquartile ranges (lines) of compost, manure and topsoil additions.

3.6. Fertilisers, pest and weed control

Participants recorded a wide variety of fertiliser use (from organic and non-organic sources) as well as pest and weed control inputs. Frequency of inputs varied across the year and peaked in late spring and early summer (Figure 6). Fertiliser was the most commonly added of these inputs, with 131 participants using fertiliser at some point during the year, varying from once to 48 times. The median number of days on which participants applied fertiliser was 7, with the distribution skewed to a small number of participants applying particularly larger than average amounts. Pest control was applied by 120 participants, ranging from once to 31 times. Weed control was used by 66 people, ranging from once to 20 times (this count did not include hand weeding of plots). The median number of days on which pest control was applied was four days in the year, and the median number of days for application of weed control was twice. Similarly to fertiliser use, both pest and weed control were skewed towards a few participants whose gardening techniques involved much greater than average use (Figure 6). Table 1 shows the counts for the total number of days on which general categories of each of these applications was used; see Supplementary Information 2 for a full list of all the methods by which people fertilised their plots, and used pest and weed control.

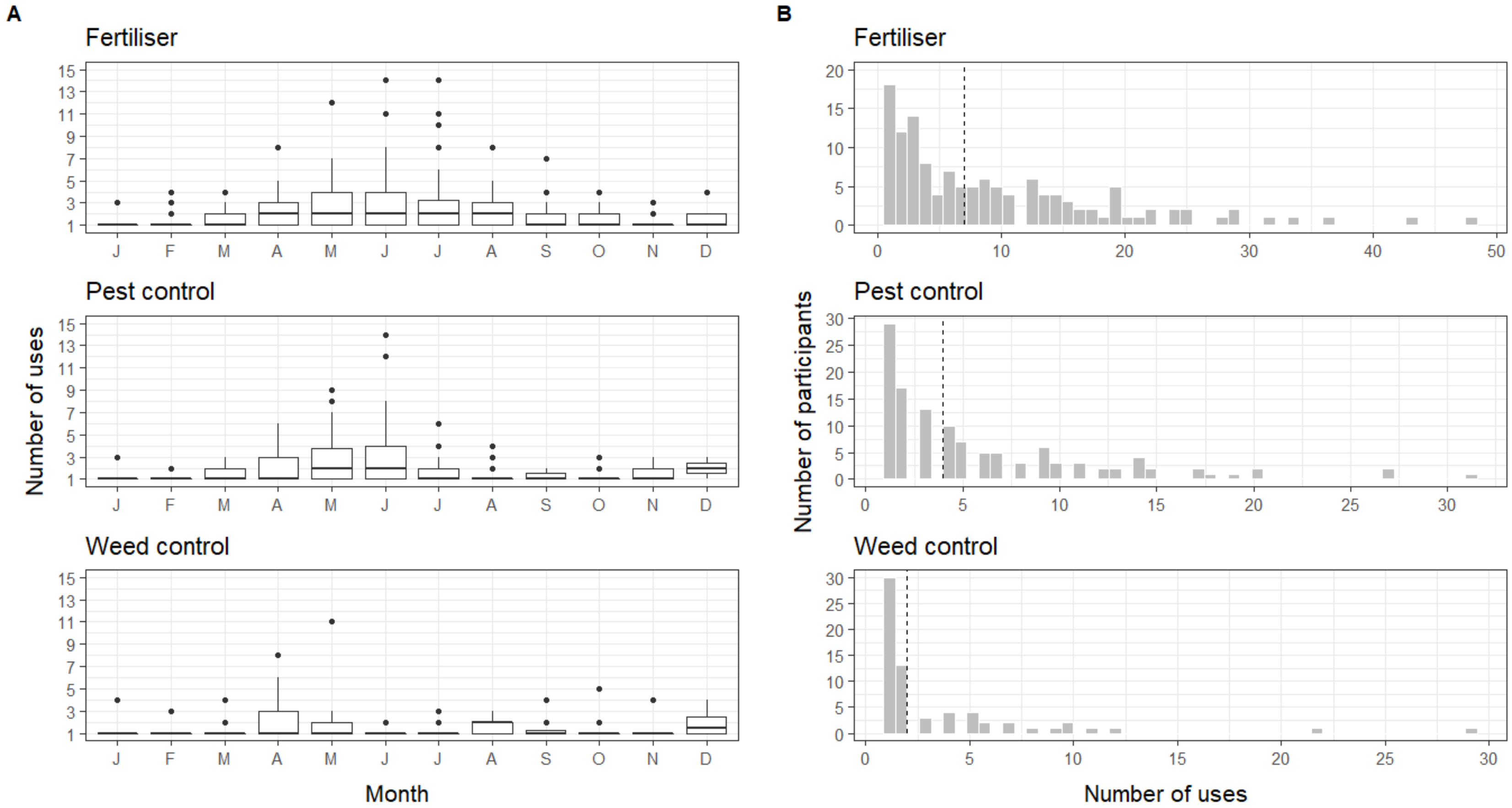


Figure 6. Fertiliser, pest control and weed control use on allotments (n = 162). **A**: Monthly median and interquartile ranges of number of days on which fertilisers, pest control measures and weed control measures were applied **B**: Distribution of number of days in the year on which fertiliser, pest control and weed control were applied. Dashed lines indicate median number of uses.

Table 1. General categories and number of days on which types of fertiliser, pest control and weed control were used on allotments from a total of 14992 plot visits by 163 gardeners. Some types which were used once or twice did not fit into these categories and are excluded from the table; see Supplementary Information for a full list and count of all types.

Fertiliser		**Pest control**		**Weed control**	
General type	**Number**	**General type**	**Number**	**General type**	**Number**
Branded e.g. Tomorite	358	Pellets (primarily slug)	530	Chemical weedkiller, e.g. Roundup	129
Seaweed, comfrey and nettles	300	Insecticide and poison	91	Bark, cardboard and woodchip	74
Chicken manure pellets	270	Homemade, e.g. washing up liquid spray	46	Fabric, mesh and carpet	21
Fish, blood and bone	190	Netting, fleece, and wire	42	Plastic	15
General (un-branded/ undisclosed brand)	184	Traps, e.g. beer traps for slugs	27		
Lime	38	Nematodes	9		

3.7. Overall resource requirements

The above results allow us to estimate the average yearly resource use on allotment gardens per metre squared at the whole plot scale (i.e. including both cultivated areas and other infrastructure, such as paths – see earlier discussion in 2. Methods). Due to the strong skew in all resource data, the median was used to calculate this.

Overall, the average (median) allotment user would visit their plot 87 times, each visit involving travel of 1.6 km in each direction: a total of 139 km travelled per year (with those journeys most likely to be made by car, or on foot, slightly less likely by bike, and rarely by public transport). They would pay £37 for the rent on their plot. Per square metre of their allotment, they would use 0.6 hours of labour and 30.4 litres of water over the year. If they used compost, manure or topsoil, their use per square metre would be 3.4 litres of compost, 0.3 litres of topsoil, and 3.9 litres of manure. If they used additional fertilisers, pest control methods and weed control methods on top of hoeing and hand weeding, they would do this seven, four and two times respectively over the course of the year (Figure 7).

Using some of the above results, we can also calculate the levels of some resources needed to produce one kilogram of fruit or vegetables. On average it is estimated that allotment gardeners produced an average yield of 1.8 kg m^{-2} the entire area of an allotment (Edmondson *et al*., 2020a). Therefore, resource requirements per kilo of produce are 16.9 litres of water, and, if the following are used, 1.9 litres of compost, 0.2 litres of topsoil, and 2.2 litres of manure.

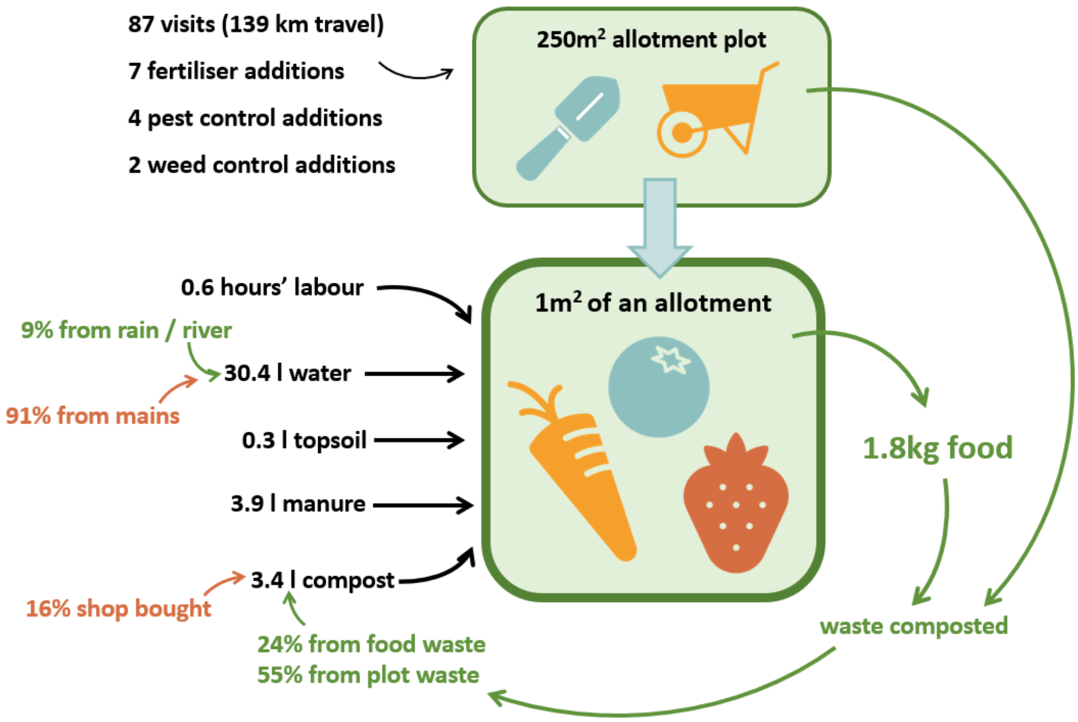


Figure 7. Yearly resource use on allotment plots, and specific requirements to produce 1kg of fruit and vegetables on an allotment, demonstrating what proportion of recycled and non-recycled resources are used in each input. Data uses the median for each resource (n = 163).

3.8. Heterogeneity of data

As the above results for individual resources indicate, there is considerable heterogeneity of data regarding many of the above resource uses, which is also important to discuss alongside presenting the overall averages as in section 3.7. Overall, all results (for transportation; water; compost, manure and topsoil; and fertilisers, pesticides and weed control) were strongly negatively skewed. This demonstrates that the mean results were being driven above the median by fewer participants using proportionally greater amounts of each of these resources (or in the case of transport, travelling a particularly great distance compared to the majority).

4. Discussion

Urban horticulture, in the form of allotment gardening, uses resources in a variety of forms. These resources are a necessary component of food production taking place in allotment gardens, which provide fresh produce for those involved, alongside other associated benefits and important ecosystem services (McClintock *et al*., 2013; Lin *et al*., 2015; Speak *et al*., 2015; Webber *et al.*, 2015; Borysiak *et al*., 2017). As global agricultural land currently under-produces fruit and vegetables relative to global need based on nutritional guidelines (Bahadur *et al*., 2018), and British vegetable production in tonnes has fallen for the past four years in a row (DEFRA, 2020a), UH presents an opportunity to increase the global supply of fruit and vegetables at a local level for urban residents. Here we present the first year-round investigation into resource requirements for allotment gardening, a key initial step in the assessment of the sustainability of this potentially important form of soil-based food production. Using a citizen science approach, we have derived a country-wide picture of the activities of allotment gardeners, including the seasonal variability in resource use and requirements. Combined with the work of Edmondson *et al*. (2020a), we were then able to determine the resource requirements to produce one kilogram of produce on an allotment. Resources varied in their roles and wider implications for allotment sustainability.

However, our results also demonstrated a great deal of heterogeneity with strong negative skew for each resource. This is perhaps to be expected, as it is more likely that there exists somebody who uses an unusually large amount of, for example, water, than somebody who uses none at all; there is indeed a *minimum* resource requirement for horticultural cultivation. Upper and lower bounds of this could be an interesting avenue for further research, along with exploring any patterns at the individual level: for example, do those who consume a particularly great amount of water also use a greater-than-average amount of compost and fertiliser?

4.1.Fertilisers, weedkillers, pesticides and compost

Previous research has found that allotment gardening maintains high levels of soil quality and its associated ecosystem services (Edmondson *et al*., 2014), and our results, showing relatively low incidences of chemical applications, and high levels of use of manure and compost, are consistent with this, demonstrating that allotment gardeners participate in management practices conducive to the maintenance of soil health. One element of these inputs is food and allotment waste. Whilst we are only just starting to quantify the capacity of UH to absorb urban waste (Goldstein *et al*., 2016b), our research demonstrates that allotment gardeners are primarily sourcing their compost from plot or home food waste, diverting compostable waste from landfill or incineration to recycling on the allotment. Use of shop-bought compost was relatively low, and 67% of participants recorded that they used only, or mostly, peat-free compost, removing the greenhouse gas and habitat destruction costs associated with peat, which are orders of magnitude higher than for peat free alternatives (Boldrin *et al*., 2009).). Further research would need to be undertaken to discern whether this is a representative level of peat awareness amongst all allotment and home gardeners, or whether this sample were particularly attuned to the merits of using peat free compost. Further to this, 83% of participants grew wholly or mostly organically (as self-reported), a proven method for the maintenance of soil health (Lorenz, 2015).

Our results detail a wide range of organic and non-organic fertilisers, pest control and weed control used by allotment gardeners, which present a challenge when attempting to understand the consequences of allotment management practices on an overall, national scale. Whilst many of the applications used by our participants were organic (such as seaweed), weedkillers such as glyphosate, and pest control methods such as slug pellets were also used. These may have negative consequences for some wildlife (Puvis and Bannon, 1992; Relyea, 2005). Over-application of non-organic fertilisers also has negative consequences for long-term soil health, water, and potentially human health (Altieri *et al*., 1999); however, the median level of applications of all fertilisers, weedkillers and pest control was low. On a national or city-wide scale, problems could present if a particular allotment site had a high density of gardeners using greater-than-average biocides. Other management techniques such as the high levels of compost and manure addition detailed above suggest that allotment gardeners generally maintain good levels of soil health and wildlife-friendly gardening practices. Use of compost and manure mean soil nutrients are restored without an over-reliance on synthetic fertilisers, which helps maintain good soil quality (Beniston and Lal, 2012). In comparison to commercial arable farming in the UK, where pesticides and herbicides are applied an average of 34 times per year (Garthwaite *et al*., 2018), and 99% of potato crops and 75% of brassica crops (for example) receive synthetic fertiliser applications (DEFRA, 2020b), overall application levels of fertiliser, weedkillers and pesticides were very low on allotments.

4.2. Water use

High soil quality also means that water use requirements of UH are likely to be lower than in commercial horticulture. However, with regard to our results on water use, it is important to note that the climatic conditions of the year during which this research was undertaken. For the UK, the summer of 2018 was the joint hottest on record (Met Office, 2018). A heatwave from May to August brought drought conditions to much of the country, and in some places broke records for the longest number of consecutive days without rainfall. Diary participants were fully aware of this, with many comments and observations regarding the summer weather (for example, diary entries from one participant: June 24th, ‘No-one can remember when it last rained’; July 18th, ‘No rain for at least two months'; July 23rd, 'Plants are dying'). The IPCC predicts that the UK will have more frequent hot, dry summers in the future due to climate change, and models found that the 2018 heatwave was thirty times more likely to have occurred than if climate change had not been a factor (Met Office, 2018). The Met Office also predict that 50% of summers could mirror the 2018 heatwave in the future (Met Office, 2019). Our data on water use requirements are therefore both historically unusual, as more watering was required than in a year of typical rainfall, but also important in the context of future climate change and the resultant changing water use requirements of UH. Our results have clearly demonstrated that with dry conditions beginning in late spring and early summer, winter stocks of rainwater harvested by individual gardeners are insufficient in the majority of cases to meet the water demands of an allotment into the summer months.

4.3. Resource capture and recycling

These results suggest opportunities for a wider integration of UH into urban energy and materials flows in order to take advantage of potential opportunities for resource recycling in the urban system. There are a number of forms that this could take, including greywater recycling, demolition and construction waste material recycling for use in infrastructure, and diversion of compostable waste from other sources. Two which arise from this study are increasing the harvesting of rainwater and the capture of compostable waste. Considering the limitations to allotment gardeners' capacity to collect and store water, which was insufficient to meet the demands of the 2018 heatwave, it is important to understand whether this is a limitation of collecting potential, storage, or both. Allotments, by virtue of being collections of plots on sites with few buildings or other hard surfaces, provide limited scope for rainwater harvesting; small sheds or greenhouses are typically the only collecting surfaces available. It may be that this limits the potential for water collecting. However, it is also important to investigate opportunities for greater storage of winter rainfall, potentially at a site-wide or even community level, and the potential for water collected elsewhere (e.g. on buildings) to be diverted for UH use. British winters are becoming wetter (the most recent decade was 12% wetter in winter than 1961-1990; Met Office, 2019), and

February 2020 broke rainfall records across the country for the wettest February ever, as part of the wettest ever winter (Met Office, 2020). An opportunity for co-benefits therefore exists here through the expansion of water storage facilities across a city to help mitigate the flood risk from heavy rainfall winters, which could then be a source of water for UH during drier months. If UH is to be upscaled with its current reliance on mains water, the pressure on the urban water supply would be exacerbated; therefore, it is key for policymakers to consider water reuse and harvesting when planning future UH sites. Further integration of UH into the sustainability fabric of a city could also utilise wastewater, if safely treated; this is another avenue that warrants further investigation (Buechler *et al*., 2006; Miller-Robbie *et al*., 2017).

The capture of compostable waste on a citywide level is the second key opportunity, highlighted by this research, to increase the sustainability of UH and integrate urban resources. Whilst we found that the majority of an allotment gardener's compost comes from home and plot waste, some integration of wider urban compostable waste can also be seen in the 5.3% of compost used that was from local authority green waste sources. Both this municipal green waste, and a wider integration of home food waste from non-gardeners to centralised compost sources that could be used in UH, would further reduce the need for gardeners to purchase compost, and prevent the disposal to landfill or by incineration of compostable material by non-gardeners. This idea is in its infancy in practice but has the potential to reduce the pressure on landfill, save on costs of central waste management in cities, and recycle nutrients currently lost through waste (De Zeeuw *et al*., 2011). Overall, with 83.9% of allotment gardeners' compost already coming from recycled sources, it is clear that the inclination to use sustainable compost sources is high amongst gardeners and suggests they would be favourable to the introduction of other reused sources in the future. Just under half of our participants brought their home waste to compost on the plot, and just over half composted the waste from their plot itself (a lower number than that found by Edmondson *et al*., 2014, who reported 95% of allotment gardeners composting plot waste on-site and 75% adding household waste), which suggests that there is a great deal of potential to expand the use of compost from personal and potentially municipal waste in the future. However, we do not know how many participants used their compostable home waste for their home gardens; high levels of home composting for gardens would reduce the potential amount available for UH; this also applies to participants who potentially brought 100% of their compostable waste to use on the plot and still needed to make purchases of commercial compost in order to have the amount they needed. Manure would probably continue to be sourced from animal agriculture in rural areas; however, city farms could also provide a source for this.

4.4. Human resources: time, money and travel

One resource unquantified by our study is the amount of money that gardeners spend on their allotments beyond the price of their rent. An investigation into this could provide an important insight into whether there are financial barriers that may prevent those from lower incomes from participating in UH, especially in light of recent research demonstrating that low-income areas have disproportionately suffered from allotment site closures over the past half century (Dobson *et al*., 2020). Our results demonstrate a huge variation in rent costs across the country, with the highest rates standing at £280 per year. Gardening has been shown to be an important opportunity for more deprived communities to actively participate in creating their own food security nets as well as creating thriving neighbourhoods through the associated wellbeing and physical health benefits of participating in UH (Travaline and Hunnold, 2010; Milbourne, 2012; Poulsen *et al*., 2014). Therefore, an important policy consideration is the need to distribute food growing areas across a city in a way that ensures equitability of local access to these areas. Given the evident time commitments required for allotment gardening, it is understandable that using a car for transportation to the plot may be a preferred form of transport for people who are time-poor. With 95% of walking trips under 2 km in length, our results suggest that if somebody lived further than this from their allotment, walking became too time-consuming to be an effective mode of transportation. However, there was no significant relationship between the distance from their plot that somebody lived and the number of times they visited their plot. This therefore appears to necessitate access to a vehicle to successfully participate in UH if the cultivation space is more than 2 km from a person's residence. Ensuring that sites of urban food production are within walking distance for participants would enable non-car owners to participate in UH, as well as limiting the use of cars and their associated emissions and congestion impacts.

5. Conclusions

UH has hitherto been an under-researched component of urban sustainability, and its place within the material flows of cities is poorly understood. As interest in upscaling UH to contribute to sustainable food production in cities grows, it is equally important to understand its resource demands. Our results suggest that there is the potential for high levels of sustainability: recycling rainwater, low pesticide use, recycling of household food waste and garden green waste, active travel, and the known health and wellbeing benefits of UH. Typical allotment management practices are conducive to the maintenance of soil health and ecosystem services, with an emphasis on the use of compost and manure. However, it is also clear that this potential is not always realised as fully as it could be, and that opportunities exist to further integrate UH into citywide resource use, for example by increasing the harvesting of rainwater to reduce the demands of UH on mains water supplies, or by spatial planning of UH sites to minimise car travel. These results help to develop a more holistic picture of UH, and provide guidance for policymakers and practitioners seeking to integrate UH into the development of more sustainable cities.

Chapter 5

"My little piece of the planet": The multiplicity of wellbeing benefits from allotment gardening

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Abstract

Purpose

Participation in urban horticulture (UH) is increasing in popularity, and evidence is emerging about the wide range of social and environmental benefits "grow your own" can also provide. UH can increase mental and physical wellbeing, as well as improve nature connectedness, social capital and community cohesion.

Approach

This study focuses on allotments, which is one of the dominant forms of UH that takes place in the United Kingdom. 163 volunteers in England and Wales participated in keeping a year-long allotment diary as part of a citizen science project investigating activities on allotment gardens. This study examines the unprompted comments that 96 of these gardeners offered as observations when visiting their allotment plots.

Findings

Participants recorded high levels of social and community activities including the sharing of surplus food produce, knowledge exchange, awareness and interaction with wildlife, emotional connection to their allotment, appreciation of time spent outside and aesthetic delight in the natural world around them.

Originality

At a time when waiting lists for allotment plots in the United Kingdom are on the rise, and allotment land is subject to multiple pressures from other forms of development, this study demonstrates that these spaces are important sites not only for food production but also health, social capital and environmental engagement.

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1. Introduction

Urban horticulture (UH), the horticultural production of fruit and vegetables within cities, is an area of research becoming increasingly relevant to policy. It has been highlighted by The Intergovernmental Panel on Climate Change as a potential way to ensure food security in an increasingly globalised world (Mbow *et al.*, 2019), ensuring that people have access to enough safe and nutritious food (World Food Summit, 1996). Indeed, recent research has demonstrated that there is a promising level of yields potential from expanding UH land in cities (Edmondson *et al.*, 2020a; Mcdougall *et al.*, 2020). However, food provision is not the only benefit of UH. Participation in UH also has the potential to increase wellbeing in a number of ways.

Two prominent British gardening organisations, Sustain (https://sustainweb.org) and Garden Organic (https://gardenorganic.org.uk) have publicised this with the message that UH can provide multiple benefits for both physical and mental health (e.g. increasing fruit and vegetable consumption, increasing overall activity levels, increasing social interactions, and reducing stress levels; Schmutz *et al.*, 2014). A systematic review of occupational health literature (Genter *et al*., 2015) found that allotment gardening, a key form of UH in the United Kingdom, provided similar wellbeing benefits to more formal therapy gardening groups, and a meta-analysis by Soga *et al.* (2017a) found across-the-board positive benefits of gardening on health. Gardeners' own opinions support these findings, with recreation and mental health coming top of a list of reasons that 144 gardeners in Philadelphia participated in food growing (Blair *et al.*, 1991). In Tokyo, a survey of 332 people found that those who participated in allotment gardening reported better physical and mental health than those who did not (Soga *et al.*, 2017b). Results from the European Quality of Life Survey also support these findings, where people who grew their own food reported feeling happier than those who did not (Church *et al.*, 2015). These wellbeing benefits of UH have been found to occur even after a single gardening session (Wood *et al.*, 2016), and for a number of different groups of people, such as refugees (Harris *et al.*, 2014); prisoners (Richards and Kafami, 2008); and school groups (Ohly *et al.*, 2016). However, the review of research specifically on allotment gardening (Genter *et al.*, 2015) found that there was a paucity of studies of individual allotment gardeners in comparison to those participating in group gardening sessions, and recommended that further investigation is needed in the research to explore the impact of everyday allotment gardening for individuals.

More broadly, there is an established evidence base of the benefits of spending time outdoors, and developing nature connectedness (the extent to which people feel that their relationship with nature forms part of their identity; Schultz, 2000), on physical and mental wellbeing (Martin *et al.*, 2016). Doctors' surgeries in Scotland have piloted 'prescribing' outdoor activities to treat mental and physical health complaints (Fleischer, 2018). The idea of a 'nature deficit disorder' (Louv, 2005) has become a popular lens through which to discuss the lack of nature connection amongst children and adults in the twenty-first century. This is particularly an issue in urban areas, which present an obvious challenge for people to connect with wildlife and greenspace when contrasted to the lives of people living in rural areas; indeed, rural dwellers experience less life stress in childhood as a result of their nearby access to greenspace (Wells and Evans, 2003). The British population is forecast to be 90% urban by 2050 (United

Nations, 2019), meaning that barriers to nature connectedness specifically faced by city dwellers are relevant topics for most of the population. It is as important for people to experience wildlife in their ‘own backyards’ as in a holiday or tourism setting (Curtin, 2009), suggesting that spaces within urban areas where people can encounter wild animals and birds are particularly precious. The psychological benefits of spending time in green spaces in urban areas also increases as biodiversity (or perceived biodiversity) increases (Fuller *et al.,* 2007).

The wellbeing benefits of nature connectedness become even more important when placed in the context of the state of mental health in the UK. The OECD estimated in 2018 that mental health problems cost the UK over one billion Euros per year, or 4% of GDP (OECD, 2018). Against this general background, there can additionally be marked increases in demand on mental health services generated by specific national or global pressures, as demonstrated by the current coronavirus crisis, which is expected to directly cause at least half a million more people in the UK to experience mental ill health (NHS Providers, 2020). Metal health in the UK worsened by an average of 8.1% during the first two months of lockdown and social distancing (Banks and Xu, 2020), and with the impacts of lockdown particularly acute in urban areas, long-term mental health impacts for city dwellers may be severe.

In the above context, and with the additional recognition of its potential role in increasing food security, particularly in urban areas (Edmondson *et al*., 2020a; Mcdougall *et al.,* 2020), it is timely to investigate the potential opportunities to ameliorate poor mental health, and engage in physical activity and connection to nature, that are presented by participation in UH. Allotments are a key form of UH in the UK (Crouch and Ward, 1997; Acton, 2015), with around 330,000 allotment plots nationwide (Campbell and Campbell, 2013). They cover a land area of 135 km^2 across the country. Plotholders rent their allotment plot for a yearly fee, and most plots consist of a patch of land (approximately 250 m^2) adjacent to other plots, forming allotment sites, which can vary in their size depending on the number of plots. Allotments are predominately owned by local authorities, with, in many cases, individual allotment societies renting the land and letting plots out to tenants, although some privately-run sites also exist. Allotments were originally conceived as a means to widen access to food production for urban dwellers (Crouch and Ward, 1997), and plotholders are legally obligated to maintain minimum cultivation levels of fruit and vegetables on their plot. However, many allotment gardeners also grow ornamental plants and have space on their plot for relaxation, such as garden chairs and tea making facilities.

Although widely recognised as an important opportunity for people to benefit from growing their own food, particularly in urban areas, there has been relatively little systemic research into the practices, resource use, and personal benefits derived from allotment gardening. Here we report some of the results from a UK-wide citizen science project. Citizen science is a unique way to collect data in collaboration with members of the general public through their active participation in the research process Robinson *et al.*, 2018): here, the volunteer citizen scientists participated by sharing their activities on their allotments for every visit over the course of a calendar year. This involved gardeners keeping year-long allotment diaries, recording a range of things such as time spent on different activities and water and fertilizer use, but also included an opportunity for recording unprompted comments. These comments are the focus on this analysis, and overall they provide a positive picture of the impact of allotment gardening on mental and physical wellbeing. Our findings add to the growing evidence base suggesting a strong link between allotment gardening and a spectrum of benefits for the individual, such as community cohesion, mental health and nature connectedness, and specifically address the research gap identified by Genter *et al.* (2015) concerning a lack of data on individual, as opposed to community group, allotments.

2. Methods

Allotment gardeners across the UK were recruited through online and in-print advertising (primarily Facebook, the MYHarvest website at https://myharvest.org.uk, and the Royal Horticultural Society magazine). In total 437 people, all of whom were individual allotment gardeners, signed up to complete a year-long (2018) allotment diary from all four constituent nations of the United Kingdom. Research was conducted in line with the University of Sheffield ethical standards and guidelines. Ethical approval was given by the University of Sheffield (Application 01284) for the project, and participants consented to the use of their data in this research project, and agreed that they could drop out of the project at any time if they so wished. They were asked to detail the amount of time they spent on their plot, resources used such as water or compost, and planting and harvesting activities. At the end of the year, participants were sent a stamped addressed envelope to return their diary pages, which were then scanned (so that originals could be returned to those who had requested this) to and data extracted manually. One hundred and sixty three participants returned their diaries, forming a geographical distribution across England and Wales. Unfortunately, no diaries were returned from Scotland or Northern Ireland.

To the best of our knowledge, none of the allotment gardeners responding to this study were engaged in more formal horticultural therapy, but all practiced allotment gardening for the primary purpose of the production of fruit and vegetables, as is typical (and indeed, legal obligated) in the United Kingdom. Participants were not directly asked about wellbeing, but on each diary page (corresponding to a visit to the allotment) there was a space specifically for 'Notes' which participants could use for any thoughts or observations they wanted to make. Ninety-seven of the 163 participants chose to write spontaneous observations and thoughts in this section for at least some of their allotment visits, giving 342 entries in all. We extracted the text of the Notes section for these entries. Participant start dates spanned late 2017 to early 2018, and as a result the full year was slightly varied in actual dates for each participant. The extracted Notes span a date range of 27 December 2017 to 25 February 2019. Two entries were undated comments written at the end of the participants' diaries.

These comments described wildlife encounters, non-plot related activities such as participating in communal building projects, social interactions on the plot, use of surplus harvests, and so on. As it was a free space to write in, the comments we received were very wide ranging. Therefore, we then analysed these comments to extract the different broad themes of the texts, coding comments into eleven dominant thematic strands. These categories were deduced a posteriori, after grouping comments together and seeing where dominant themes emerged (a "cutting and sorting" technique, as described in Ryan and Bernard, 2003; Popping, 2016; Vaughn and Turner, 2016). After comments had been assigned a dominant theme, any comment related less strongly to another theme as well as its main one was also given a sub-category so it could be included when analysing the comments theme by theme. Each comment was also coded to be positively, or negatively, related to its dominant theme, where this was applicable (such as negative or positive attitudes towards the weather). For example, "Educating children of visiting family re allotment culture" (09/08; hereon this denotes the date of example comments; see Supplementary Info for full list of comments, dates, and anonymised participant ID) was categorised primarily as 'Social' and secondarily as 'Knowledge', with no positive / negative coding as there was no obvious emotion communicated by the participant in this comment. However, "So very very dry – no rain still, not a lot of pollinators in sight, no bees probably little nectar in such dry weather" (10/07) was coded primarily as 'Weather', secondarily as 'Wildlife', and with a negative associated emotion. All comments were weighted the same for analysis and themes were checked by a co-author after the initial effort to separate by theme by the other authors. Coding was carried out by hand in Microsoft Excel and statistical analysis to produce figures was undertaken using R 4.0.0 (R Core Team, 2020).

3. Results

3.1. Overall thematic observations

Some participants had included more comments entries over the year than others, which led to a slight bias in the thematic interpretation of the data. However, as shown in Figure 1, which demonstrates the number of comments per participant per emotion, the bias effect was minimal, with the vast majority of participants noting only one, two or three comments of either emotion (positive / negative) over the course of the year (Figure 1).

Overall, comments related to social activities or expressing emotions were the most common across the aggregation of primary and secondary thematic types (Table 1).

Comments related to social activities were the most commonly expressed in positive terms, and comments related to the weather were the most commonly expressed in negative terms (Table 2). On average, there were a median of 6 negative and 13 positive comments made each month. Positive entries started earlier in the year and ended later than negative responses; June and July were the only months with more negative than positive responses, and these months were dominated by the theme of weather in the negative comments (Figure 2). See Supplementary Information for a full list of comments with their associated themes.

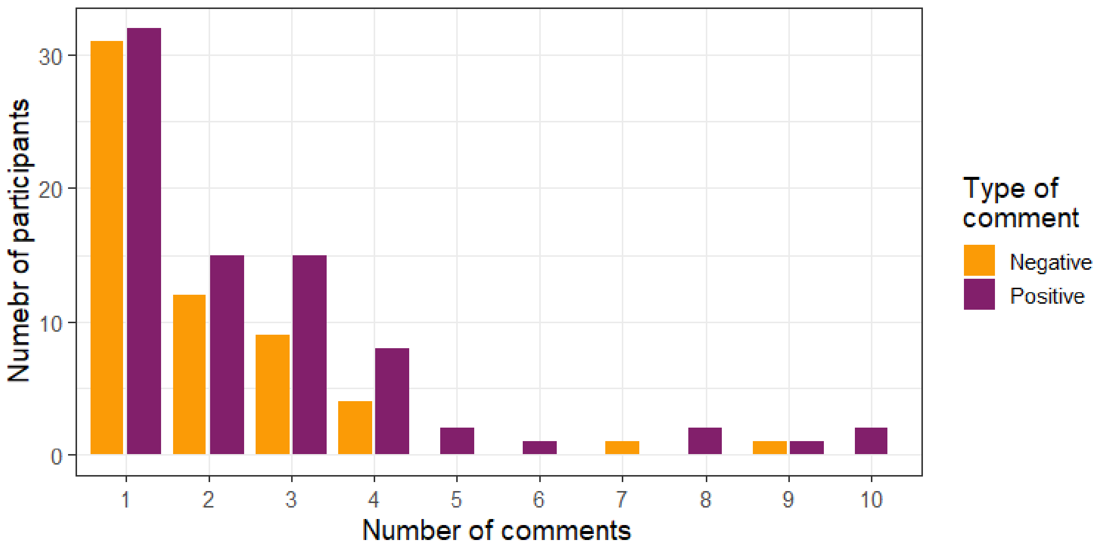

Figure 1. Graph showing the number of comments received per participant of a negative or positive nature in allotment diaries over the course of the year.

Table 1. Thematic analysis of comments written in allotment diaries over the course of a year.

Theme	Number of entries, primary theme	Number of entries, secondary theme	Total number of entries associated with theme
Emotional	44	22	66
Health	10	3	13
Knowledge	4	5	9
Organisation	19	11	30
Pride	12	3	15
Relaxation	4	1	5
Sharing	18	10	28
Social	86	11	97
Surplus	6	9	15
Weather	83	11	93
Wildlife	56	9	65

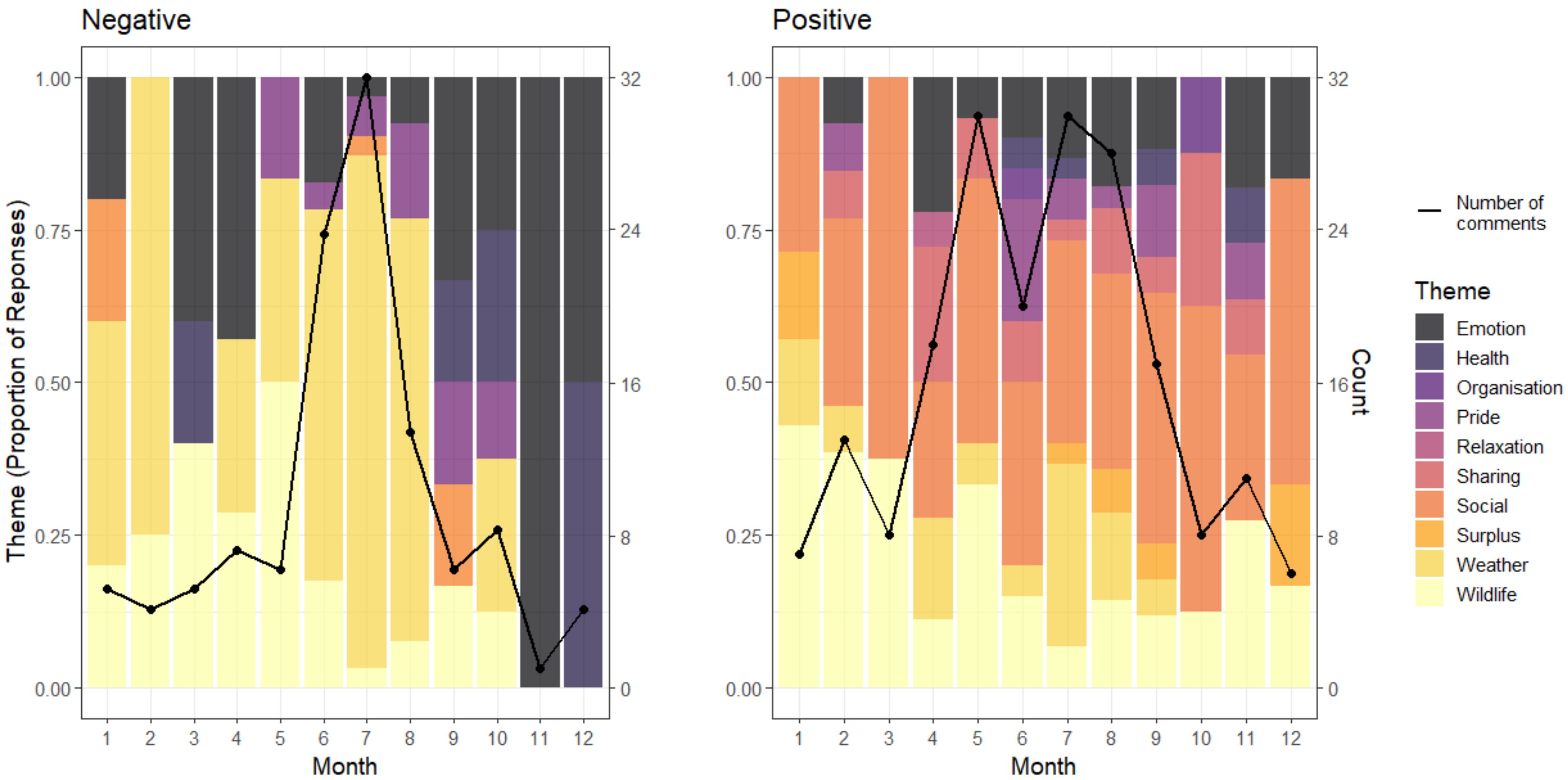

Figure 2. Graphs showing the count, and distribution of themes, within negative and positive comments made in allotment diaries for each month of the year.

Table 2. Analysis of positive or negative emotions associated with different primary themes of comments written in allotment diaries over the course of a year.

Theme	Positive comments	Negative comments
Emotional	25	19
Health	4	6
Knowledge	0	0
Organisation	2	9
Pride	11	0
Relaxation	1	0
Sharing	18	0
Social	71	3
Surplus	6	0
Weather	23	60
Wildlife	39	17

3.2. Specific themes and examples

Comments related primarily to the Emotional theme comprised 13.1% of responses. They generally captured a spontaneous observation of a participant's emotional response to their presence on the plot, for example, "A lovely morning: just right to be down on the allotments!" (18/11). Positive comments such as this were 57% of the Emotional theme; the other 43% were negative. The negative responses were often related to outside influences, such as "Dictatorial council inspected the allotments!!" (31/03), or "Today was a sad day. I helped [a fellow plotholder] to bury his pet dog at the bottom of his allotment" (16/06).

Primarily health-related responses made up 3% of responses. These were often related to physical health, both pertaining to events occurring in the course of allotment gardening, such as "Hurt my back :(" (25/03), or general health consequences of gardening, such as "Who needs the gym!! I'm 70 next year!!" (16/06). Mental health was also discussed, always in positive language, such as "The plot is my safe place. It is my mental health balancer" (31/12). Negative health-related comments were all to do with accidents while gardening, such as the above participant who hurt their back, and positive comments were more general and related to the overall benefit of having an allotment for physical and mental health.

The theme of knowledge made up 1% of responses, either through advice such as "Hoe when you can't see a weed and you will never see a weed" (08/05) or uncertainty such as "Still not sure about funny courgettes, if they're squashes or not. Only time will tell" (11/08). All these comments were neutral emotionally, not positive or negative.

Organisation-related responses were 6% of the total. These were defined as comments primarily relating to the organisation of allotments at a site-wide level, such as participation in community events or the management of a site and involvement in committee activities. Committee activities ranged from annoyance such as "As a member of the committee - covered a vacant plot with tarpaulin to prevent weeds spreading. Also tidied up a bit of rubbish. It's amazing what some plotholders dump!" (20/05) to positive engagement such as "Allotment Association Working Party with 5 helpers" (14/01) and "Helped sort out seed potatoes in the shop = main reason for visit. Put up notices re volunteers for working party, shop opening & shop rota" (13/03). Of these comments, 81% were negative and related to having to deal with outside influences on the plot, such as the local council or new rules, suggesting that people have a strong sense of plot ownership and personal space that they do not like to be interfered with.

Comments on the theme of Pride were another 3% of responses. These were intrinsic observations or external validation from competition results, and all were positive comments. For example, "Autumn show 4 bunches herbs - 3rd, carrot - 2nd, sweetcorn - 1st place, melon - 1st place, sugar snap peas - 3rd. Proud day :)" (08/09) and the more general "Allotment looking good" (02/11).

Another 1% of comments were on the theme of Relaxation. For example, visiting just to spend time on the plot – "Just looked around" (30/06) – or satisfaction after hard work - "Pooped now. Time for a beer!" (20/04).

The theme of Sharing occurred in 5% of comments. These were always related to having surplus produce, or social connections: “Left all my dahlia tubers in a box near the allotment gates with a note saying ‘For anyone who wants them’” (22/05), “The "April" cabbage seed I planted are ready to move on. I will have far more than I need so will share!” (19/09), and “Brought tray of green broccoli plants from home to plot greenhouse. Gave some away to plot neighbours” (21/04). Along with the Social and Surplus categories, Sharing related comments demonstrate the networks of free exchange and mutual help that exist as part of having an allotment. All Sharing comments were positive.

Social observations were the most dominant form of response, with primary-type Social comprising 25% of observations. Mostly this was related to chatting and socialising with fellow plotholders, such as “Cut a cucumber for a friend on another plot. Drank a bottle of sparkling apple juice and had a laugh with two fellow allotmenteers!” (08/07) and “Spent too much time talking and not enough gardening! Must try harder tomorrow” (12/11). There were also incidents of bringing non-plotholders onto site such as “Took a walk around the allotment site to show a friend the place and just to enjoy it in its spring glory!” (05/05) and contributing to the wider community such as “Spent the morning 11am-1300 at my old allotment site encouraging them to vote” (28/10). Of these comments, 96% were positive.

The theme of Surplus related to having surplus produce and made up 2% of responses, such as “Didn't pick veg because too much waiting in the kitchen to be eaten already!” (28/08). This also connected to sharing of such produce, including in the wider community, such as “Spinach and loads of courgettes which we put outside the house "Help Yourself!"” (06/07). All such comments were positive.

Weather was the second most dominant category for the primary response type, with 24% of entries discussing the weather. The allotment survey was conducted in 2018, where record-breaking heatwaves and drought hit the United Kingdom during the summer, which may explain a heightened and more emotional focus on the weather than would otherwise be expected. For example, “No-one can remember when it last rained”, “No rain for at least two months” (24/06 and 18/07, from the same participant), and “RAINED AT LAST!!” (30/07). Weather was most often talked about in negative terms due both to the effect of the drought on crop productivity but also structural damage to plot items such as greenhouses in autumn and winter storms. Negative comments about the weather made up 72% of occurrences.

Wildlife was the dominant theme in 16% of responses. These were of varying emotions, such as “B****** squirrel. It had all my cobnuts & 80% of my apples” (14/10). When wildlife was not interfering with the plotholders’ gardening, observations were mostly made of animal behaviour, such as “Two seagulls fighting over scrap of food. A crow joined in like a boxing referee. The gulls fought so much they dropped the food and the crow nipped in and stole it! You had to be there” (04/05) and “Fox sitting at gate – resident on site” (14/01). 70% of comments about wildlife were positive.

4. Discussion

Here, we have uncovered the different ways that allotment gardeners interact with their growing space through unprompted thoughts and observations related to several key themes. These themes demonstrate that whilst the overarching purpose of allotment gardening is one of food production, co-benefits for participants’ nature connectedness, social capital and mental wellbeing also arise as strong themes. Previous research, demonstrating that participation in UH can improve quality of life, is therefore supported by our findings here; and there is no evidence that the benefits uncovered in this paper do not occur more widely in other UH contexts. Further to this, we have also found that the benefits of allotment gardening have the potential to extend beyond the gardeners themselves, with participants talking about friends and family visiting and helping on their plots, as well as the potential to share surplus produce amongst the wider community. Overall, our results confirm the findings of Genter *et al.* (2015) that “Allotment gardening provides stress-relieving refuge, contributes to healthier lifestyle, creates social opportunities, provides valued contact with nature, and enables self-development”. This study has demonstrated that these findings of Genter *et al.* (2015) on allotment gardening groups also apply to individual allotment gardeners.

The observations offered by participants in this project fell broadly into two categories: interactions with other humans, and interactions with the natural world.

Interactions with other humans were generally spoken of in positive terms, except for negative interactions with outside authorities such as the council, or when plotholders were dealing with vandalism or break-ins at the plot. Most interactions, however, demonstrate that allotment gardeners have strong social links with other members on their sites, participating in knowledge exchange regarding plot management practices, free sharing of tools, surplus produce and seeds, and participation in activities related to the organisation of the site. Many plotholders spoke of bringing friends, children or grandchildren onto their plot to help them with food growing activities, and a large amount of the time spent on allotments is shown by this study to be involvement in social activities such as chatting and sharing cups of tea.

Participants also demonstrated a high level of engagement with the natural world and wildlife, from comments about the beauty of flowers and being outside, to specific observations about wildlife. When observing wildlife, participants mentioned the same animal (for example, a particular fox or frog) on multiple occasions, which shows that repeated visits to a specific place, such as an allotment, create human-nature bonds that are revisited throughout the year. As may be expected, participants also demonstrated a high level of engagement with the weather and changing seasons. Most comments about the weather were negative, and whilst this may corroborate British stereotypes, it also demonstrates an awareness and connection to the changing weather systems that show allotment gardeners have a depth of knowledge of the effect of weather patterns on their plot productivity, and ability to successfully cultivate their land

The overall benefit of a year spent visiting an allotment, which requires an average of 55 visits, and 190 hours (Edmondson *et al.*, 2020a), was mentioned in positive terms in regard to mental health and time spent outdoors observing and directly participating in activities related to nature and growing. A sense of pride and ownership of successful gardening was a strong theme, showing that food growing can help people feel fulfilled and productive. Overall negative comments about organisation-related activities such as local council involvement with allotments, combined with the positive comments regarding prizewinning at allotment shows, demonstrate that a strong sense of personal ownership is prevalent amongst allotment gardeners.

Allotment gardens clearly provide a multiplicity of benefits for their tenants. However, the number of allotments in the UK has declined by almost two-thirds since the 1950s, with the most deprived urban areas experiencing eight times the level of closures as the least deprived (Dobson *et al.*, 2020). Research has demonstrated that gardening can be an important way for deprived communities to improve mental and physical health as well as create stronger, more resilient community networks (Travaline and Hunnold, 2010; Milbourne, 2012; Poulsen *et al*., 2014). Our findings add to these by demonstrating that nature connectedness can also be added to the list of benefits for these communities; lower levels of green space access are associated with loneliness (Maas *et al.*, 2009), and more deprived communities in the UK have less access to greenspace (Jones *et al.*, 2009). Improving access to land for UH, not only in the form of allotments but also the broader swathe of soil-based UH such as community gardening projects, could therefore be one avenue to improve the standards of living in deprived urban areas. Further research would be needed to elucidate whether allotment gardening is addressing specific mental or physical health problems, or more generally contributing to overall wellbeing; this would allow policymakers to target horticultural therapy interventions to deal with specific issues. In general, this study should provide valuable evidence to policymakers of the benefits to be gained for communities from maintaining, preserving and increasing access to allotment gardening: it demonstrates a broad spectrum of issues (such as individual mental health, nature connection and social capital) that are benefited by allotment gardens. As cities expand their urban horticultural activities, this study demonstrates that focusing on co-benefits beyond food production means that urban horticulture can be addressed from a number of policy perspectives, such as physical health, nutrition, mental health and community cohesion.

Our findings also present a number of possible future avenues for research. Firstly, the definition of the term ‘horticulture’; here, we have focused on allotments cultivated for fruit and vegetables, but gardeners often also cultivate ornamental flowers. Horticultural therapy literature often covers both the cultivation of fruit and vegetables, and the cultivation of ornamental plants; in future research, investigating whether wellbeing benefits differ between those who do and do not also cultivate flowers could present some interesting findings. Secondly, this project discussed only allotments cultivated privately by individuals or families; a targeted study comparing the wellbeing benefits of allotments for gardeners such as our participants, and other allotment-based projects such as allotments for schoolchildren or refugee communities, could elucidate the specific nature of gardens where wellbeing is maximised, to provide clear evidence to produce policy guidelines to maximise wellbeing on a plot. Using unprompted comments, such as we have done here, has resulted in a non-standardised data set; this is both a limitation and a unique aspect of this study. Further research mirroring our approach assessing gardeners year-round should involve targeted questions about wellbeing at different points in the year; but also preserve the space for unprompted comments, as many unique observations from participants arose in this way. One way to do this would be to conduct longer semi-structed interviews with gardeners at regular intervals throughout the year; more detailed insight from gardeners rather than the brief entries we have analysed here could provide some interesting results.

In conclusion, the findings of this project echo the statement, "'Local food projects' in urban areas are not really about food, and are best described as community projects with food as the pretext and a vector for social agency and the development of community capacity" (Maye 2019). This was captured by one participant's end of year reflection: "Read back the year's diary. Sat + reflected upon the year. The plot is my safe place. It's my mental health balancer. Peaceful, but sociable, accepting, a place to connect, to disconnect. A place to grow, to write, to accept that things die and turn to compost. To be me without being judged. To eat and share food, drink + friendship. Not tidy or regimented, it changes + develops. It flowers and envelopes blossoms and blooms or freezes and browns. The bird song at all times, the outside industrial noises of the docks, roads, next door's motorbike, generator, chainsaw, rotavator, strimmer, friends, but mostly... it's mine. It's my little piece of earth, the planet. I aim for no chemicals, using rainwater, last year's seeds, cuttings, pots donated, second hand stuff made into plant containers. A calm place to listen, to cry, to eat, to welcome friends, to walk around + know deep in my heart here, I feel connected, balanced (despite the wobbly deckchair) and recharged. I'm drawn here in the winter to the stark bareness of it all. Stripped back to the structure, paths + beds defined, perennials on show, spring bulbs daring to peek out... It's time for soup. Thank you for this diary. It helps me to write so some days you've helped my mental health" (31/12).

As the quote demonstrates, there is a spectrum of benefits aside from food production that allotment gardening can provide: peace, health, social interaction, nature connectedness, commensality, recycling and a feeling of autonomy, pride and ownership of one's allotment plot. In an increasingly disconnected, socially isolated society where the idea of 'nature deficit disorder' in cities is connected to increasing mental health problems (Louv, 2005), this study has shown that the activity of allotment gardening, and by implication other forms of urban horticulture, can play a role in helping people to deal with many aspects of the issues facing communities in urban areas. Waiting lists for allotments are often long (Campbell and Campbell, 2013), suggesting that increased allotment provision could bring these benefits to many more people than presently provided for.

Chapter 6

The structure and co-benefits of urban allotments

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Abstract

Urban horticulture, such as allotment gardening, is of increasing research interest as evidence grows about its ability to contribute to urban food security, as well as providing a variety of co-benefits through the provisioning of ecosystem services. This study uses allotment gardens as a case study urban horticultural system, conducting a nationwide field audit of the structure and features on allotments throughout the United Kingdom, in nine urban areas. In doing so, we analyse the co-benefits of allotment gardening beyond food provision, assessing the extent of land cover types conducive to the provision of ecosystem services; the benefits that allotment gardeners self-report gaining from their allotment; and the trade-offs that exist between different land uses. We find that allotment gardens contribute a significant amount to urban greenspace in their non-food production spaces, which form a substantial portion of allotment land nationwide. Overall, allotment gardeners cultivate only 41% of their plots for food and ornamentals, and the rest is given to other land uses. These include wild and overgrown areas, infrastructure such as sheds, ponds, and livestock. Gardeners report predominantly positive effects on physical, mental and dietary health from their allotments, as well as the development of skills and friendships. We suggest that, as a result of this research, policymakers place a greater emphasis on allowing space on plots for the provision of non-food production ecosystem services in cultivation guidelines.

1. Introduction

As the world's population grows and becomes more concentrated in urban areas (United Nations, 2019), issues of urban sustainability are at the forefront of tackling current and future environmental problems. A key facet of sustainable cities is that of resilient urban food systems, with a large and increasing body of literature examining the potential of localising city food systems to provide resilience against shocks such as price volatility (Lee, 2012; Wiskerke and Viljoen, 2012), as well as reducing the greenhouse gas emissions embodied in the international food supply chain (Caputo, 2012; Kulak *et al*., 2013). Land use change, particularly the shift into unsustainably managed conventional agricultural land has resulted in widespread environmental degradation, for example causing issues such as soil erosion and desertification (Rosegrant and Cline, 2003); however, the challenge to produce food sustainably is further exacerbated by climate change (Wiskerke and Viljoen, 2012; Eigenbrod and Gruda, 2013). In light of this, attention has turned in recent years to the potential for cities to become partially or wholly self-sufficient in fruits and vegetables by upscaling the amount of food produced within city limits using urban horticulture (UH) (for example: Wiskerke and Viljoen, 2012; Lin *et al*., 2015; Eigenbrod and Gruda, 2015; Aerts *et al*., 2016, Edmondson *et al*., 2020a; Grafius *et al*., 2020; Mcdougall *et al*., 2020).

Urban horticulture, in the form of soil-based cultivation of fruit and vegetable crops, has been practiced internationally throughout urban history (Barthel and Isendahl, 2013). Spaces used for UH form part of the network of urban green infrastructure which provides a range of ecosystem services (Schwarz *et al*., 2017; Setälä *et al*., 2017). In the case of UH one key service is, obviously, the production of food, but there may be a range of others. The one which has received most attention is the role of such spaces in supporting insect or floral biodiversity (for example: Borysiak *et al*., 2015; Speak *et al*., 2015; Clucas *et al*., 2018, Baldock *et al*, 2019), but others include: regulation of local climate and air quality (Lovell, 2010, Lin *et al*., 2015, Goldstein *et al*., 2016b); mitigation of flood risk (Goldstein *et al*., 2016b; Gittleman *et al*., 2016); conservation of plant genetic diversity (Barthel *et al*., 2010, Galluzzi *et al*., 2010, Speak *et al*., 2015); reduction of emissions from food production elsewhere (Kulak *et al*., 2013, Benis and Ferao, 2017); carbon storage in soils and trees (Edmondson *et al*., 2014a, Lin *et al*., 2015, Speak *et al*., 2015); improvements in mental and physical wellbeing (Howe and Wheeler, 1999, Eigenbrod and Gruda, 2015, Church *et al*., 2015, Nordh *et al*., 2016); and providing education and skills development (Barthel *et al*., 2010, Taylor and Lovell, 2014, CoDyre *et al*., 2015, Martin *et al*., 2016). These studies, amongst others, clearly suggest the potential for UH to provide numerous ecosystem services in addition to the production of food.

A key issue for assessing this is understanding the overall structure of UH spaces, and the ways in which different features (for example, the proportion of crop cultivation or the amount of land dedicated to infrastructure such as sheds and greenhouses) result in trade-offs or harmonies among ecosystem services (Russo *et al*., 2017), but at present there are no analyses of this structure, or its consequences. In part this is because it can be difficult to assess: UH spaces are heterogenous, subject to individual gardeners' management preferences and the different levels and types of crop cultivation. For example, allotment gardens, which are one of the primary forms of UH across Europe (Church *et al*., 2015), are cultivated with different purposes depending on the cultural context; a comparative study of allotments in Poland and the UK demonstrated this, where Polish gardens were more dominantly cultivated for ornamental flowers, and British gardens more dominantly for food crops (Speak *et al*., 2015). Here we focus on British allotment gardens, where the legal requirement for the primary function of the plot is food production, to examine the variation in structure and composition of allotment plots, and the potential implications this has for the ecosystem services other than food production which they may provide.

Allotments in the UK occupy 135 km^2, usually comprising sites owned by a local authority, divided up into multiple plots (typically 250 m^2) rented out to individuals to cultivate food. There are around 330,000 allotment plots in the country, and demand for them is high: in 2013, for every two plots occupied nationwide, one person was on a waiting list (Campbell and Campbell, 2013), and demand for allotments during the 2020 coronavirus lockdown rose greatly, with some areas experiencing a 300% increase in waiting list length (Smithers, 2020). Guidelines for the cultivation of allotments in the UK often set out minimum levels to which plots are expected to be cultivated (typically 75%, e.g. Sheffield City Council, 2018); however, studies suggest that the average plot is more likely to produce fruit and vegetables on only about half its land area (Edmondson *et al*., 2020b). This leads to questions arising regarding the structure, purpose, and potential benefits that the remaining area of allotment land delivers.

In this paper we assess the structure of allotment gardens in order to more accurately account for different land covers within plots and provide an evidence base for the potential of allotments to support the delivery of ecosystem services beyond food production. Using detailed plot mapping of 180 allotment plots across the UK, and questionnaires, we assess the extent of features such as overgrown areas, ornamental planting, ponds, sheds, lawns, and compost heaps; permeable and impermeable surface area; investigate the impact of allotment gardening on the wider lives of our participants; and assess the diversity of crops that allotment holders typically grow. We use these data to develop a better understanding of the overall characteristics of allotment plots, and address the following specific questions:

1. What are the primary uses of non-food growing space on allotments?
2. What associations and trade-offs between different land uses occur on a plot level, and what does this mean for ecosystem service delivery?
3. Do allotments fall into distinct types associated with plotholder characteristics?

2. Methods

Nine cities were chosen for our study, geographically distributed throughout Great Britain: Bristol, Cardiff, Edinburgh, Leeds, Leicester, Liverpool, Milton Keynes, Nottingham, and Southampton. Site visits were conducted in 2014 (Leicester), 2017 (Bristol, Nottingham and Southampton) and 2018 (Cardiff, Edinburgh, Leeds, Liverpool and Milton Keynes). For each city, site selection was done by dividing the city into equal quadrants and selecting one allotment site (with ≥ 25 plots) at random from each quadrant. Plots were selected during field visits by approaching plotholders present on their plot at the time of the visit. Visits were conducted during working hours on weekdays, except for Leeds, where two sites were surveyed on a Saturday. Overall, mapping was conducted on 180 allotments. This was subject to bias as plot visits were conducted only with plotholders present on the plots at the same time as the researchers, and only those who gave permission for plot access.

Plot dimensions were measured with a laser rangefinder. The *x* and *y* dimensions of each feature of the plot were then measured by hand with a tape measure (Figure 1). Any impermeable surface areas were measured, and then summed together to give overall impermeable surface measurements. Where trees were growing above crops, the area of the tree canopy was measured as well as the area of any crops underneath, so total areas of features on allotments could sum to a greater area than the individual plot area (as calculated from *x* and *y* dimensions). Where there was bare soil, this was identified separately based on whether it had been or was going to be used for planting crops (if yes, this was then included in cultivated area calculations), or whether it was space not used for cultivation. Cultivation also included areas of crops inside greenhouses, which meant that some crops could form part of the impermeable surface within a plot. Ornamental planting was differentiated between ornamentals planted outside and those inside greenhouses.

Figure 1. Examples of the structure of allotment plots. **A**: Recording dimensions of each feature on an allotment; **B**: Example photographs of allotment plots showing variety in layouts and features.

Questionnaires (see Supplementary Information 1) were also conducted with plotholders in eight of the nine cities (excluding Leicester), where plotholders agreed to participate (*n* = 146). Plotholders were asked demographic questions, and details about how long they spent on their plot and how much money they spent on it.

Statistical analysis was conducted in R version 4.0.0 (R Core Team, 2020). Crop diversity was calculated using the Shannon H' index. Data were non-parametric and therefore medians, Kendall's tau, and Kruskal-Wallis tests were used. To make comparisons between plots, and account for variation in plot sizes, features were converted to the proportion of the total plot area that they occupied for each plot.

Principal Components Analysis (PCA) was undertaken to assess underlying drivers of the relationship between different plot features related to the delivery of biodiversity-related ecosystem service provision (proportion of allotment used for crops, ornamental plating, permeable surface area, weeds and wild areas, grass areas and crop diversity index). The PCA approach was chosen as it is a statistical method used to explore the correlation structure of a dataset.

3. Results

3.1. Questionnaire responses

Participants lived a median distance of 1.6 km away from their allotment, with a range of 0 (an allotment backing on to a resident's home garden) to 15.1 km away. With regard to age, 0.5% of respondents were 18-25 years old; 9.8% were 26-40; 24.0% were 41-60; and 65.6% were 61 or over, a probable function of plot visits primarily being conducted during working hours on weekdays, but also potentially reflective of the demographics of allotment holders in general. Overall, respondents estimated that they spent a median of 10.8 hours per week working on the plot over the course of a year, although this ranged from 1.8 to 84 hours. Excluding rent prices for their plot, 58% of plotholders spent under £100 annually on resources (e.g. seeds, tools), 88%

spent under £250 and 97% spent under £500. Rents ranged from free to £240 annually, with the median plot rent £50 per year.

The median length of time that plotholders had managed their plot was 7 years, but respondents ranged in length of plot occupancy from two weeks to 61 years. Previous growing experience prior to taking on their allotment ranged from none to a lifetime of growing, but the majority (76%) of respondents had no previous experience. When previous experience was added to current plot occupancy, the median length of a plotholder's growing experience was 11 years. Just under half the respondents (48%) were the sole worker on their plot; 43% worked the plot with one other person, and the remaining plotholders managed their plot alongside multiple people (up to eight). Fifty-one percent of respondents also grew food in their home gardens, 4% also grew in a community growing space, 19% also grew indoors (such as herbs or chilli), and 2% grew in another space (one respondent worked as a landscape gardener and two grew in school yards). A high proportion (76%) of respondents saved seeds to replant, with 76% of those that saved seeds also participating in seed sharing with neighbouring allotment holders.

3.2. Plot size and cultivation

The median allotment plot area was 255 m^2, which is consistent with the standard allotment plot size in the UK of 250 m^2 (it is to be expected that there is some deviation from the standard size in practice). The median area cultivated for crops, including fruit trees, was 113 m^2, with a range of 19 m^2 to 401 m^2. Excluding fruit trees from this gave a median cultivated crop area of 92 m^2, ranging from 9 m^2 to 383 m^2. Including ornamental planting, trees and non-tree crops resulted in a median cultivated area of 124 m^2, ranging from 24 m^2 to 406 m^2. Ornamental planting covered a median of 6 m^2 ranging from no ornamental planting to 97 m^2. Taking plot size into account, the median proportion of an allotment plot used to cultivate crops and ornamentals was 41%, ranging from 27% to 91%. This was significantly negatively correlated with plot size (Kendall's tau, n = 180, tau = -0.18, $p = 0.0004$, z = -3.52, Figure 2).

The number of hours participants spent on their plot was not significantly correlated to the proportion of a plot under cultivation (Kendall's tau, n = 142, tau = 0.06, *p* = 0.32, z = 0.98), but the number of years that plotholders had been tenants on their plot was significantly positively correlated to cultivated proportion (Kendall's tau, n = 145, tau = 0.19, *p* = 0.0007, z = 3.40), suggesting that the proportion of a plot under cultivation increases over time (Figure 3). However, this trend was driven by the few plots we surveyed where tenants had managed their plot for between 20 and 61 years. There was a less strong, but still significant, association between cultivation and tenancy length when only tenants of 20 years or fewer were included (Kendall's tau, n = 122, tau = 0.12, *p* = 0.049, z = 1.97).

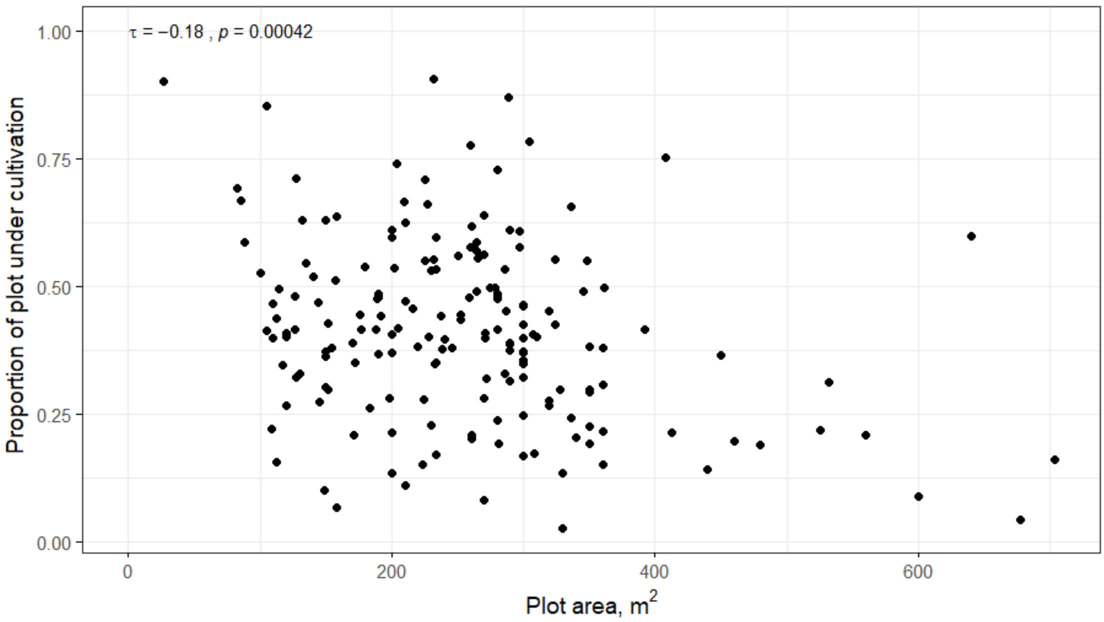


Figure 2. Correlation between allotment plot area and proportion of plot cultivated for crops or ornamentals (n = 180) using Kendall's tau, tau - -0.18, *p* = 0.00042.

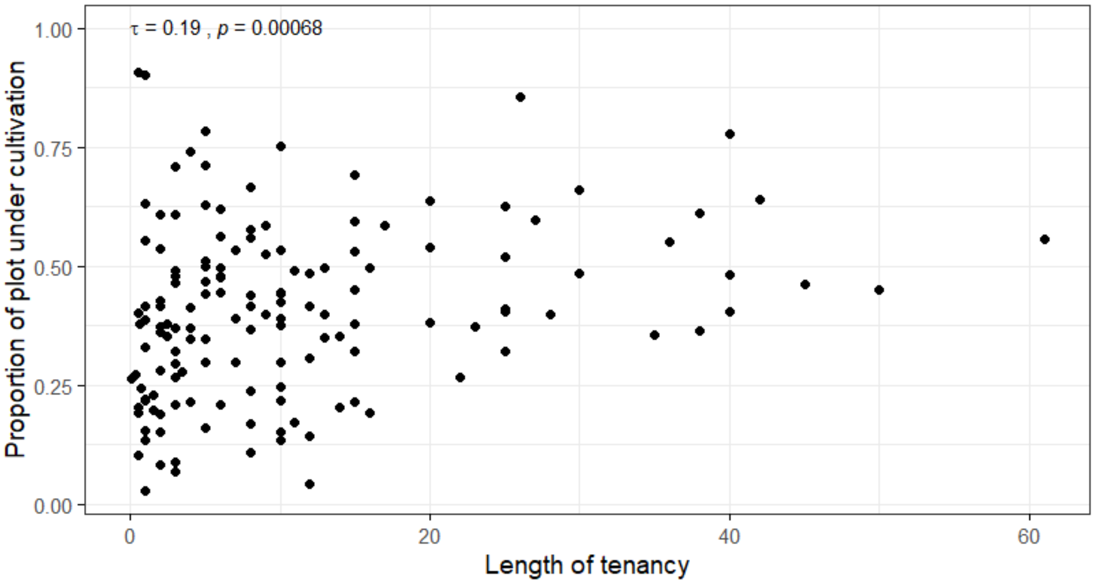


Figure 3. Correlation between the length of allotment tenancy and the proportion of the plot that is cultivated (n = 145), using Kendall's tau, tau = 0.19, p = 0.00068.

3.3. Crop diversity

Shannon's diversity of crops on the surveyed allotments ranged from 0.52 to 3.24, with a median of 2.53 (Figure 4). Crop diversity was not significantly correlated to the proportion of a plot under cultivation (Kendall's tau, n = 180, tau = -0.002, p = 0.97, z = -0.04), the total area of the plot (Kendall's tau, n = 180, tau = 0.88, p = 0.08, z = 1.75), or the average number of hours per week the participant spent on their plot (Kendall's tau, n = 142, tau = -0.02, p = 0.79, z = -0.26). However, crop diversity was significantly positively correlated to the length of the plotholder's tenancy on their allotment (Kendall's tau, n = 145, tau = 0.19, p = 0.0008, z = 3.34, Figure 5), and the proportion of their plot used to plant ornamentals (Kendall's tau, n = 180, tau = 0.30, p < 0.0001, z = 5.80, Figure 6).

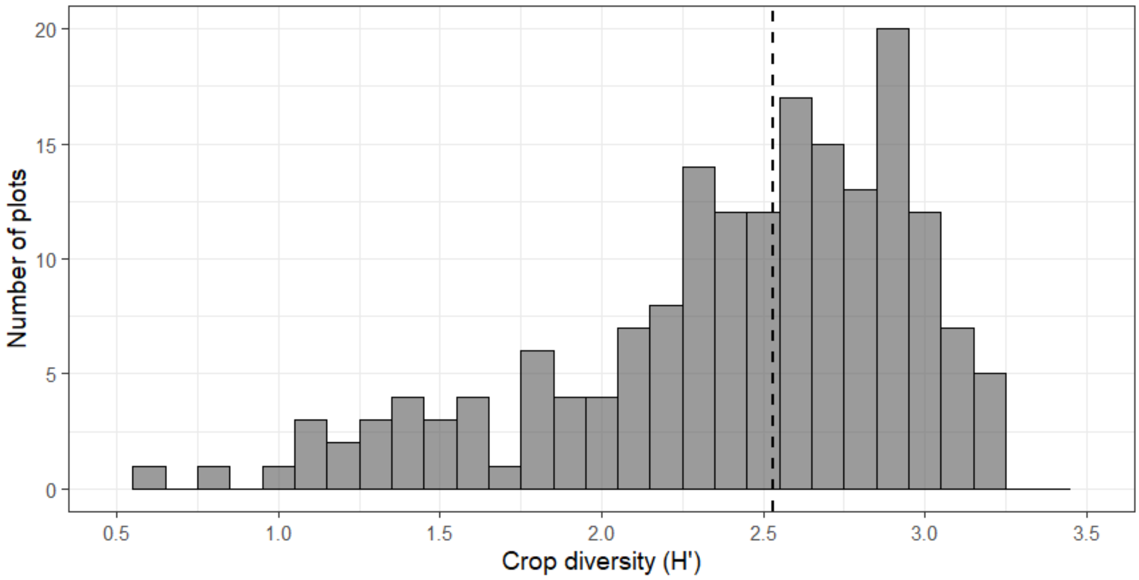


Figure 4. Diversity index (Shannon H') of crops on allotments in the United Kingdom (n = 180). Dashed line indicates median diversity of 2.53.

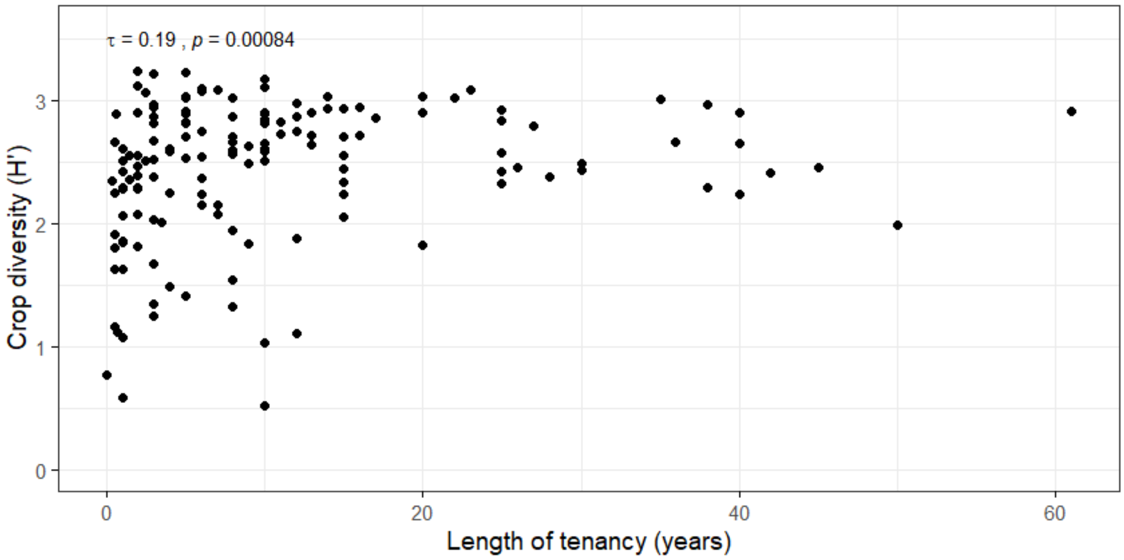


Figure 5. Significant positive correlation between crop diversity and the length of tenancy of growers on their allotments (n = 145) using Kendall's tau, tau = 0.19, *p* = 0.000184.

Figure 6. Significant positive correlation between the proportion of an allotment used to plant ornamentals, and the Shannon diversity index for crops, on British allotments (n = 180), using Kendall's tau, tau = 0.3, $p < 0.0001$.

3.4. Assessment of non-crop features

Permeable and impermeable surfaces

Overall, there was a median area of 22 m^2 of impermeable surface on allotments. This included sheds and greenhouses as well as impermeable paths. Taking plot size into account, the median proportion of a plot that was impermeable was 8.7%, ranging from no impermeable surfaces to 84.7% impermeable surface (an outlier plot, where only 27% of the plot was cultivated). The median area of permeable surface was 210 m^2. As a proportion of plot size, the median permeable surface area ranged from 15% to 100%, with a median of 91%.

Extent, proportion of, and relationships between different features on allotments

The features recorded on allotment plots were grass and lawn; ornamental planting; sheds; greenhouses; polytunnels; compost bins; compost heaps; water storage; ponds; weeds and wild areas; and livestock. There was a large variation in the frequency of different features present on plots, with sheds, water storage areas, outside ornamental planting and compost heaps occurring most commonly, and inside ornamental planting, livestock and ponds occurring the least commonly (Table 1). For all features there was a great deal of individual variation between plots in regard to the size of the features, with most data skewed towards plotholders who had disproportionately large features (for example, a 79.5 m^2 shed).

The presence or absence of greenhouses, sheds, polytunnels, ponds, compost, weeds and wild areas, grass, ornamental planting, water storage, and livestock were not significantly affected by plot size according to Kruskal-Wallis tests (Supplementary Information 2). There was a significant correlation between the proportion of a plot used for ornamentals and the proportion of a plot used to cultivate crops (Kendall's tau, n = 180, tau = -0.13, p = 0.01, z = -2.46), and there was no significant correlation between the proportion of ornamental planting and total plot size (Kendall's tau, n = 180, tau = -0.10, p = 0.07, z = -1.83). Where people had a shed, there was a significant positive correlation between plot size and shed size (Kendall's tau, n = 150, tau = 0.21, p = 0.0002, z = 3.71). The size of greenhouses, but not polytunnels, were also significantly positively correlated to plot size (Kendall's tau, greenhouses: n = 105, tau = 0.20, p = 0.003, z = 2.91; polytunnels: n = 25, tau = 0.89, p = 0.54, z = 0.61). The amount of overgrown (weeds or wild) space was not significantly correlated to plot size (Kendall's tau, n = 180, tau = -0.02, p = 0.69, z = -0.40), plotholders' tenancy length (Kendall's tau, n = 145, tau = 0.03, p = 0.66, Z = 0.44) or total growing experience (Kendall's tau, n = 145, tau = -0.04, p = 0.53, Z = -0.63). There was a significant negative correlation between the extent of overgrown areas and the estimated number of hours per week the plotholder spent on their plot (Kendall's tau, n = 142, tau = -0.17, p = 0.006, Z = -2.75), suggesting that those with more time were able to actively manage a greater proportion of their plot.

Table 1. Features on allotment gardens; the number of plots on which features occur from 180 surveyed plots in total; the median areal extent where they occur; the median proportion of the allotment they occupy where they occur, and for all plots whether they occur or not; the range in sizes of the feature.

Feature	Number of plots	Median size	Median proportion of plot occupied (where occurring)	Median proportion of plot occupied (all plots)	Range of sizes
Grass / lawn	96	53.7 m^2	27%	2.0%	0.2 – 556.2 m^2
Ornamental planting (outside)	121	10.2 m^2	4.0%	1.8%	0.3 – 93.4 m^2
Ornamental planting (inside)	6	1.0 m^2	0.3%	0.0%	0.2 – 9.7 m^2
Shed	150	3.6 m^2	1.8%	1.6%	1.3 – 79.5 m^2
Greenhouse	105	6.1 m^2	2.4%	1.2%	0.2 – 92.4 m^2
Polytunnel	25	14 m^2	5.2%	0.0%	1.0 – 58.9 m^2
Compost bin	87	2 bins	NA	NA	1 – 7 bins
Compost heap	113	3.6 m^2	1.5%	0.9%	0.9 – 30.4 m^2
Water storage	133	1.2 m^2	0.5%	0.3%	0.2 – 7.3 m^2
Weeds / wild area	72	8.0 m^2	4.3%	0.0%	0.2 – 350.6 m^2
Livestock	10	9.3 m^2	2.4%	0.0%	0.6 – 27.5 m^2
Ponds	15	1.3 m^2	0.7%	0.0%	0.1 – 8.0 m^2

3.5. Relationships between plot features

There was no significant correlation between plot size and proportion of weeds and wild planting, pond, compost heap, grass, or ornamental planting; or the sum of the above areas (Table 2); this is to be expected given the non-significant relationships found between the presence or absence of these features and total plot size in 3.4.

Table 2. Kendall's tau correlations of allotment plot size and features on allotments that deliver ecosystem services (n = 180).

Kendall's correlation of plot size to proportion of	tau	*p*	Z
Weeds and wild areas	-0.023	0.686	-0.404
Pond area	-0.021	0.723	-0.354
Compost heap area	-0.077	0.145	-1.458
Grass area	-0.004	0.948	-0.065
Ornamental planting (outside only)	-1.826	0.068	-0.096
Sum of the above areas	-0.018	0.722	-0.355

The sum of these areas was significantly negatively correlated with the average weekly hours the participant spent on their plot (Kendall's tau, n = 142, tau = -0.12, p = 0.04, z = -2.05, Figure 7), but not with tenancy length (Kendall's tau, n = 145, tau = -0.09, p = 0.13, z = -1.50).

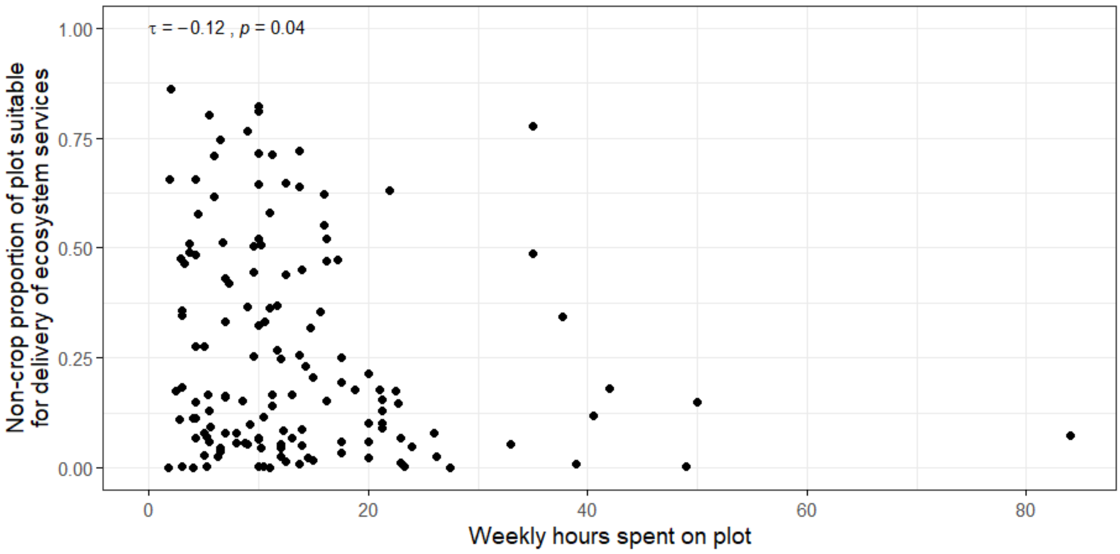


Figure 7. Significant negative correlation between proportion of allotment plots not cultivated for crops, but suitable for the provision of other ecosystem services, and the estimated number of hours per week plotholders spent on their allotment (n = 142) using Kendall's tau, tau = -0.12, p = 0.04.

A PCA of the proportions of different features on allotment plots identified above as being related to the delivery of biodiversity-related ecosystem services indicated that there were some particular associations among features (Table 3). In particular, the first principal component shows that nearly 30% of the variation is described by an axis having decreasing permeable surface, proportion of weed and proportion of grass, combined with increasing crop diversity and proportion of ornamental planting. Interestingly, the proportion of the allotment used for crops is relatively independent of this axis, suggesting the mixture of non-crop land uses is relatively unaffected by how much of the allotment is crop area. The ordination of plots on the first two principal components (which account for 50% of the variance) do not suggest that there are distinct clusters or groupings of allotments into specific 'types' characterised by particular features; may different permutations of land use occur. Coding the plots by city, age of plotholder, length of tenancy, growing experience, presence / absence of a pond, presence / absence of a compost heap, or the number of hours the plotholder spent gardening per week (see Figure 8) did not suggest that any of these features map consistently on to specific combinations of non-food land use.

Table 3. Axes of principal components analysis of the proportions of different features on allotment plots identified above as being related to the delivery of biodiversity-related ecosystem services.

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Standard deviation	1.3118	1.1350	1.0079	0.9434	0.8334	0.6250
Proportion of variance	0.2868	0.2147	0.1693	0.1483	0.1158	0.0651
Cumulative proportion	0.2868	0.5015	0.6708	0.8192	0.9349	1.0000

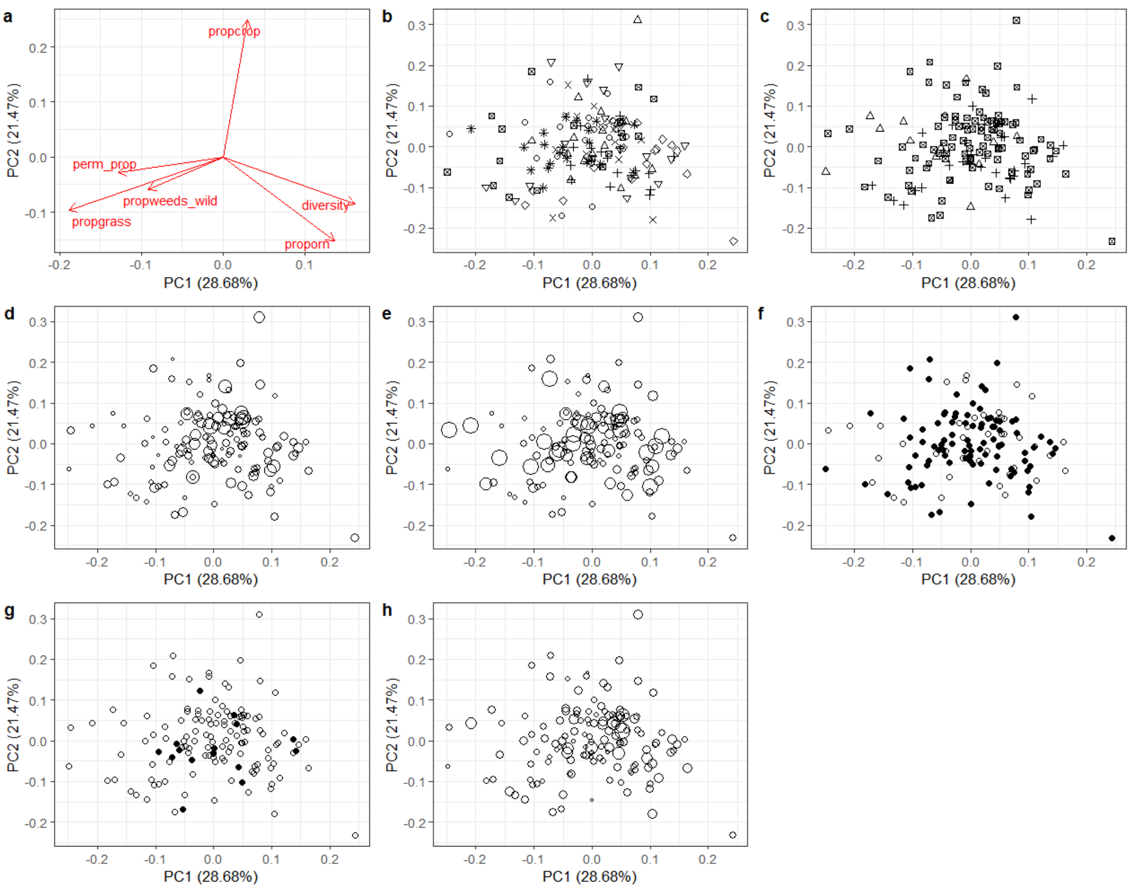


Figure 8. Principal Components Analysis of the proportion of allotment plot dedicated to crops ("propcrop"), ornamental planting ("proporn"), permeable surface area ("perm_prop"), weeds and wild areas ("propweeds_wild"), grass ("propgrass"), and crop diversity index using Shannon's index (H') ("diversity"), on 146 allotments (cumulative variance = 50.15%): a) loading plot; b) plots grouped by city; c) plots grouped by age of tenant; d) plots grouped by length of tenancy (increasing with increasing point size); e) plopts grouped by growing experience of tenant (increasing with increasing point size); f) plots grouped by presence or absence of a compost heap (● = present; ○ = absent); g) plots grouped by presence or absence of a pond (● = present, ○ = absent); and h) average weekly hours spent on the plot (increasing with increasing point size).

4. Discussion

Our results demonstrate that, whilst allotments are defined as sites of urban horticulture, there is considerable space on allotment plots not used for horticulture or its associated (e.g. sheds) structures. Our plot mapping showed that, on average, only

41% of a plot was cultivated for crops or ornamental flowers, and that when sheds, water storage and compost storage (features necessary for the practice of horticulture) were added to this, the median proportion of a plot occupied was 53%. Both of these figures represent a substantially lower in-practice level of plot cultivation than the 75% generally required by municipal authorities (for example, Sheffield City Council, 2018). We expect that part of the reason for this is that what constitutes ‘cultivation’ may have a broader definition used in practice by councils than what we have used here, and perhaps refers to all managed space of a plot (that is, everything excluding weeds or overgrown areas), in which case most plots would have met this cultivation target, as we found that not many plots had any substantial weeds or overgrown areas. However, whilst this may be how the guidelines play out in practice, the actual rules in, for example, Sheffield, state that “At least 75% of your plot **must** be used to cultivate fruit and vegetables” (Sheffield City Council, 2018, bold emphasis in original). Therefore, the majority of people do not meet cultivation guidelines (indeed, only seven of our 180 plots cultivated 75% or more of their plot for fruit and vegetables). Our assessment of the average amount of a plot used to cultivate crops demonstrates that a large proportion of most allotments is not directly under crop production.

In regard to our second and third research questions set out at the beginning of this paper (“What associations and trade-offs between different land uses occur on a plot level, and what does this mean for ecosystem service delivery?” and “Do allotments fall into distinct types associated with plotholder characteristics?”), we found that allotments, in general, demonstrate a large degree of heterogeneity causing difficulty in elucidating whether there are obvious factors driving the structure of allotment plots, whether this is a feature on a plot, or a plotholder characteristic. The proportion of a plot used to plant crops was relatively independent of other features; and increasing space given to ornamental planting (and increasing crop diversity), along with decreasing space for grass and overgrown areas, was the most explanatory axis found in the PCA; however, with an explanatory power of only 30% of the variance, it is clear that there are many other factors driving plot heterogeneity which our methodology here, using plot mapping and questionnaires, did not adequately capture. However, we did draw out a number of interesting observations from our results, which do capture some of the primary characteristics of plotholders, and themes in the way that plots are managed.

In general, most plots fell towards the higher end of the range of crop diversity that we found across the country; the results were strongly skewed to higher Shannon H' index scores, suggesting that allotment gardeners tend to plant a wide range of crops. Crop diversity, along with the diversity of ornamental plants on allotments (which we did not measure here) is associated with supporting the activity of pollinators in urban environments (Borysiak *et al*., 2017); allotments have been found to support the highest levels of pollinators in urban greenspace outside of home gardens, and are disproportionately important for plant-pollinator community robustness in terms of their areal extent across a city (Baldock *et al*., 2019). The significant correlation between more ornamental planting and crop diversity that we found suggests that gardeners with an interest in growing a more diverse range of crops also have more interest in growing other, non-crop, plants. Further research into whether differing levels of crop and ornamental plant diversity support different levels of pollinators within allotment sites or at a city scale would be useful in assessing whether the individual plot levels of crop diversity are driving pollinator abundance and diversity; or whether this is an effect occurring more at the site level, and therefore site-wide crop diversity is more important than the individual variation within plots that we have assessed here. Further to this, from a broader biodiversity perspective it is positive to have found that three-quarters of our allotment gardener participants participated in seed sharing and seed saving; this is an important tool in maintaining plant genetic diversity (Galluzzi *et al*., 2010).

Other features found on allotments have been studied outside of the allotment land use type for their ecological value; for example, home garden lawn areas have been found to be similar in species richness to semi-natural grasslands (Thompson *et al*., 2004), and ponds are known to harbour diverse and species rich communities (Oertli *et al*., 2002, Davies *et al*., 2008). These features therefore add to the support of urban biodiversity that allotments can provide as part of the urban greenspace network, which is also supported by spontaneous flora in overgrown areas on allotments. Compost heaps on allotments also present an addition to the extent of compost heaps in domestic gardens at a citywide scale: on top of the estimated 50,750 compost heaps in gardens in Sheffield (Gaston *et al*., 2005), we can use our results to estimate that the 3,600 allotments in the city provide around another 2,257 compost heaps (another 4.4%). Whilst this is not a great absolute addition, using the same estimate as the garden compost research (Gaston *et al*., 2005), these allotment compost heaps have the potential to process 258 metric tons of compostable waste per annum (2.2kg of material per week per heap). However, our PCA results demonstrated that the proportion of a plot cultivated for crops did not correlate with the extent of any of these particular features, suggesting that individual plotholders' motivations to have various features on their plot are not easily explained simply in terms of the amount of space plotholders decide to grow fruit and vegetables on. Further to this, the presence of these features was not explained by plot size. Finally, the combination of features on allotments providing permeable surface area within cities provides a multiplicity of benefits such as flood mitigation (Coutts *et al*., 2012; Lin *et al*., 2015).

The observation that greater tenancy length tends to be correlated with greater proportion of plot area cultivated, and greater crop diversity is interesting. Whilst it suggests that it takes time to bring a plot into full cultivation, it is clear that plots with relatively new tenants occur at all levels of cultivation, and that the correlation is driven by the fact that few plots with long running tenancies have substantial uncultivated area (Figure 3). The state of a plot when a new tenant takes it on may be an explanatory variable for this, but was not measured in our mapping: if a plot is seriously overgrown, it will take longer to make the whole plot suitable for cultivation than if somebody takes on a plot that has been cultivated to a high standard by the previous tenant.

We also found that larger plots were significantly less cultivated than smaller plots. Recent trends in the management of waiting lists of allotment sites have led to many plots being split to let as half plots. However, our research shows that this increased food cultivation may trade off with non-food production ecosystem services as smaller plots have less space for, for example, ponds or wild areas. This leads to a broader question about the purpose of urban agricultural sites: how important are the other benefits they provide alongside food production? As a broader contribution to urban green infrastructure, where the primary but not sole purpose is food production, our findings suggest that larger plots with space for support of spontaneous floral and animal diversity have the potential to deliver a greater variety of ecosystem services than smaller plots. However, with already large waiting lists for allotments and recent evidence that waiting lists have been growing as a result of the coronavirus crisis (Smithers, 2020), the option of splitting plots to allow more tenants to have allotments, albeit smaller ones, may be attractive. Taking into account the evidence that allotments deliver ecosystem services unrelated to crop production, expanding the amount of land given to UH rather than decreasing plot size may be a better policy option to ensure that those on waiting lists are given plots whilst not detracting from the ability of existing plots to support pollinators and other biodiversity through reducing plot size.

Our participants estimated that the amount of time they spent on their plot was higher than that found by either Edmondson *et al.* (2020a), who found that plotholders visit on average 55 times per year, or Dobson *et al.* (unpublished work; Chapter 4 of this thesis), who found that plotholders visit on average 87 times per year. However, demographic and sampling differences as well as more accurate reporting by these studies (records of every visit throughout a year rather than an estimation by the participant) explains this variation. Either result shows a substantial amount of time for people to engage with allotment gardening outside of their working day. It is to be expected that those of our participants in the retired age category spent more time on their plot, as well as our visits which were conducted during the working day skewing our data to the older participants who were less likely to be at work when we conducted plot visits. Understanding the time resources required to successfully cultivate an allotment is one of the key pieces of information that it would be helpful for prospective gardeners to have, and policy practices that enable time-poor people to still participate in food growing are key to develop (for example, expansion of community garden schemes so people don’t have the responsibility of solely tending their plot but can share the labour) to ensure that plots are not abandoned after a short while as people underestimate the amount of time it takes to grow.

Overall, this research provides important insights into the structure of urban allotments, using a nationwide approach that captures the typical variations in, and common features on, allotments in the UK. We have presented evidence that allotment gardens contribute a significant amount to urban greenspace in their non-food production spaces, which form a substantial proportion of allotment land nationwide. This research has important policy implications; it cements the value of allotments as part of the urban green infrastructure network, delivering on multiple ecosystem services and thus worthy of effort to protect not only for provision of food growing space but also their ecological and social value. It also demonstrates that larger allotment plots are supporting a greater area of non-food growing beneficial features, demonstrating that consideration of these spaces as part of the value of allotments is important to protect their ecological value, and suggesting that the trend of downsizing plots to meet waiting list demand may have unforeseen ecological consequences. Finally, it shows that opportunities exist to educate plotholders about the best way to use their allotment space not only for the cultivation of food but also for the protection and preservation of the wider environment, adding to the knowledge and skills development inherent in the cultivation of an allotment.

Chapter 7

General discussion

1. Introduction

In this study I have conducted a wide-ranging investigation into the primary urban horticultural land use type in the United Kingdom, allotment gardening, using a range of approaches to assess the characteristics of allotments at a nationwide scale. Chapter 2 situated allotment provision in its historical context, identifying trends in land use change, the impact of allotment closures on deprived communities, and potential availability of land suitable for reconversion for allotment use. Chapter 3 assessed the state of allotment soil quality across the country, its contribution to organic carbon storage, and the management practices employed by allotment gardeners that contribute to maintaining its significantly higher quality than commercial arable and horticultural soils. In Chapter 4, the resource requirements for allotment gardening were analysed, providing a quantification of the magnitude and pattern of inputs used to produce food on an allotment. It also investigated where opportunities for more integration of allotments into whole-city resource flows may occur to improve the sustainability of allotments and cities as a whole in future policymaking. Chapter 5 demonstrated the diversity of physical and mental wellbeing benefits that allotment gardeners self-report from their time spent on their plot. Finally, in Chapter 6, the variety of structures and land uses in addition to food growing within allotment plots were analysed, identifying multiple features that contribute to ecosystem service provision on allotments as part of the urban green infrastructure network.

Here, I synthesise some of the key findings across chapters, focusing on two themes: firstly, allotments and urban deprivation; and secondly, the potential loss of ecosystem services associated with allotment closures. I also discuss the implications of this thesis for policymakers, planners and practitioners in greater detail, set the findings within the context of current research, and suggest avenues for further research.

2. Allotments and urban deprivation

Throughout this thesis, an emphasis has been placed on the potential positive benefits of allotment gardening for the practitioners, and for the environment. However, the question of inequitable access to these benefits has not yet truly been explored. As we move towards a vision of sustainable cities where urban horticulture takes a central place in planning and policy, this is perhaps the most important issue to consider when envisaging the future of sustainable urban food production. Gatekeeping a more sustainable urban future cannot be an unintended consequence of an over-focus on those already resourced and able to participate at the expense of those who are, for whatever reasons, excluded.

In Chapter 2, I revealed that the most deprived urban communities have experienced eight times the level of allotment land closures as the least deprived. I noted that this impacts not only access to food growing space, but also access to the associated social and cultural ecosystem services related to allotment gardening, such as empowerment, friendship and education, that were discussed in Chapter 5, along with mental and physical wellbeing. Overall these results suggested that expanding access to urban horticulture in deprived areas would produce a multiplicity of benefits for diet, empowerment and community cohesion.

However, potential barriers to access beyond simple provision of land should also be considered. Barriers exist not only in the form of a lack of physical proximity to an allotment site, but also in the form of time availability (which we now know is around 87 visits per year from the research in Chapter 4), lack of knowledge, skills or tools, and financial constraints. Based on the most recent available data for Sheffield (July 2019; Sheffield City Council 2019), there is a significant correlation between the waiting list length and Indices of Multiple Deprivation (IMD) of allotment sites in Sheffield (Kendall's tau, n = 73, tau = 0.28, $p = 0.001$, z = 3.24), with allotments in more affluent areas having longer waiting lists than those in more deprived areas (where IMD 10 is the most affluent and IMD 1 is the most deprived). As a percentage of population in each IMD decile, the two most affluent deciles have substantially higher numbers on waiting lists than the most deprived areas. This is reflected in the total number of plots available per person in the population of each IMD, which again is highest in the most affluent areas, suggesting that longer waiting lists are not a function of less overall plot availability. Overall, waiting list length per available plot for each IMD in Sheffield varies across the deprivation indices, but is lowest in more deprived areas (Figure 1). This is particularly interesting given that there are many more people in Sheffield overall in the two most deprived IMD deciles (133,252 people live in decile 1; 63,850 in decile 2; 48,260 in decile 9; and 55,901 in decile 10).

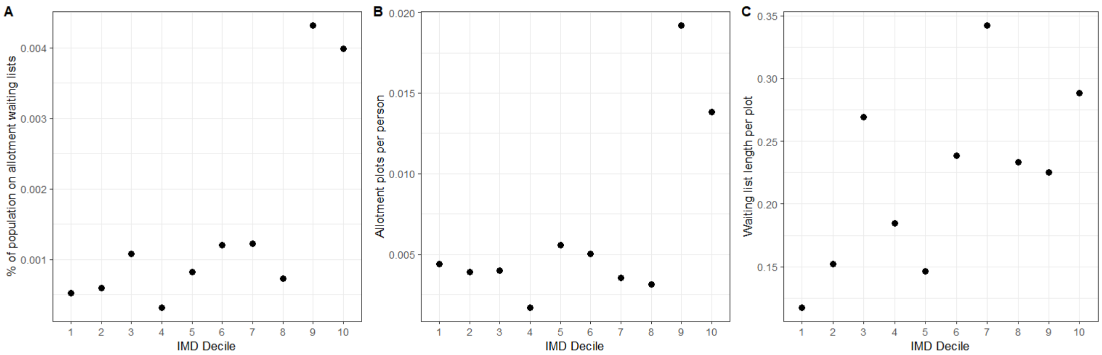


Figure 1. A: Proportion of the population in each Index of Multiple Deprivation decile in Sheffield, UK, who are on waiting lists for allotments, where decile 1 is the most deprived and decile 10 is the most affluent; **B:** Total allotment plot numbers per head of the population for each IMD decile in Sheffield; **C:** Length of waiting list for allotments per allotment plot in each IMD decile.

The very low numbers of people on waiting lists for allotments in more deprived urban areas imply that increasing the number of allotment sites provided in these areas, as suggested as a policy intervention in Chapter 2, may not be a sufficient intervention to encourage expansion of participation in urban horticulture for poorer urban communities (however, it is clear that an expansion of allotment land area in more affluent communities is needed, with 208 and 223 people on allotment waiting lists in IMD deciles 9 and 10 respectively in Sheffield). However, overall my results in Chapter 2 found the highest availability of former allotment land suitable for conversion to urban horticultural use in the most deprived areas; therefore, it is worth considering how best to make use of this potentially available land.

As well as land, four key barriers to urban horticultural participation can be identified from my findings in Chapters 4 and 6. Although my results from Chapter 4 have the potential to be used as an educational tool to allow prospective tenants to decide whether they have the time and resources necessary to successfully cultivate a plot, the reality of these barriers still remains. Chapter 4 demonstrated the necessity of **time**, however those from lower income households have less leisure time than more affluent people (Office for National Statistics, 2015). As well as this, resources are necessary, particularly to cover rent and inputs, and therefore there is a need to be able to meet the financial **cost** of allotment gardening. Chapters 5 and 6 demonstrated that skills development and knowledge are key outcomes for allotment gardeners, but did not explore the fact that in order to confidently take on an allotment plot, some baseline **knowledge** is necessary. Finally, Chapter 4 also demonstrated that **distance** can be a limiting factor in access to allotments; 95% of journeys to the allotment were under 2.1 km, which suggests that beyond this distance, people without access to a vehicle would be disadvantaged when attempting to take on an allotment plot.

The existence of these barriers is understood outside of allotment gardening, with much community and vacant land food growing activity in the global North existing with the express purpose of expanding access to urban horticulture for more deprived communities, and research has previously been conducted on what barriers exist for participation (e.g. Lovell, 2010; Castillo *et al*., 2013; Cohen and Reynolds, 2015 – all of which focus on the United States of America). For example, Lovell (2014) identified lack of secure tenure on land as a key barrier to urban horticulture, particularly when projects are established without direct permission from the landowner. Other barriers include the difficult with identifying suitable land parcels with enough access to sunlight and water; and competition for other land uses (Lovell, 2014). Castillo *et al.* (2013) identified seven barriers to the uptake of urban horticulture in Chicago, most of which were to do with unclear town planning regulations. Cohen and Reynolds (2015) covered urban agriculture in New York where farmers also identified access to and longevity of tenure on land as a key barrier to expanding urban agriculture, as well as the need for a more coherent and supportive legal framework. My research presents new evidence for the existence of these, and other, barriers that are specifically faced by prospective allotment gardeners in the UK, and quantifies the needed resources to an extent not previously understood.

The more informal nature of urban horticultural activities, such as community gardens, covered in this literature on barriers to urban horticultural participation, suffers from the lack of one of the main benefits that allotments offer, which is (at least some) legal protection of the land status as land for urban horticulture. Projects occupying vacant space have suffered from so-called "green gentrification" (the process of development of green space and beautification of an area being used as a strategy to encourage new, more affluent, residents, and the investment of capital in the area, or 'the implementation of an environmental planning agenda related to public green spaces that leads to the exclusion of the most economically vulnerable human population while espousing an environmental ethic', Dooling, 2009). As community gardens are developed, and the visual attractiveness of an area increases, gentrification occurs, and the very communities that stood most to benefit from the area's improvement are priced out of their locality as developers show more of an interest in it (Alkon and Cadji, 2018).

Green gentrification has become a noted issue in the academic literature in human geography, political ecology and urban planning over the past decade (Anguelovski *et al.*, 2019). It can cause health inequalities by displacing lower income residents and raising the cost of living for those that remain in the neighbourhood (Cole *et al.*, 2017); this leads to unequal delivery of cultural ecosystem services which can be a driver of inequality at a citywide level (Maia *et al.*, 2020). More concerted effort to accompany neighbourhood greening with housing policy to mitigate the impact of gentrification could be one example of an option address this (Gould and Lewis, 2018).

There is no easy answer to this issue. However, it is one that proponents of urban horticulture, whether practitioners or policymakers, must keep at the forefront of their minds as cities and spaces are created which seek to increase current levels of urban horticultural production. Protection of urban horticultural sites, such as through legislation similar to that which covers allotment gardens, combined with community growing initiatives, could be part of a strategy to address this and retain food growing spaces for communities who most need it. Indeed, many allotment sites are beginning to lease plots to community groups, which gives these community gardens the added benefit of being able to share knowledge with experienced allotment holders who are also tenants on the site.

3. Ecosystem service loss from allotment closures

This study has also demonstrated that the closure of allotments has consequences beyond the loss of food growing space for a city's residents. In Chapter 2, I found that 65% of allotment land area has been lost since its peak in the 1950s. This suggests not only that this has resulted in the loss of food provisioning space for 6% of the urban population, but that there has been a concurrent loss of the non-food features of allotments discussed in Chapter 6, and the ecosystem services provided by allotment soils discussed in Chapter 3. Combining the results from Chapters 2 and 6 suggests that since the peak decades of allotment provision, 9.8 km^2 of spontaneous flora, 49028 ponds, 4.1 km^2 of lawn and 3677 km^2 of ornamental planting have also been lost through the closure of allotments over the twentieth century. This evidences the suggestions in the discussion of Chapter 2 that the loss of allotment land impacts not only food provisioning, but also the delivery of other associated ecosystem services on allotments. However, these figures alone do not capture the distinctions between conversion to grey space and conversion to other forms of urban green space, in terms of loss of ecosystem delivery.

One of the key ecosystem services that would be lost through grey space conversion but not through green space conversion is that of soil permeability. Taking the results from Chapter 2 in this regard, we know that 48% of former allotment land is now urban grey space, suggesting that 240 km^2 of former allotment land is now sealed (based on current areal allotment extent of 135 km^2 representing 27% of former extent). Soil sealing has a number of consequences for the provision of urban ecosystem services. It leads to increased runoff, amplifying flood risk and reducing flood mitigation potential through the loss of permeable surface area; increases the urban heat island effect; causes a loss of biodiversity; and reduces the capacity of the landscape to act as a carbon store (Perry and Nawaz, 2008; Scalenghe, 2009; Miller *et al*., 2014; Edmondson *et al*., 2016; Fokaides *et al*., 2016). Urban flooding is a major expected consequence of climate change in the United Kingdom (Miller and Hutchins, 2017); a continuation of the sealing of permeable surfaces in urban areas that has been seen through the conversion of allotment land to grey space, amongst loss of other greenspaces, will have significant negative consequences for this.

Further to this, Chapter 3 demonstrated that the good quality of allotment soils provide a wide range of urban ecosystem services, and contribute disproportionately high levels of soil carbon storage nationally to overall accounts. A full assessment of the carbon storage contribution that urban greenspace makes nationally is yet to be undertaken; however, these results are a promising indicator of the necessity of including urban areas in carbon accounts. If replicated in other forms of urban greenspace, my results demonstrate that the conversion of urban green space such as allotments to grey space analysed in Chapter 2 would have disproportionately negative impacts on the total carbon storage in the United Kingdom.

As it becomes increasingly important to mitigate both the environmental consequences of climate change, and the human health consequences of related urban issues such as air pollution, the findings of my research regarding ecosystem service delivery on allotments are a timely contribution to the literature on urban ecosystem services. They demonstrate that when policymakers are considering either expanding or reducing urban horticultural areas, there are a myriad of impacts on the wider environment that also need to be considered as direct results of these choices.

4. Consequences for policy

The policy landscape governing allotment gardens is relatively unique for urban horticulture, given that they enjoy some form of legal protection and are legally meant to be created to meet demand where it is available. This was first compelled by the 1887 Allotment Act, but the first major piece of legislation was the 1908 Smallholdings and Allotments Act which regulated allotment provision, tenancy fees, and term of use such as the requirement that allotments are primarily used to cultivate fruit and vegetables. Further Acts in 1922, 1925 and 1926 expanded on this slightly; the 1950 Allotments Act clarified rent levels and terms of notifying tenants if they were required to quit their allotment. Reduced rents for the elderly, unemployed and other special groups were also introduced in this Act. In 1980 and 1981 the Local Government Forward Planning and Land Act and its amendment Act brought a requirement on councils to safeguard land existing as allotments and outlined restrictions on circumstances in which allotment sites could be closed.

Individual allotment sites or associations have varied policies covering the maintenance and rules of their plots; the policy landscape governing specific rules for the upkeep of plots and tenancy agreements is therefore relatively incoherent at a national level and is extremely devolved. Many councils have Allotment Strategies governing their policy towards allotments; however, these are not often updated and resource limitations in local councils have restricted the ability of allotment officers to keep their policies in line with the present situation in their area (Dobson, 2020, pers. comm).

This study provides a range of information of potential value to policymakers, aspects of which have been briefly discussed above, as well as in the research chapters. Here I provide a more targeted overview of the practical implications of the findings of this thesis, setting out five key points for policymakers.

1. The need for intervention in deprived areas

Improving access to urban horticulture results in benefits for nutritional, mental and physical wellbeing. Targeted schemes in communities who stand to benefit the most from such improvements also have the potential to reduce pressures on health services that results from poor diet and mental health issues. However, investigation is needed to identify barriers preventing people from participating in urban horticulture.

2. The need to reassess minimum cultivation level requirements

The results of Chapter 6 demonstrated that very few allotment gardeners meet the minimum cultivation standard of cultivating 75% of an allotment plot: only seven of 180 surveyed plots had >75% cultivation for fruit and vegetables. Producing guidelines which necessitate such levels of cultivation may be detrimental as it puts people off leasing an allotment who would be capable of maintaining what I have found is the true average level of plot cultivation (just under half the area). To ensure that plots are being worked rather than left mostly abandoned, plot cultivation guidelines should recognise the actual level of cultivation most gardeners engage in; educate plotholders on features that are acceptable in addition to crops; and encourage features that could be beneficial for biodiversity (such as ponds) or that maximise the wellbeing benefits of allotments (such as recreational lawn space).

3. Integration of resources

In Chapter 4, I explored some possibilities to expand the use of renewable or recycled resources on allotments, primarily regarding compost and water. Urban horticulture does not exist in a vacuum outside of the flows of resources within and between cities, and urban horticulture also requires a high level of inputs from resources that are often wasted elsewhere in the urban system. Key policy opportunities therefore exist here to target food waste and flood mitigation. A diversion of home compostable food waste on a municipal level to centralised compost schemes, where those who practice urban horticulture were able to access compost, would decrease the costs and emissions associated with food waste as well as allowing gardeners to use more recycled sources of compost rather than shop-bought compost with its associated environmental costs of production (and financial costs to the gardeners themselves). Such schemes already exist, in part, with many councils providing green waste recycling services. However, there are a great number of benefits to be gained from expanding this to compostable food waste. Further to this, rainfall capturing on a broader scale would reduce the pressure that urban horticulture places on mains supplies during the drier summer months, as well as reducing the impact of sudden heavy rainfalls on areas at risk of flash flooding.

4. Educational possibilities for current and prospective gardeners

Educational possibilities for current and prospective allotment gardeners based on this research are numerous, and primarily derive from Chapters 3, 4 and 6. These comprise: soil management techniques best suited to the maintenance of soil and ecosystem health; resource requirements and expectations of allotment gardening; and the identification of ways to support the delivery of non-food provisioning ecosystem services on allotments. Prospective allotment tenants could be given information about the best ways to cultivate soil health; encourage pollinators and worms on their plot; and maximise harvesting of rainwater. Much of this information already exists as advice from online sources, however a collation, revision and extension based on the research I have set out in this thesis would provide a useful information package for new and existing plotholders.

5. Legal protection of allotment sites

Allotments benefit from legal protection; however, competing demands on urban land have led many to be closed as urban development takes priority over the maintenance of urban horticultural space. Evidence from the research in this thesis should lend weight to arguments for protecting those allotments we have as an invaluable feature of the urban landscape delivering a multiplicity of wide-ranging benefits for human and environmental health.

5. Contribution to the field and avenues for further research

During the course of this study, from late 2016 to mid-2020, the popularity of urban horticulture as research enquiry, policy proposal, and activity has exploded. In this time, urban food production had its first mention in an Intergovernmental Panel on Climate Change report (Mbow *et al*., 2018); allotment waiting lists grew up to 300% during the coronavirus lockdown in the United Kingdom (Smithers, 2020); and Google Scholar indexed 16700 papers using the terms "urban horticulture" or "urban agriculture" published between 2016 and 2020 (of which 1840 use the term "urban horticulture"). Overall, the work described in this thesis contributes to our understanding of the current form and nature of allotment gardens. The interdisciplinary nature of the preceding research has enabled me to answer a range of questions regarding this historically and presently significant form of urban horticulture and has relevance to the wider body of research into soil-based urban horticulture.

In Chapter 1, I outlined several gaps within the academic literature on urban horticulture. The specific objectives of this study, in light of that literature review, were:

1. To identify the historical context leading to current structure and provision of allotments.

    - Have former allotment gardens all become part of the urban built infrastructure, or do opportunities exist to utilise former allotments in future urban horticulture?

    - Has the pattern of allotment land closures varied demographically within cities?

Chapter 2 focused on this first objective and its arising research questions. I identified that the historical context of the provision of allotments across the United Kingdom provides important insights into patterns of higher allotment land loss in more deprived areas. I also analysed the land use change of former allotments to produce an estimate of former allotment land potentially suitable for reconversion to use in urban horticulture; this estimate, in most cases, was a sufficient land area to meet the waiting list demand in the city.

2. To discern the resource demands of allotment gardening based on typical management practices across the year.

    - To what extent are the resources used by allotment gardeners sustainable?
    - Where do opportunities exist to integrate the resource demands of allotments within the flows of materials in the wider urban system?
    - Do certain management practices contribute to higher levels of soil quality?

This research objective was addressed by Chapters 3 and 4. I found that around half of allotment holders (Chapter 3) were growing organically and almost all used compost from their home or plot waste. I did not find any significant differences in soil quality on allotments under different management practices; however, this may have been due to a number of reasons as discussed in the chapter. I also found that the year-round use of resources (Chapter 4) on allotment gardens uncovered varying levels of sustainable resource use, and found several potential opportunities to increase the integration of resource demands to improve this, particularly regarding water use.

3. To assess the ecosystem service provision of allotments, with a particular focus on soil, and understand the contribution of allotment soils to national carbon storage.

    - Do allotment soils maintain high levels of soil quality, and how does this compare to commercial horticultural soils?
    - To what extent to allotments contribute to national soil carbon stocks?
    - How do the structure and features of the non-crop production areas of allotments contribute to the delivery of ecosystem services?
    - How do allotment gardeners self-report physical or mental wellbeing benefits of allotment gardening?

Chapters 3, 5 and 6 addressed this final research objective. I discovered that allotment soils, on a nationwide scale, are consistently of higher quality than commercial arable and horticultural soils, suggesting that allotment gardeners successfully maintain management techniques conducive to sustainable soil quality (Chapter 3). I found that allotment soils contribute disproportionately to national carbon stock estimates relative to their areal extent, underscoring the need for further consideration of urban green spaces when estimating carbon stocks (Chapter 3). Chapter 6 assessed the non-crop production areas of allotments, which I discovered were around half the total plot area, and found several different features present that are conducive to ecosystem service provision. I found that allotment gardeners self-reported high levels of mental and physical wellbeing as a result of time spent on their plot, including engagement with nature and social interactions (Chapter 5).

Previous research on allotments has primarily been at a case study city level (for example: Edmondson *et al*., 2014a; Spilková *et al*., 2016; Cabral *et al*., 2017; Seguí *et al*., 2017; Scott *et al*., 2018; Edmondson *et al*., 2020b) with some exceptions at a nationwide scale (for example: Foster *et al*., 2017). The nationwide scale of the research in this thesis is therefore an important step forward. I have demonstrated a variety of methods that can be used to assess allotments, or indeed any chosen case study system, on a national level: the use of GIS; citizen science; and extensive field study. This scale has enabled me to draw nationally representative conclusions about the nature of allotments and allotment gardeners. More national and even international-scale research could build on these methods to enable research on urban horticulture to go beyond the limitations of single-city case studies to understand broader patterns and drivers, and generalise from them.

A number of possible directions for future research arise from my results. Firstly, throughout this study allotment gardens have been the case study urban horticultural system. Whilst there is some precedent for finding similar results in other soil-based urban horticulture, such as community gardens (for example: Cabral *et al*., 2017; van der Jagt *et al*., 2017; Baldock *et al*., 2019), comparative research is necessary to elucidate where commonalities and differences occur in different urban horticultural types. Developing urban horticulture to be a productive and sustainable method for urban food production in future cities requires that planners are able to utilise the wide variety of types available, and accurately assess the most suitable and effective type for each possible available land parcel (Edmondson *et al*., 2020a; Grafius *et al*., 2020). Further research should address this with comparative assessments, for example by expanding the work of Chapter 4 to look at resource demands of different urban horticultural forms.

Chapters 3 and 6 discussed the potential ecosystem service provision of allotments as part of the urban green infrastructure network. However, it would be interesting to be able to set these assessments within the context of other forms of urban greenspace. Further research, building on, for example, the carbon storage estimates for allotments in Chapter 3, could build on this thesis to draw up a more detailed assessment of the nature and structure of urban greenspace as a whole, investigating how urban horticulture delivers on multiple ecosystem services but also assessing where the greater benefit may be gained from another form of green infrastructure land use in ecological or cultural terms. A holistic understanding of the different forms of urban greenspace and their differing contributions to ecosystem service provision would be invaluable for planners; multifunctional urban greenspace is key for resilience and sustainability of cities now, and in the future (Deelstra *et al*., 2001; Clark and Nicholas, 2013).

Chapter 6 assessed the structure of allotments and focused on some different features known to deliver on different ecosystem services. However, quantification of the potential delivery was not undertaken. Using the understanding of the structure of allotments that this thesis has developed, a logical next step for investigation would be to quantify the potential trade-offs or harmonies of ecosystem service delivery based on different structures of allotments, in order to be able to inform plotholders of the options they have in developing their plots to most efficiently benefit crop production and the wider environment.

6. Conclusions

Going forward, it is not enough to know what already exists. We should also ask what could be, when imagining a future vision of sustainable and equitable urban food production. The question, therefore, is not simply "How can we produce more food in urban areas?" but more fundamentally one of improving the quality of urban life for the vast majority of the world's population who now reside in cities. I have demonstrated throughout this thesis that urban horticulture is not simply an issue of food: it impacts many aspects of a participant's life and contributes to the quality of the wider environment, with associated benefits for climate and ecological function. Future efforts to expand urban food production should take this spectrum of associated co-benefits into account, alongside a holistic approach to integrate urban horticulture into the wider energy and resource flows of cities, with a focus on improving both food security and quality of life for the most disadvantaged communities. Allotment gardening is not a magic bullet for the problems of twenty-first century society. However, I have here provided a suite of evidence to show that it can be one part of a much-needed cure, and a practical avenue to improve social and environmental health on multiple levels.

Reference list

1. Acton, L. (2011). Allotment Gardens: A Reflection of History, Heritage, Community and Self. *Papers from the Institute of Archaeology*, *21*(0), 46. https://doi.org/10.5334/pia.379

2. Acton, L. (2015). *Growing Space: A History of the Allotment Movement*. Nottingham: Five Leaves Publications.

3. Aerts, R., Dewaelheyns, V., & Achten, W. (2016). Potential ecosystem services of urban agriculture: a review. *PeerJ Preprints, 4*, e2286v1. https://doi.org/10.7287/peerj.preprints.2286

4. Alkon, A. H., & Cadji, J. (2020). Sowing Seeds of Displacement: Gentrification and Food Justice in Oakland, CA. *International Journal of Urban and Regional Research*, *44*(1), 108–123. https://doi.org/10.1111/1468-2427.12684

5. Altieri, M. A., Companioni, N., Cañizares, K., Murphy, C., Rosset, P., Bourque, M., & Nicholls, C. I. (1999). The greening of the “barrios”: Urban agriculture for food security in Cuba. *Agriculture and Human Values*, *16*(2), 131–140. https://doi.org/10.1023/A:1007545304561

6. Andersson, E., Barthel, S., & Ahrné, K. (2007). Measureing social-ecological dynamics behind generation of ecosystem services. *Ecological Applications, 17*(5), 1267-1278. https://doi.org/10.1890/06-1116.1

7. Anguelovski, I., Connolly, J. J. T., Garcia-Lamarca, M., Cole, H., & Pearsall, H. (2019). New scholarly pathways on green gentrification: What does the urban ‘green turn’ mean and where is it going? *Progress in Human Geography*, *43*(6), 1064-1086.

8. Aubry, C., & Kebir, L. (2013). Shortening food supply chains: A means for maintaining agriculture close to urban areas? The case of the French metropolitan area of Paris. *Food Policy*, *41*, 85–93. https://doi.org/10.1016/j.foodpol.2013.04.006

9. Badami, M. G., & Ramankutty, N. (2015). Urban agriculture and food security: A critique based on an assessment of urban land constraints. *Global Food Security*, *4*, 8–15. https://doi.org/10.1016/j.gfs.2014.10.003

10. Bahadur Kc, K., Dias, G. M., Veeramani, A., Swanton, C. J., Fraser, D., Steinke, D., Lee, E., Wittman, H., Farber, J. M., Dunfield, K., McCann, K., Anand, M., Campbell, M., Rooney, N., Raine, N. E., Van Acker, R., Hanner, R., Pascoal, S., Sharif, S., Benton, T. G, & Fraser, E. D. G. (2018). When too much isn't enough: Does current food production meet global nutritional needs? *PLoS ONE*, *13*(10). https://doi.org/10.1371/journal.pone.0205683

11. Bahers, J. B., & Giacchè, G. (2019). Towards a metabolic rift analysis: The case of urban agriculture and organic waste management in Rennes (France). *Geoforum*, *98*, 97–107. https://doi.org/10.1016/j.geoforum.2018.10.017

12. Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., … Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1803), 20142849. https://doi.org/10.1098/rspb.2014.2849

13. Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Morse, H., … Memmott, J. (2019). A systems approach reveals urban pollinator hotspots and conservation opportunities. *Nature Ecology and Evolution*, *3*(3), 363–373. https://doi.org/10.1038/s41559-018-0769-y

14. Banks, J., & Xu, X. (2020). The mental health effects of the first two months of lockdown and social distancing during the Covid-19 pandemic in the UK. *IFS Working Paper W20/16*. https://www.ifs.org.uk/uploads/WP202016-Covid-and-mental-health.pdf. (Accessed 12 June 2020)

15. Barnidge, E. K., Hipp, P. R., Estlund, A., Duggan, K., Barnhart, K. J., & Brownson, R. C. (2013). Association between community garden participation and fruit and vegetable consumption in rural Missouri. *International Journal of Behavioral Nutrition and Physical Activity*, *10*. https://doi.org/10.1186/1479-5868-10-128

16. Barthel, S., Folke, C., & Colding, J. (2010). Social-ecological memory in urban gardens-Retaining the capacity for management of ecosystem services. *Global Environmental Change*, *20*(2), 255–265. https://doi.org/10.1016/j.gloenvcha.2010.01.001

17. Barthel, S., & Isendahl, C. (2013). Urban gardens, Agriculture, And water management: Sources of resilience for long-term food security in cities. *Ecological Economics*, *86*, 224–234. https://doi.org/10.1016/j.ecolecon.2012.06.018

18. Barthel, S., Parker, J., & Ernstson, H. (2015). Food and Green Space in Cities: A Resilience Lens on Gardens and Urban Environmental Movements. *Urban Studies*, *52*(7), 1321–1338. https://doi.org/10.1177/0042098012472744

19. Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1-48. doi:10.18637/jss.v067.i01.

20. Batjes, N. H. (2014). Total carbon and nitrogen in the soils of the world. *Soil Science*, 65:1, 10-21. https://doi.org/10.1111/ejss.12114_2

21. Beck, T. (2001). Emergy evaluation of food production in urban residential landscapes. *Urban Ecosystems*, *5*(3), 187–207. https://doi.org/10.1023/A:1024093920660

22. Benis, K., & Ferrão, P. (2017). Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – a life cycle assessment approach. *Journal of Cleaner Production*, *140*(2), 784–795. https://doi.org/10.1016/j.jclepro.2016.05.176

23. Beniston, J., & Lal, R. (2012). Improving soil quality for urban agriculture in the north central U.S. In *Carbon Sequestration in Urban Ecosystems* (pp. 279–313). https://doi.org/10.1007/978-94-007-2366-5_15

24. Benton, T., Crawford, J., Doherty, B., Fastoso, F., Jimenez, H. G., Ingram, J., Lang, T. & Tiffin, R. (2017). British Food: What role should UK producers have in feeding the UK? Independent Report.

http://www.leeds.ac.uk/download/481/british_food_makers_report. Accessed August 24 2020.

25. Blair, D., Giesecke, C. C., & Sherman, S. (1991). A dietary, social and economic evaluation of the Philadelphia urban gardening project. *Journal of Nutrition Education*, 23(4), 161-167.

26. Bohn, K., & Viljoen, A. (2011). The edible city: envisioning the Continuous Productive Urban Landscape (CPUL). In *Field* (Vol. 4). Retrieved from www.field-journal.org

27. Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H., & Favoino, E. (2009). Composting and compost utilization: Accounting of greenhouse gases and global warming contributions. *Waste Management and Research*, *27*, 800–812. https://doi.org/10.1177/0734242X09345275

28. de Bon, H., Parrot, L., & Moustier, P. (2010). Sustainable urban agriculture in developing countries. A review. *Agronomy for Sustainable Development, 30*, 21-32

29. Born, B., & Purcell, M. (2006). Avoiding the Local Trap: Scale and Food Systems in Planning Research. *Journal of Planning Education and Research*, *26*(2), 195–207. https://doi.org/10.1177/0739456X06291389

30. Borysiak, J., Mizgajski, A., & Speak, A. (2017). Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. *Urban Ecosystems*, *20*(2), 323–335. https://doi.org/10.1007/s11252-016-0595-4

31. Bradley, R., Milne, R., Bell, J., Lilly, A., Jordan, C. & Higgins, A. (2005), A soil carbon and land use database for the United Kingdom. *Soil Use and Management*, *21*, 363-369. https://doi.org/10.1079/SUM2005351

32. Bretzel, F., Calderisi, M., Scatena, M., & Pini, R. (2016). Soil quality is key for planning and managing urban allotments intended for the sustainable production of home-consumption vegetables. *Environmental Science and Pollution Research*, *23*(17), 17753–17760. https://doi.org/10.1007/s11356-016-6819-6

33. de Brogniez, D., Ballabio, C., Stevens, A., Jones, R. J. A., Montanarella, L., & van Wesemael, B. (2014). A map of the topsoil organic carbon content of Europe generated by a generalised additive model. *European Journal of Soil Science 66*(1), 121-134. https://doi.org/10.1111/ejss.12193

34. Brown, K. H., & Jameton, A. L. (2000). Public health implications of urban agriculture. *Journal of Public Health Policy*, *21*(1), 20–39. https://doi.org/10.2307/3343472

35. Buechler, S., Mekala, G. D., & Keraita, B. (2006). Wastewater use for urban and peri-urban agriculture. In *Cities farming for the future: Urban agriculture for green and productive cities* (Vol. 2006).

36. Cabral, I., Keim, J., Engelmann, R., Kraemer, R., Siebert, J., & Bonn, A. (2017). Ecosystem services of allotment and community gardens: A Leipzig, Germany case study. *Urban Forestry and Urban Greening*, *23*, 44–53. https://doi.org/10.1016/j.ufug.2017.02.008

37. Campbell, M., & Campbell, I. (2011). Allotment waiting lists in England 2011. *Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom*. http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2011.pdf

38. Campbell, M., & Campbell, I. (2013). Allotment waiting lists in England 2013. *Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom*. http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2013.pdf

39. Caputo, S. (2012). Chapter 22 The purpose of urban food production in developed countries. In *Sustainable food planning: evolving theory and practice* (pp. 259–270). https://doi.org/10.3920/978-90-8686-187-3_22

40. Carney, P. A., Hamada, J. L., Rdesinski, R., Sprager, L., Nichols, K. R., Liu, B. Y., & Shannon, J. (2012). Impact of a community gardening project on vegetable intake, food security and family relationships: A community-based participatory

research study. *Journal of Community Health, 37*(4), 874-881. https://dx.doi.org/10.1007%2Fs10900-011-9522-z

41. Castillo, S., Winkle, C., Krauss, S., Turkewitz, A., Silva, C., & Heinemann, E. (2013). Regulatory and Other Barriers to Urban and Peri-Urban Agriculture: A Case Study of Urban Planners and Urban Farmers from the Greater Chicago Metropolitan Area. *Journal of Agriculture, Food Systems, and Community Development*, *3*(3), 155–166. https://doi.org/10.5304/jafscd.2013.033.001

42. Chaudhary, A., Pfister, S., & Hellweg, S. (2016). Spatially Explicit Analysis of Biodiversity Loss Due to Global Agriculture, Pasture and Forest Land Use from a Producer and Consumer Perspective. *Environmental Science and Technology*, *50*(7), 3928–3936. https://doi.org/10.1021/acs.est.5b06153

43. Chen, C., Chaudhary, A., & Mathys, A. (2020). Nutritional and environmental losses embedded in global food waste. *Resources, Conservation and Recycling*, *160*(December 2019), 104912. https://doi.org/10.1016/j.resconrec.2020.104912

44. Church, A., Mitchell, R., Ravenscroft, N., & Stapleton, L. M. (2015). “Growing your own”: A multi-level modelling approach to understanding personal food growing trends and motivations in Europe. *Ecological Economics*, *110*, 71–80. https://doi.org/10.1016/j.ecolecon.2014.12.002

45. Clark, K. H., & Nicholas, K. A. (2013). Introducing urban food forestry: A multifunctional approach to increase food security and provide ecosystem services. *Landscape Ecology*, *28*(9), 1649–1669. https://doi.org/10.1007/s10980-013-9903-z

46. Clavin, A. A. (2011). Realising ecological sustainability in community gardens: A capability approach. *Local Environment*, *16*(10), 945–962. https://doi.org/10.1080/13549839.2011.627320

47. Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., … Gong, P. (2018). A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth’s Future*, *6*(1), 40–60. https://doi.org/10.1002/2017EF000536

48. Clucas, B., Parker, I. D., & Feldpausch-Parker, A. M. (2018). A systematic review of the relationship between urban agriculture and biodiversity. *Urban Ecosystems*, *21*(4), 635–643. https://doi.org/10.1007/s11252-018-0748-8

49. CoDyre, M., Fraser, E. D. G., & Landman, K. (2015). How does your garden grow? An empirical evaluation of the costs and potential of urban gardening. *Urban Forestry and Urban Greening*, *14*(1), 72–79. https://doi.org/10.1016/j.ufug.2014.11.001

50. Cohen, N. (2012). Chapter 8 Planning for urban agriculture: problem recognition, policy formation, and politics. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (1st ed., pp. 103–114). https://doi.org/10.3920/978-90-8686-187-3_8

51. Cohen, N., & Reynolds, K. (2015). Resource needs for a socially just and sustainable urban agriculture system: Lessons from New York City. *Renewable Agriculture and Food Systems*, *30*(01), 103–114.

52. Cole, H. V. S., Lamarca, M. G., Connolly, J. J. T., & Anguelovski, I. (2017). Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *Journal of Epidemiol Community Health, 71*, 1118-1121.

53. Coleman-Jensen, A., Rabbitt, M. P., Gregory, A. C., & Singh, A. (2019). *Household Food Security in the United States in 2018.* ERR-270, U.S. Department of Agriculture, Economic Research Service.

54. Cooksey-Stowers, K., Schwartz, M. B., & Brownell, K. D. (2017). Food swamps predict obesity rates better than food deserts in the United States. *International Journal of Environmental Research and Public Health*, *14*(11), 1366. https://doi.org/10.3390/ijerph14111366

55. Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M. (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography*, *37*(1), 2–28. https://doi.org/10.1177/0309133312461032

56. Crouch, D. & Ward, C. (1997) *The Allotment: Its Landscape And Culture*. Faber and Faber.

57. Crush, J., Hovorka, A., & Tevera, D. (2011). Food security in Southern African cities: The place of urban agriculture. *Progress in Development Studies*, *11*(4), 285–305. https://doi.org/10.1177/146499341001100402

58. Cummins, S., & Macintyre, S. (2002). "Food deserts" – evidence and assumption in health policy making. *BMJ*, *325*(7361), 436-438. https://doi.org/10.1136/bmj.325.7361.436

59. Curtin, S. (2009). Wildlife tourism: The intangible, psychological benefits of human–wildlife encounters. *Current Issues in Tourism*, Vol 12 Nos.5-6, pp.451-474.

60. Davies, B. R., Biggs, J., Williams, P. J., Lee, J. T. & Thompson, S. (2008). A comparison of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape. *Hydrobiologia*, *597*, 7-17. https://doi.org/10.1007/s10750-007-9227-6

61. Davies, Z. G., Fuller, R. A., Loram, A., Irvine, K. N., Sims, V., & Gaston, K. J. (2009). A national scale inventory of resource provision for biodiversity within domestic gardens. *Biological Conservation*, *142*(4), 761–771. https://doi.org/10.1016/j.biocon.2008.12.016

62. Davies, Z. G., Edmondson, J. L., Heinemeyer, A., Leake, J. R., & Gaston, K. J. (2011). Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology*, *48*(5), 1125–1134. https://doi.org/10.1111/j.1365-2664.2011.02021.x

63. Deelstra, T., Boyd, D. and van den Biggelaar, M. (2001) Multifunctional land use: an opportunity for promoting urban agriculture in Europe. *The International Institute for the Urban Environment*, Urban Agriculture Magazine 4.

64. DEFRA (2015). *Food Statistics Pocketbook 2015*. British Government, London.

65. DEFRA (2017). *Family food 2015*. British Government, London.

66. DEFRA (2020a). Agriculture in the United Kingdom 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904024/AUK_2019_27July2020.pdf. Accessed August 24 2020.

67. DEFRA (2020b). Food Statistics in your pocket: Prices and expenditure. https://www.gov.uk/government/publications/food-statistics-pocketbook/food-statistics-in-your-pocket-prices-and-expenditure. Accessed August 24 2020.

68. de Graaf, P. A. (2012). Chapter 42 Room for urban agriculture in Rotterdam: defining the spatial opportunities for urban agriculture within the industrialised city. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (pp. 533–546). https://doi.org/10.3920/978-90-8686-187-3_42

69. De Kimpe, C. R., & Morel, J. L. (2000). Urban soil management: A growing concern. *Soil Science, 165*(1), 31–40. https://doi.org/10.1097/00010694-200001000-00005

70. De Zeeuw, H., Van Veenhuizen, R., & Dubbeling, M. (2011). The role of urban agriculture in building resilient cities in developing countries. *Journal of Agricultural Science, 149*(S1), 153–163. https://doi.org/10.1017/S0021859610001279

71. Denny, G. M. (2012). Chapter 27 Urban agriculture and seasonal food footprints: an LCA study of tomato production and consumption in the UK. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (pp. 323–336). https://doi.org/10.3920/978-90-8686-187-3_27

72. Derkzen, P., & Morgan, K. (2012). Chapter 4 Food and the city: the challenge of urban food governance. In *Sustainable food planning: evolving theory and practice* (pp. 59–66). https://doi.org/10.3920/978-90-8686-187-3_4

73. Devereaux, S., Béné, C., & Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Security, 12*, 769-772. https://doi.org/10.1007/s12571-020-01085-0

74. Devigne, C., Mouchon, P., & Vanhee, B. (2016). Impact of soil compaction on soil biodiversity – does it matter in urban context? *Urban Ecosystems*, *19*(3), 1163–1178. https://doi.org/10.1007/s11252-016-0547-z

75. Dickinson, D. C., & Hobbs, R. J. (2017, June 1). Cultural ecosystem services: Characteristics, challenges and lessons for urban green space research. *Ecosystem Services*, Vol. 25, pp. 179–194. https://doi.org/10.1016/j.ecoser.2017.04.014

76. Dobson, M. C., Edmondson, J. L., & Warren, P. H. (2020). Urban food cultivation in the United Kingdom: Quantifying loss of allotment land and identifying potential for restoration. *Landscape and Urban Planning*, *199*. https://doi.org/10.1016/j.landurbplan.2020.103803

77. Dominati, E., Patterson, M., & Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological Economics*, *69*(9), 1858–1868. https://doi.org/10.1016/j.ecolecon.2010.05.002

78. Dooling, S. (2009). Ecological gentrification: A research agenda exploring justice in the city. *International Journal of Urban and Regional Research*, *33*, 621-639.

79. Doron, G. (2005). Urban agriculture: Small, medium, large. *Architectural Design*, *75*(3), 52–59. https://doi.org/10.1002/ad.76

80. Edmondson, J. L., Davies, Z. G., McCormack, S. A., Gaston, K. J., & Leake, J. R. (2011). Are soils in urban ecosystems compacted? A citywide analysis. *Biology Letters*, *7*(5), 771–774. https://doi.org/10.1098/rsbl.2011.0260

81. Edmondson, J. L., Davies, Z. G., McHugh, N., Gaston, K. J., & Leake, J. R. (2012). Organic carbon hidden in urban ecosystems. *Scientific Reports*, *2*, 963. https://doi.org/10.1038/srep00963

82. Edmondson, J. L., Davies, Z. G., Gaston, K. J., & Leake, J. R. (2014a). Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. *Journal of Applied Ecology*, *51*(4), 880–889. https://doi.org/10.1111/1365-2664.12254

83. Edmondson, J. L., Davies, Z. G., McCormack, S. A., Gaston, K. J., & Leake, J. R. (2014b). Land-cover effects on soil organic carbon stocks in a European city. *Science of the Total Environment*, *472*, 444–453.

84. Edmondson, J. L., Stott, I., Davies, Z. G., Gaston, K. J., & Leake, J. R. (2016). Soil surface temperatures reveal moderation of the urban heat island effect by trees and shrubs. *Scientific Reports*, *6*(1), 33708. https://doi.org/10.1038/srep33708

85. Edmondson, J. L., Blevins, R. S., Cunningham, H., Dobson, M. C., Leake, J. R., & Grafius, D. R. (2019). Grow your own food security? Integrating science and citizen science to estimate the contribution of own growing to UK food production. *Plants, People, Planet*, *1*(2), 93–97. https://doi.org/10.1002/ppp3.20

86. Edmondson, J. L., Cunningham, H., Densley Tingley, D. O., Dobson, M. C., Grafius, D. R., Leake, J. R., … Cameron, D. D. (2020a). The hidden potential of urban horticulture. *Nature Food*, *1*(3), 155–159. https://doi.org/10.1038/s43016-020-0045-6

87. Edmondson, J. L., Childs, D. Z., Dobson, M. C., Gaston, K. J., Warren, P. H., & Leake, J. R. (2020b). Feeding a city – Leicester as a case study of the importance of allotments for horticultural production in the UK. *Science of the Total Environment*, *705*. https://doi.org/10.1016/j.scitotenv.2019.135930

88. Edwards-Jones, G. (2010). Does eating local food reduce the environmental impact of food production and enhance consumer health? *Proceedings of the Nutrition Society*, *69*(4), 582–591. https://doi.org/10.1017/S0029665110002004

89. Egerer, M. H., Philpott, S. M., Liere, H., Jha, S., Bichier, P., & Lin, B. B. (2018). People or place? Neighborhood opportunity influences community garden soil properties and soil-based ecosystem services. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *14*(1), 32–44. https://doi.org/10.1080/21513732.2017.1412355

90. Egerer, M., Lin, B. B., & Diekmann, L. (2020). Nature connection, experience and policy encourage and maintain adaptation to drought in urban agriculture. *Environmental Research Communications*, *2*(4), 041004. https://doi.org/10.1088/2515-7620/ab8917

91. Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities. A review. *Agronomy for Sustainable Development*, *35*(2), 483–498. https://doi.org/10.1007/s13593-014-0273-y

92. Emmett, B.A., Reynolds, B., Chamberlain, P.M., Rowe, E., Spurgeon, D., Brittain, S.A., Frogbrook, Z., Hughes, S., Lawlor, A.J., Poskitt, J., Potter, E., Robinson, D.A., Scott, A., Wood, C., Woods, C. (2010). Countryside Survey: Soils Report from 2007. Technical Report No. 9/07 NERC/Centre for Ecology & Hydrology 192pp. (CEH Project Number: C03259).

93. Entwistle, J. A., Amaibi, P. M., Dean, J. R., Deary, M. E., Medock, D., Morton, J., … Bramwell, L. (2019). An apple a day? Assessing gardeners' lead exposure in urban agriculture sites to improve the derivation of soil assessment criteria. *Environment International*, *122*, 130–141. https://doi.org/10.1016/j.envint.2018.10.054

94. Environmental Protection Agency (2020). Composting at home. https://www.epa.gov/recycle/composting-home. Accessed 30 March 2020.

95. Eriksen, S. N. (2013). Defining local food: Constructing a new taxonomy - three domains of proximity. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science*, *63*(SUPPL.1), 47–55. https://doi.org/10.1080/09064710.2013.789123

96. FAO (2006). Food security policy brief. Retrieved from http://www.fao.org/fileadmin/templates/faoitaly/documents/pdf/pdf_Food_Security_Cocept_Note.pdf

97. FAO (2017). Prevalence of Undernourishment - % of Population (United Kingdom). Retrieved from https://data.worldbank.org/indicator/SN.ITK.DEFC.ZS?end=2017&locations=GB&start=2017&view=bar

98. FAO (2020a). FAO Food Price Index. http://www.fao.org/worldfoodsituation/foodpricesindex/en/. Accessed August 24 2020.

99. FAO (2020b). *COVID-19 and the risk to food supply chains: How to respond?* Rome. https://doi.org/10.4060/ca8388en

100. Fleischer, E. (2018). Doctors in Scotland can now prescribe nature. *World Economic Forum Agenda,* https://www.weforum.org/agenda/2018/10/doctors-in-scotland-can-now-prescribe-nature (Accessed 29 January 2020)

101. Fokaides, P. A., Kylili, A., Nicolaou, L., & Ioannou, B. (2016). The effect of soil sealing on the urban heat island phenomenon. *Indoor and Built Environment*, *25*(7), 1136–1147. https://doi.org/10.1177/1420326X16644495

102. Foster, G., Bennett, J., & Sparks, T. (2017). An assessment of bumblebee (Bombus spp) land use and floral preference in UK gardens and allotments cultivated for food. *Urban Ecosystems*, *20*(2), 425–434. https://doi.org/10.1007/s11252-016-0604-7

103. Franzluebbers, A. J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. *Soil and Tillage Research*, 66:2, 95-106. https://doi.org/10.1016/S0167-1987(02)00018-1

104. Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Lawler, J. J., … Wood, S. A. (2017, July 1). Nature contact and human health: A research agenda. *Environmental Health Perspectives*, Vol. 125. https://doi.org/10.1289/EHP1663

105. Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., & Gaston, K. J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, *3*(4), 390–394. https://doi.org/10.1098/rsbl.2007.0149

106. Gaston, K. J., Warren, P. H., Thompson, K., & Smith, R. M. (2005). Urban domestic gardens (IV): the extent of the resource and its associated features. *Biodiversity and Conservation*, *14*, 3327-3349. http://doi.org/10.1007/s10531-004-9513-9

107. Galluzzi, G., Eyzaguirre, P., & Negri, V. (2010). Home gardens: Neglected hotspots of agro-biodiversity and cultural diversity. *Biodiversity and Conservation*, *19*(13), 3635–3654. https://doi.org/10.1007/s10531-010-9919-5

108. Garthwaite, D., Ridley, L., Mace, A., Parrish, G., Barker, I., Rainford, J. & MacArthur, R. (2018). Pesticide usage survey report 284: Arable crops in the United Kingdom 2018. https://secure.fera.defra.gov.uk/pusstats/surveys/documents/arable2018.pdf. Accessed August 6, 2020.

109. Genter, C., Roberts, A., Richardson, J., & Sheaff, M. (2015). The contribution of allotment gardening to health and wellbeing: a systematic review of the literature. *British Journal of Occupational Therapy*, Vol 78 No 10, pp.593-605.

110. Ghosh, S., Yeo, D., Wilson, B., & Ow, L. F. (2012). Application of char products improves urban soil quality. *Soil Use and Management*, *28*(3), 329–336. https://doi.org/10.1111/j.1475-2743.2012.00416.x

111. Gittleman, M., Farmer, C. J. Q., Kremer, P., & McPhearson, T. (2017). Estimating stormwater runoff for community gardens in New York City. *Urban Ecosystems*, *20*(1), 129–139. https://doi.org/10.1007/s11252-016-0575-8

112. Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution*, *25*(2), 90–98. https://doi.org/10.1016/j.tree.2009.07.016

113. Goldstein, B., Hauschild, M., Fernández, J., & Birkved, M. (2016a). Urban versus conventional agriculture, taxonomy of resource profiles: a review. *Agronomy for Sustainable Development*, *36*(1), 1–19. https://doi.org/10.1007/s13593-015-0348-4

114. Goldstein, B., Hauschild, M., Fernández, J., & Birkved, M. (2016b). Testing the environmental performance of urban agriculture as a food supply in northern climates. *Journal of Cleaner Production*, *135*, 984–994. https://doi.org/10.1016/j.jclepro.2016.07.004

115. Gondhalekar, D., & Ramsauer, T. (2017). Nexus City: Operationalizing the urban Water-Energy-Food Nexus for climate change adaptation in Munich, Germany. *Urban Climate*, *19*, 28–40. https://doi.org/10.1016/j.uclim.2016.11.004

116. Gould, K. A., & Lewis, T. L. (2018). From green gentrification to resilience gentrification: An example from Brooklyn. *City & Community, 17*(1), 12-15.

117. Grafius, D., Hall, S., McHugh, N., & Edmondson, J. L. (2019). How much heat can we grow in our cities? Modelling UK urban biofuel production potential. *GCB Bioenergy, 00,* 1-15. https://doi.org/10.1111/gcbb.12655

118. Grafius, D. R., Edmondson, J. L., Norton, B. A., Clark, R., Mears, M., Leake, J. R., … Warren, P. H. (2020). Estimating food production in an urban landscape. *Scientific Reports, 10*(1). https://doi.org/10.1038/s41598-020-62126-4

119. Grard, B. J. P., Chenu, C., Manouchehri, N., Houot, S., Frascaria-Lacoste, N., & Aubry, C. (2018). Rooftop farming on urban waste provides many ecosystem services. *Agronomy for Sustainable Development*, *38*(1). https://doi.org/10.1007/s13593-017-0474-2

120. Graves, A. R., Morris, J., Deeks, L. K., Rickson, R. J., Kibblewhite, M. G., Harris, J. A., … Truckle, I. (2015). The total costs of soil degradation in England and Wales. *Ecological Economics, 119,* 399–413. https://doi.org/10.1016/j.ecolecon.2015.07.026

121. Gregory, M. M., Leslie, T. W., & Drinkwater, L. E. (2016). Agroecological and social characteristics of New York city community gardens: contributions to urban food security, ecosystem services, and environmental education. *Urban Ecosystems*, *19*(2), 763–794. https://doi.org/10.1007/s11252-015-0505-1

122. Grewal, S. S., & Grewal, P. S. (2012). Can cities become self-reliant in food? *Cities*, *29*(1), 1–11. https://doi.org/10.1016/j.cities.2011.06.003

123. Guitart, D., Pickering, C., & Byrne, J. (2012). Past results and future directions in urban community gardens research. *Urban Forestry and Urban Greening*, *11*(4), 364–373. https://doi.org/10.1016/j.ufug.2012.06.007

124. Harris, N., Minniss, F. R., & Somerset, S. (2014). Refugees connecting with a new country through community food gardening. *International Journal of*

Environmental Research and Public Health, 11(9), 9202-9216. https://doi.org/10.3390/ijerph110909202

125. Hennig, E. I., & Ghazoul, J. (2012). Pollinating animals in the urban environment. *Urban Ecosystems*, *15*(1), 149–166. https://doi.org/10.1007/s11252-011-0202-7

126. Horst, M., Mcclintock, N., & Hoey, L. (2017). The Intersection of Planning, Urban Agriculture, and Food Justice: A Review of the Literature. *Journal of the American Planning Association*, *83*(3), 277–295. https://doi.org/10.1080/01944363.2017.1322914

127. Houba, V. J. G, Temminghoff, G. A. G., & van Vark, W. (2000). Soil analysis procedures using 0.01 *M* calcium chloride as extraction reagent. *Communications in Soil Science and Plant Analysis, 31*:9-10, 1299-1396. https://doi.org/10.1080/00103620009370514

128. Howe, J., & Wheeler, P. (1999). Urban food growing: The experience of two UK cities. *Sustainable Development*, *7*(1), 13–24. https://doi.org/10.1002/(SICI)1099-1719(199902)7:1<13::AID-SD100>3.0.CO;2-B

129. Isendahl, C., & Smith, M. E. (2013). Sustainable agrarian urbanism: The low-density cities of the Mayas and Aztecs. *Cities*, *31*, 132–143. https://doi.org/10.1016/j.cities.2012.07.012

130. Jansma, J.-E., Sukkel, W., Stilma, E. S. C., van Oost, A. C., & Visser, A. J. (2012). The impact of local food production on food miles, fossil energy use, and greenhouse gas emission: The case of the Dutch city in Almere. In *Sustainable food planning: Evolving theory and practice.* (pp. 307–322). https://doi.org/http://www.wageningenacademic.com/doi/10.3920/978-90-8686-187-3_26

131. Jansson, Å. (2013). Reaching for a sustainable, resilient urban future using the lens of ecosystem services. *Ecological Economics*, *86*, 285–291. https://doi.org/10.1016/j.ecolecon.2012.06.013

132. Jones, A. P., Brainard, J., Bateman, I. J., & Lovett, A. A. (2009). Equity of access to public parks in Birmingham, England. *Environmental Research Journal* Vol 3 Nos.2-3, pp.237-256.

133. Jones, B. A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M. Y., … Pfeiffer, D. U. (2013). Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(21), 8399–8404. https://doi.org/10.1073/pnas.1208059110

134. Katongole, C. B., Nambi-Kasozi, J., Lumu, R., Bareeba, F., Presto, M., Ivarsson, E., & Lindberg, J. E. (2012). Strategies for coping with feed scarcity among urban and peri-urban livestock farmers in Kampala, Uganda. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 113*(2), 165-174. http://nbn-resolving.de/urn:nbn:de:hebis:34-2012092441842

135. Kim, B. F., Poulsen, M. N., Margulies, J. D., Dix, K. L., Palmer, A. M., & Nachman, K. E. (2014). Urban community gardeners' knowledge and perceptions of soil contaminant risks. *PLoS ONE*, *9*(2). https://doi.org/10.1371/journal.pone.0087913

136. Knight, A., Cheng, Z., Grewal, S. S., Islam, K. R., Kleinhenz, M. D., & Grewal, P. S. (2013). Soil health as a predictor of lettuce productivity and quality: A case study of urban vacant lots. *Urban Ecosystems*, *16*(3), 637–656. https://doi.org/10.1007/s11252-013-0288-1

137. Kortright, R., & Wakefield, S. (2011). Edible backyards: A qualitative study of household food growing and its contributions to food security. *Agriculture and Human Values*, *28*(1), 39–53. https://doi.org/10.1007/s10460-009-9254-1

138. Kremer, P., & DeLiberty, T. L. (2011). Local food practices and growing potential: Mapping the case of Philadelphia. *Applied Geography*, *31*(4), 1252–1261. https://doi.org/10.1016/j.apgeog.2011.01.007

139. Kulak, M., Graves, A., & Chatterton, J. (2013). Reducing greenhouse gas emissions with urban agriculture: A Life Cycle Assessment perspective. *Landscape and Urban Planning*, *111*(1), 68–78. https://doi.org/10.1016/j.landurbplan.2012.11.007

140. Kumar, K., & Hundal, L. S. (2016). Soil in the city: sustainably improving urban soils. *Journal of Environmental Quality*, *45*(1), 2–8. https://doi.org/10.2134/jeq2015.11.0589

141. Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: tests in linear mixed effects models, *Journal of Statistical Software,* 82:13, 1-25. https://doi.org/10.18637/jss.v082.i13

142. Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma,* 123:1-2, 1-22. https://doi.org/10.1016/j.geoderma.2004.01.032

143. Lal, R. (2010). Beyond Copenhagen: Mitigating climate change and achieving food security through soil carbon sequestration. *Food Security*, *2*(2), 169–177. https://doi.org/10.1007/s12571-010-0060-9

144. Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability*, *7*(12), 5875–5895. https://doi.org/10.3390/su7055875

145. Lal, R. (2018). Urban agriculture in the 21st century. In Lal, R., & Stewart, B. A. (eds.), *Urban Soils,* 1-13. CRC Press, Taylor and Francis, London.

146. Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Security*, Vol. 12, pp. 871–876. https://doi.org/10.1007/s12571-020-01058-3

147. Langellotto, G. A., Melathopoulos, A., Messer, I., Anderson, A., McClintock, N., & Costner, L. (2018). Garden pollinators and the potential for ecosystem service flow to urban and peri-urban agriculture. *Sustainability (Switzerland)*, *10*(6), 2047. https://doi.org/10.3390/su10062047

148. Langemeyer, J., Camps-Calvet, M., Calvet-Mir, L., Barthel, S., & Gómez-Baggethun, E. (2018). Stewardship of urban ecosystem services: understanding the value(s) of urban gardens in Barcelona. *Landscape and Urban Planning*, pp. 79–89. https://doi.org/10.1016/j.landurbplan.2017.09.013

149. Leake, J. R., Adam-Bradford, A., & Rigby, J. E. (2009). Health benefits of “grow your own” food in urban areas: Implications for contaminated land risk

assessment and risk management? *Environmental Health: A Global Access Science Source*, *8*(SUPPL. 1), S6. https://doi.org/10.1186/1476-069X-8-S1-S6

150. Lee, H. C. (2012). Chapter 36 How food secure can British cities become? In A. Voljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (pp. 453–466). https://doi.org/10.3920/978-90-8686-187-3_36

151. Levidow, L., & Psarikidou, K. (2012). Chapter 18 Making local food sustainable in Manchester. *Sustainable Food Planning: Evolving Theory and Practice*, 209–222. https://doi.org/10.3920/978-90-8686-187-3_18

152. Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and Applied Ecology*, *16*(3), 189–201. https://doi.org/10.1016/j.baae.2015.01.005

153. Lin, B. B., Philpott, S. M., Jha, S., & Liere, H. (2017). *Urban Agriculture as a Productive Green Infrastructure for Environmental and Social Well-Being*. https://doi.org/10.1007/978-981-10-4113-6_8

154. Litt, J. S., Soobader, M. J., Turbin, M. S., Hale, J. W., Buchenau, M., & Marshall, J. A. (2011). The influence of social involvement, neighborhood aesthetics, and community garden participation on fruit and vegetable consumption. *American Journal of Public Health*, *101*(8), 1466–1473. https://doi.org/10.2105/AJPH.2010.300111

155. Liu, Z., He, C., & Wu, J. (2016). The Relationship between Habitat Loss and Fragmentation during Urbanization: An Empirical Evaluation from 16 World Cities. *PLOS ONE*, *11*(4), e0154613. https://doi.org/10.1371/journal.pone.0154613

156. Loram, A., Warren, P. H., & Gaston, K. J. (2008). Urban domestic gardens (XIV): The characteristics of gardens in five cities. *Environmental Management*, *42*(3), 361–376. https://doi.org/10.1007/s00267-008-9097-3

157. Lorenz, K. (2015). Organic urban agriculture. *Soil Science*, *180*(4–5), 146–153. https://doi.org/10.1097/SS.0000000000000129

158. Lorenz, K. (2018). Managing urban soils for food production. In Lal, R., & Stewart, B. A. (eds.), *Urban Soils,* 295-312. CRC Press, Taylor and Francis, London.

159. Lorenz, K., & Lal, R. (2009). Biogeochemical C and N cycles in urban soils. *Environment International*, *35*(1), 1–8. https://doi.org/10.1016/j.envint.2008.05.006

160. Lorenz, K., & Lal, R. (2015). Managing soil carbon stocks to enhance the resilience of urban ecosystems. *Carbon Management*, *6*(1–2), 35–50. https://doi.org/10.1080/17583004.2015.1071182

161. Louv, R. (2005). *Last child in the woods: saving our children from nature-deficit disorder.* Algonquin Books of Chapel Hill, Chapel Hill, NC.

162. Lovell, S. T. (2010). Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability*, *2*(8), 2499–2522. https://doi.org/10.3390/su2082499

163. Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., … von Wehrden, H. (2015). A review of urban ecosystem services: six key challenges for future research. *Ecosystem Services*, *14*, 98–112. https://doi.org/10.1016/J.ECOSER.2015.05.001

164. Lupindu, A. M., Ngowi, H. A., Dalsgaard, A., Olsen, J. E., & Msoffe, P. L. M. (2012). Current manure management practices and hygiene aspects of urban and peri-urban livestock farming in Tanzania. http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/2040

165. Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J. P., & Griffith, C. (2015). A meta-analysis of urban and peri-urban agriculture and forestry in mediating climate change. *Current Opinion in Environmental Sustainability*, *13*, 68–73. https://doi.org/10.1016/j.cosust.2015.02.003

166. Maia, A. T. A., Calcagni, F., Connolly, J. J. T., Anguelovski, I., & Langemeyer, J. (2020). Hidden drivers of social injustice: uncovering unequal cultural ecosystem services behind green gentrification. *Environmental Science and Policy, 112,* 254-263.

167. Mancebo, F. (2018). Gardening the city: Addressing sustainability and adapting to global warming through urban agriculture. *Environments - MDPI*, *5*(3), 1–11. https://doi.org/10.3390/environments5030038

168. Martin, G., Clift, R., & Christie, I. (2016). Urban cultivation and its contributions to sustainability: Nibbles of food but oodles of social capital. *Sustainability (Switzerland)*, *8*(5), 409. https://doi.org/10.3390/su8050409

169. Mass, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health Place*, Vol 15 No 2, pp.586-595. https://doi.org/10.1016/j.healthplace.2008.09.006

170. Maye, D. (2019). 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City, Culture and Society*, *16*, 18–24. https://doi.org/10.1016/j.ccs.2017.12.001

171. Mbow, C. C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., & Xu, Y. (2018). Food Security. In: *Climate Change and Land: an IPCC special report on climate change, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H. -O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley (eds.)]. In press.

172. McClintock, N., Cooper, J., & Khandeshi, S. (2013). Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landscape and Urban Planning*, *111*(1), 46–58. https://doi.org/10.1016/j.landurbplan.2012.12.009

173. McDougall, R., Kristiansen, P., & Rader, R. (2019). Small-scale urban agriculture results in high yields but requires judicious management of inputs to

achieve sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(1), 129–134. https://doi.org/10.1073/pnas.1809707115

174. Mcdougall, R., Rader, R., & Kristiansen, P. (2020). Urban agriculture could provide 15% of food supply to Sydney, Australia, under expanded land use scenarios. *Land Use Policy, 94*, 104554. https://doi.org/10.1016/j.landusepol.2020.104554

175. Mees, C., & Stone, E. (2012). Chapter 35 Food, homes and gardens: public community gardens potential for contributing to a more sustainable city. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (pp. 431–452). https://doi.org/10.3920/978-90-8686-187-3_35

176. Met Office (2018). Chance of summer heatwaves now thirty times more likely. https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave. Accessed 8 July 2020.

177. Met Office (2019). UK climate projections: headline findings. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf. Accessed 30 March 2020.

178. Met Office (2020). Record breaking rainfall. https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2020/2020-winter-february-stats. Accessed 30 March 2020.

179. Milan Urban Food Policy Pact (2020). Signatory Cities. http://www.milanurbanfoodpolicypact.org/signatory-cities/. Accessed 24 August 2020.

180. Milbourne, P. (2012). Everyday (in)justices and ordinary environmentalisms: community gardening in disadvantaged urban neighbourhoods. *The Internaitonal Journal of Justice and Sustainability, 17*(9), 943-957. https://doi.org/10.1080/13549839.2011.607158

181. Miller, J. D., Kim, H., Kjeldsen, T. R., Packman, J., Grebby, S., & Dearden, R. (2014). Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. *Journal of Hydrology*, *515*, 59–70. https://doi.org/10.1016/j.jhydrol.2014.04.011

182. Miller, J. D., & Hutchins, M. (2017, August 1). The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *Journal of Hydrology: Regional Studies*, Vol. 12, pp. 345–362. https://doi.org/10.1016/j.ejrh.2017.06.006

183. Miller-Robbie, L., Ramaswami, A., & Amerasinghe, P. (2017). Wastewater treatment and reuse in urban agriculture: Exploring the food, energy, water, and health nexus in Hyderabad, India. *Environmental Research Letters*, *12*(7), 075005. https://doi.org/10.1088/1748-9326/aa6bfe

184. Mkwambisi, D. D., Fraser, E. D., & Dougill, A. J. (2011). Urban agriculture and poverty reduction: Evaluating how food production in cities contributes to food security, employment and income in Malawi. *Journal of International Development, 23*(2), 181-203. https://doi.org/10.1002/jid.1657

185. Mohareb, E., Heller, M., Novak, P., Goldstein, B., Fonoll, X., & Raskin, L. (2017). Considerations for reducing food system energy demand while scaling up urban agriculture. *Environmental Research Letters*, *12*(12), 125004. https://doi.org/10.1088/1748-9326/aa889b

186. Mok, H.-F., Williamson, V. G., Grove, J. R., Burry, K., Barker, S. F., & Hamilton, A. J. (2014). Strawberry fields forever? Urban agriculture in developed countries: a review. *Agronomy for Sustainable Development*, *34*(1), 21–43. https://doi.org/10.1007/s13593-013-0156-7

187. Moreau, T. L., Adams, T., Mullinix, K., Fallick, A., & Condon, P. M. (2012). Recommended Practices For Climate-Smart Urban and Peri-Urban Agriculture. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable Food Planning: Evolving Theory and Practice* (pp. 295–306). Wageningen: Wageningen Academic Publishers.

188. Morel, J. L., Chenu, C., & Lorenz, K. (2015). Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs). *Journal of Soils and Sediments*, *15*(8), 1659–1666. https://doi.org/10.1007/s11368-014-0926-0

189. Morgan, K. (2015). Nourishing the city: The rise of the urban food question in the Global North. *Urban Studies*, *52*(8), 1379–1394. https://doi.org/10.1177/0042098014534902

190. Morris, S. (2015). Bristol bus protesters take to the trees. *The Guardian*. Retrieved from https://www.theguardian.com/uk-news/2015/feb/02/bristol-bus-protesters-trees-european-green-capital-2015

191. Nasr, J. L., & Komisar, J. D. (2012). Chapter 3 The integration of food and agriculture into urban planning and design practices. *Sustainable Food Planning: Evolving Theory and Practice*, 47–58. https://doi.org/10.3920/978-90-8686-187-3_3

192. National Society of Allotment and Leisure Gardeners Ltd. (2012). Creating a new allotment site. Retrieved from https://www.nsalg.org.uk/wp-content/uploads/2012/09/A5_Creating_a_new_allotment_site_LR.pdf

193. National Soil Resources Institute (2001). NATMAPVECTOR: Carbon, Cranfield University, Cranfield, UK.

194. NHS Providers (2020). Coronavirus briefing: The impact of COVID-19 on mental health trusts in the NHS. https://nhsproviders.org/media/689590/spotlight-on-mental-health.pdf. Accessed 12 June 2020

195. Niala, J. C. (2020). Dig for vitality: UK urban allotments as a health-promoting response to COVID-19. *Cities & Health*, 1–5. https://doi.org/10.1080/23748834.2020.1794369

196. Nordh, H., Wiklund, K. T., & Koppang, K. E. (2016). Norwegian allotment gardens — a study of motives and benefits. *Landscape Research*, *41*(8), 853–868. https://doi.org/10.1080/01426397.2015.1125457

197. Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., … Rowe, B. (2007). Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*, *57*(10), 823–833. https://doi.org/10.1641/B571005

198. OECD/European Union (2018). *Health at a Glance: Europe 2018: State of Health in the EU Cycle*, OECD Publishing, Paris/European Union, Brussels, https://doi.org/10.1787/health_glance_eur-2018-en.

199. Oertli, B., Joye, D. A., Castella, E., Juge, R., Cambin, D., & Lachavanne, J. (2002). Does size matter? The relationship between pond area and biodiversity. *Biological Conservation, 104*(1), 59-70. https://doi.org/10.1016/S0006-3207(01)00154-9

200. Office for National Statistics (2015). Leisure time in the UK: 2015. https://www.ons.gov.uk/economy/nationalaccounts/satelliteaccounts/articles/leisuretimeintheuk/2015#those-from-lower-income-households-are-more-likely-to-be-working-on-weekends. Accessed August 31 2020.

201. Ohly, H., Gentry, S., Wigglesworth, R., Bethel, A., Lovell, R., & Garside, R. (2016). A systematic review of the health and well-being impacts of school gardening: synthesis of quantitative and qualitative evidence. *BMC Public Health, 16*, 286. https://doi.org/10.1186/s12889-016-2941-0

202. Omudu, E. A., & Amuta, E. U. (2007). Parasitology and urban livestock farming in Nigeria: prevalence of ova in faecal and soil samples and animal ectoparasites in Makurdi. *Journal of the South African Veterinary Association*, *78*(1), 40-45. ps://hdl.handle.net/10520/EJC99701

203. Opitz, I., Berges, R., Piorr, A., & Krikser, T. (2016). Contributing to food security in urban areas: differences between urban agriculture and peri-urban agriculture in the Global North. *Agriculture and Human Values*, *33*(2), 341–358. https://doi.org/10.1007/s10460-015-9610-2

204. Ordnance Survey (2017). *OS Open Greenspace.* https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-greenspace.html

205. Orsini, F., Gasperi, D., Marchetti, L., Piovene, C., Draghetti, S., Ramazzotti, S., … Gianquinto, G. (2014). Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: the potential impact on food and nutrition security, biodiversity

and other ecosystem services in the city of Bologna. *Food Security*, *6*(6), 781–792. https://doi.org/10.1007/s12571-014-0389-6

206. Owen, T., & Pilbeam, E. (1992). *Ordnance Survey: Map-makers to Britain since 1791.* Southampton – Ordnance Survey.

207. Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., … Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, *9*(1), 27–36. https://doi.org/10.1890/090220

208. Pavao-Zuckerman, M. A. (2008). The nature of urban soils and their role in ecological restoration in cities. *Restoration Ecology*, *16*(4), 642–649. https://doi.org/10.1111/j.1526-100X.2008.00486.x

209. Perry, T., & Nawaz, R. (2008). An investigation into the extent and impacts of hard surfacing of domestic gardens in an area of Leeds, United Kingdom. *Landscape and Urban Planning*, *86*(1), 1–13. https://doi.org/10.1016/j.landurbplan.2007.12.004

210. Peters, C. J., Bills, N. L., Lembo, A. J., Wilkins, J. L., & Fick, G. W. (2012). Mapping potential foodsheds in New York State by food group: An approach for prioritizing which foods to grow locally. *Renewable Agriculture and Food Systems*, *27*(02), 125–137. https://doi.org/10.1017/S1742170511000196

211. Petit-Boix, A., Llorach-Massana, P., Sanjuan-Delmás, D., Sierra-Pérez, J., Vinyes, E., Gabarrell, X., … Sanyé-Mengual, E. (2017, November 10). Application of life cycle thinking towards sustainable cities: A review. *Journal of Cleaner Production*, Vol. 166, pp. 939–951. https://doi.org/10.1016/j.jclepro.2017.08.030

212. Poore, J., & Nemecek, T. (2018). Reducing food’s environmental impacts through producers and consumers. *Science, 360*(6392), 987-992. https://doi.org/10.1126/science.aaq0216

213. Popping, R. (2015). Analyzing open-ended questions by means of text analysis procedures. *Bulletin de Méthodologie Sociologique,* Vol 128, pp.23-39.

214. Potter, A., & LeBuhn, G. (2015). Pollination service to urban agriculture in San Francisco, CA. *Urban Ecosystems*, *18*(3), 885–893. https://doi.org/10.1007/s11252-015-0435-y

215. Poulsen, M. N., Hulland, K. R. S., Gulas, C. A., Pham, H., Dalglish, S. L., Wilkinson, R. K., & Winch, P. J. (2014). Growing an urban oasis: A qualitative study of the perceived benefits of community gardening in Baltimore, Maryland. *Culture, Agriculture, Food and Environment 36*(2), 69-82. https://doi.org/ 10.1111/cuag.12035

216. Pouyat, R. V., Yesilonis, I. D., & Nowak, D. J. (2006). Carbon storage by urban soils in the United States. *Journal of Environmental Quality*, 35:4, 1566-1575. https://doi.org/10.2134/jeq2005.0215

217. Powlson, D. S., Gregory, P. J., Whalley, W. R., Quinton, J. N., Hopkins, D. W., Whitmore, A. P., Hirsch, P. R., & Goulding, K. W. T. (2011). Soil management in relation to sustainable agriculture and ecosystem services. *Food Policy*, *36*(Supplement 1), S72-S87. https://doi.org/10.1016/j.foodpol.2010.11.025

218. Pulighe, G., & Lupia, F. (2020). Food first: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. *Sustainability (Switzerland)*, *12*(12), 5012. https://doi.org/10.3390/su12125012

219. Purvis, G., & Bannon, J. W. (1992). Non-target effects of repeated methiocarb slug pellet application on carabid beetle (Coleoptera: Carabidae) activity in winter-sown cereals. *Annals of Applied Biology*, *121*(2), 401–422. https://doi.org/10.1111/j.1744-7348.1992.tb03453.x

220. R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

221. Rae, A., Hamilton, R., Crisp, R., & Powell, R. (2016). Overcoming deprivation and disconnection in UK cities. *Joseph Rowntree Foundation.* https://www4.shu.ac.uk/research/cresr/sites/shu.ac.uk/files/overcoming-deprivation-disconnection-uk-cities.pdf

222. Rawlins, B. G., Harris, J., Price, S., & Bartlett, M. (2015). A review of climate change impacts on urban soil functions with examples and policy insights from England, UK. *Soil Use and Management*, *31*, 46–61. https://doi.org/10.1111/sum.12079

223. Reeves, J., Cheng, Z., Kovach, J., Kleinhenz, M. D., & Grewal, P. S. (2014). Quantifying soil health and tomato crop productivity in urban community and market gardens. *Urban Ecosystems*, *17*(1), 221–238. https://doi.org/10.1007/s11252-013-0308-1

224. Reis, S., Liska, T., Steinle, S., Carnell, E., Leave, D., Roberts, E., Veino, M., Beck, R., & Dragosits, U. (2017). UK gridded population 2011 based on Census 2011 and Land Cover Map 2015. NERC Environmental Information Data Centre. https://doi.org/10.5285/0995e94d-6d42-40c1-8ed4-5090d82471e1

225. Relyea, R. A. (2005). The lethal impact of roundup on aquatic and terrestrial amphibians. In *Ecological Applications* (Vol. 15). https://doi.org/10.1890/04-1291

226. Richards, H. J., & Kafami, D. M. (2008). Impact of horticultural therapy on vulnerability and resistance to substance abuse among incarcerated offenders. *Journal of Offender Rehabilitation*, *29*(3-4), 183-193. https://doi.org/10.1300/J076v29n03_11

227. Richards, P., Reardon, T., Tschirley, D., Jayne, T., Oehmke, J., & Atwood, D. (2016). Cities and the future of agriculture and food security: a policy and programmatic roundtable. *Food Security*, *8*(4), 871–877. https://doi.org/10.1007/s12571-016-0597-3

228. Ritchie, H., & Roser, M. (2019). Urbanization. Our World In Data. https://ourworldindata.org/urbanization. Accessed August 19, 2020.

229. Ritchie, H., & Roser, M. (2020). Emissions by sector. Our World In Data. https://ourworldindata.org/emissions-by-sector. Accessed August 26, 2020.

230. Robert, A., & Yengué, J. L. (2017). When Allotment Gardens Become Urban Green Spaces like Others, Providing Cultural Ecosystem Services. *Environment and Ecology Research*, *5*(6), 453–460. https://doi.org/10.13189/eer.2017.050606

231. Robinson, D. A., Hockley, N., Cooper, D. M., Emmett, B. A., Keith, A. M., Lebron, I., Reynolds, B., Tipping, E., Tye, A. M., Watts, C. W., Whalley, W. R., Black, H. I. J., Warren, G. P., & Robinson, J. S. (2013). Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. *Soil Biology and Biochemistry*, 57, 1023-1033. https://doi.org/10.1016/j.soilbio.2012.09.008

232. Robinson L.D., Cawthray, J.L., West, S.E., Bonn, A., & Ansine, J. (2018). Ten principles of citizen science. In S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel, & A. Bonn. *Citizen Science: Innovation in Open Science, Society and Policy*. London, UCL Press. 1–23.

233. Rosegrant, M. W., & Cline, S. A. (2003). Global Food Security: Challenges and Policies. *Science*, Vol. 302, pp. 1917–1919. https://doi.org/10.1126/science.1092958

234. Rowland, C. S., Morton, R. D., Carrasco, L., McShane, G., O'Neil, A. W., & Wood, C. M. (2017). Land Cover Map 2015 (vector, GB). *NERC Environmental Information Data Centre*. https://doi.org/10.5285/6c6c9203-7333-4d96-88ab-78925e7a4e73

235. Royal Horticultural Society (2020). Soil: understanding pH and testing soil. https://www.rhs.org.uk/advice/profile?pid=239. Accessed July 1, 2020.

236. Rural Business Research. (2012). *Farm business survey - East Midlands region commentary*. London.

237. Russo, A., Escobedo, F. J., Cirella, G. T., & Zerbe, S. (2017, May 1). Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments. *Agriculture, Ecosystems and Environment*, Vol. 242, pp. 53–66. https://doi.org/10.1016/j.agee.2017.03.026

238. Ryan, G. W., & Bernard, H. R. (2003). Techniques to identify themes. *Field Methods* Vol 15 No 1, pp.85-109.

239. Safi, Z., Dossa, L. H., & Buerkert, A. (2011). Economic analysis of cereal, vegetable and grape production systems in urban and peri-urban agriculture of Kabul,

Afghanistan. *Experimental Agriculture, 47*(4), 705. https://doi.org/10.1017/S0014479711000482

240. Sanyé-Mengual, E., Oliver-Solà, J., Montero, J. I., & Rieradevall, J. (2015). An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. *International Journal of Life Cycle Assessment*, *20*(3), 350–366. https://doi.org/10.1007/s11367-014-0836-9

241. Scalenghe, R., & Marsan, F. A. (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*, *90*(1–2), 1–10. https://doi.org/10.1016/j.landurbplan.2008.10.011

242. Schmutz, U., Kneafsey, M., Sarrouy Kay, C., Doernberg, A., & Zasada, I. (2018). Sustainability impact assessments of different urban short food supply chains: examples from London, UK. *Renewable Agriculture and Food Systems*, *33*(6), 518–529. https://doi.org/10.1017/S1742170517000564

243. Schneider, N. (2017). Between promise and scepticism: the global South and our role as engaged intellectuals. *The Global South, 11*(2), 18-38.

244. Schultz, P. W. (2002). Inclusion with nature: The psychology of human-nature relations. In P. W. Schmuck & W. P. Schultz (Eds.*), Psychology of sustainable development*. 62-78. Norwell, MA: Kluwer Academic.

245. Schwarz, N., Moretti, M., Bugalho, M. N., Davies, Z. G., Haase, D., Hack, J., … Knapp, S. (2017). Understanding biodiversity-ecosystem service relationships in urban areas: A comprehensive literature review. *Ecosystem Services*, *27*, 161–171. https://doi.org/10.1016/j.ecoser.2017.08.014

246. Scott, A., Dean, A., Barry, V., & Kotter, R. (2018). Places of urban disorder? Exposing the hidden nature and values of an English private urban allotment landscape. *Landscape and Urban Planning*, *169*, 185–198. https://doi.org/10.1016/j.landurbplan.2017.09.004

247. Seguí, A. E., Mackiewicz, B., & Rosol, M. (2017). From leisure to necessity: Urban allotments in Alicante province, Spain in times of crisis. *Acme*, *16*(2), 276–304.

248. Setälä, H., Francini, G., Allen, J. A., Jumpponen, A., Hui, N., & Kotze, D. J. (2017). Urban parks provide ecosystem services by retaining metals and nutrients in soils. *Environmental Pollution*, *231*, 451–461. https://doi.org/10.1016/j.envpol.2017.08.010

249. Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

250. Sharma, K., Cheng, Z., & Grewal, P. S. (2015). Relationship between soil heavy metal contamination and soil food web health in vacant lots slated for urban agriculture in two post-industrial cities. *Urban Ecosystems*, *18*(3), 835–855. https://doi.org/10.1007/s11252-014-0432-6

251. Shaw, M., Smith, G. D., & Dorling, D. (2005). Health inequalities and New Labour: how the promises compare with real progress. *BMJ*, *330*(7498), 1016–1021. https://doi.org/10.1136/bmj.330.7498.1016

252. Sheffield City Council (2018). The allotment handbook. https://www.sheffield.gov.uk/content/dam/sheffield/docs/parks-sports-and-recreation/allotments/Allotment%20Handbook%20June%202018.pdf

253. Sheffield City Council (2019). Allotment waiting lists July 2019. https://www.sheffield.gov.uk/content/dam/sheffield/docs/parks-sports-and-recreation/allotments/Allotment%20waiting%20lists%20and%20vacancies%20updated%20July%202019.pdf. Accessed August 25 2020.

254. Siddique, H., & Topping, A. (2016). Watford allotment campaigners lose high court battle to save site. *The Guardian*. Retrieved from https://www.theguardian.com/lifeandstyle/2016/nov/02/watford-allotment-campaigners-lose-high-court-battle-to-save-site

255. Siegner, A., Sowerwine, J., & Acey, C. (2018). Does urban agriculture improve food security? Examining the nexus of food access and distribution of urban produced foods in the United States: A systematic review. *Sustainability (Switzerland)*, *10*(9), 2988. https://doi.org/10.3390/su10092988

256. Smith, D., Thompson, C., Harland, K., Parker, S., & Shelton, N. (2018). Identifying populations and areas at greatest risk of household food insecurity in England. *Applied Geography*, *91*, 21–31. https://doi.org/10.1016/j.apgeog.2017.12.022

257. Smithers, R. (2020). Interest in allotments soars in England during coronavirus pandemic. *The Guardian* (10 August 2020). https://www.theguardian.com/lifeandstyle/2020/aug/10/interest-in-allotments-soars-in-england-during-coronavirus-pandemic. Accessed August 25 2020.

258. Soga, M., & Gaston, K. J. (2016). Extinction of experience: The loss of human-nature interactions. *Frontiers in Ecology and the Environment*, Vol. 14, pp. 94–101. https://doi.org/10.1002/fee.1225

259. Soga, M., Gaston, K. J., & Yamaura, Y. (2017a). Gardening is beneficial for health: A meta-analysis. *Preventive Medicine Reports*, Vol 5, pp.92-99.

260. Soga, M., Cox, D. T., Yamaura, Y., Gaston, K. J., Kurisu, K., & Hanaki, K. (2017b). Health benefits of urban allotment gardening: improved physical and psychological well-being and social integration. *International journal of environmental research and public health*, Vol 14 No 1, pp.71-84.

261. Speak, A. F., Mizgajski, A., & Borysiak, J. (2015). Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. *Urban Forestry & Urban Greening*, *14*(4), 772–781. https://doi.org/10.1016/j.ufug.2015.07.007

262. Sperling, C. D., & Lortie, C. J. (2010). The importance of urban backgardens on plant and invertebrate recruitment: A field microcosm experiment. *Urban Ecosystems*, *13*(2), 223–235. https://doi.org/10.1007/s11252-009-0114-y

263. Spilková, J., & Vágner, J. (2016). The loss of land devoted to allotment gardening: The context of the contrasting pressures of urban planning, public and private interests in Prague, Czechia. *Land Use Policy*, *52*, 232–239. https://doi.org/10.1016/j.landusepol.2015.12.031

264. Statista (2020). United Kingdom: Degree of urbanization from 2009 to 2019. https://www.statista.com/statistics/270369/urbanization-in-the-united-kingdom/. Accessed August 19, 2020.

265. Stockmann, U., Adams, M. A., Crawford, J. W., Field, D. J., Henakaarchchi, N., Jenkins, M., … Zimmermann, M. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agriculture, Ecosystems and Environment*, *164*, 80–99. https://doi.org/10.1016/j.agee.2012.10.001

266. Sustainable Food Places (2020). Members. https://www.sustainablefoodplaces.org/members/. Accessed 24 August 2020.

267. Swan Products Ltd. (2020). The Flow Rate of a Garden Hose. https://www.swanhose.com/garden-hose-flow-rate-s/1952.htm. Accessed 8 July 2020.

268. Taylor, J. R., & Lovell, S. T. (2012). Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning*, *108*(1), 57–70. https://doi.org/10.1016/j.landurbplan.2012.08.001

269. Taylor, J. R., & Lovell, S. T. (2014). Urban home food gardens in the Global North: Research traditions and future directions. *Agriculture and Human Values*, *31*(2), 285–305. https://doi.org/10.1007/s10460-013-9475-1

270. Thirtle, C., Lin, L., Holding, J., Jenkins, L., & Piesse, J. (2004). Explaining the decline in UK agricultural productivity growth. *Journal of Agricultural Economics*, *55*(2), 343–366. https://doi.org/10.1111/j.1477-9552.2004.tb00100.x

271. Thompson, K., Hodgson, J. G., Smith, R. M., Warren, P. H., & Gaston, K. J. (2004). Urban domestic gardens (III): Composition and diversity of lawn floras.

Journal of Vegetation Science, *15*(3), 373–378. https://doi.org/10.1111/j.1654-1103.2004.tb02274.x

272. Tratalos, J., Fuller, R. A., Warren, P. H., Davies, R. G., & Gaston, K. J. (2007). Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning*, *83*(4), 308–317. https://doi.org/10.1016/j.landurbplan.2007.05.003

273. Traveline, K., & Hunold, C. (2010). Urban agricultural and ecological citizenship in Philadelphia. *The International Journal of Justice and Sustainability, 15*(6). https://doi.org/10.1080/13549839.2010.487529

274. Tresch, S., Moretti, M., Le Bayon, R., Mäder, P., Zanetta, A., Frey, D., & Fliessback, A. (2018). A gardener's influence on urban soil quality. *Frontiers in Environmental Science,* 6. https://doi.org/10.3389/fenvs.2018.00025

275. United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420).* New York: United Nations.

276. van der Jagt, A. P. N., Szaraz, L. R., Delshammar, T., Cvejić, R., Santos, A., Goodness, J., & Buijs, A. (2017). Cultivating nature-based solutions: The governance of communal urban gardens in the European Union. *Environmental Research*, *159*, 264–275. https://doi.org/10.1016/j.envres.2017.08.013

277. van der Schans, J. W., & Wiskerke, J. S. C. (2012). Chapter 21 Urban agriculture in developed economies. In *Sustainable food planning: evolving theory and practice* (pp. 243–258). https://doi.org/10.3920/978-90-8686-187-3_21

278. Vasenev, V. I., Stoorvogel, J. J., & Vasenev, L. I. (2013). Urban soil organic carbon and its spatial heterogeneity in comparison with natural and agricultural areas in the Moscow region. *CATENA*, 107, 96-102. https://doi.org/10.1016/j.catena.2013.02.009

279. Vaughn, P., & Turner, C. (2016). Decoding via coding: Analyzing qualitative text data through thematic coding and survey methodologies. *Journal of Library Administration,* Vol 56 No 1, pp.41-51.

280. Vieira, J., Matos, P., Mexia, T., Silva, P., Lopes, N., Freitas, C., … Pinho, P. (2018). Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. *Environmental Research*, *160*, 306–313. https://doi.org/10.1016/j.envres.2017.10.006

281. Walker, R. E., Keane, C. R., & Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place*, *16*(5), 876-884. https://doi.org/10.1016/j.healthplace.2010.04.013

282. Warren, E., Hawkesworth, S., & Knai, C. (2015). Investigating the association between urban agriculture and food security, dietary diversity, and nutritional status: A systematic literature review. *Food Policy*, *53*, 54–66. https://doi.org/10.1016/j.foodpol.2015.03.004

283. Webber, J., Hinds, J., & Camic, P. M. (2015). The Well-Being of Allotment Gardeners: A Mixed Methodological Study. *Ecopsychology*, *7*(1), 20–28. https://doi.org/10.1089/eco.2014.0058

284. Wells, N. M., & Evans, G. W. (2003). Nearby nature: A buffer of life stress among rural children. *Environment and Behaviour*, Vol 35 No 3, pp.311-330.

285. White, M. M. (2011). Sisters of the Soil: Urban Gardening as Resistance in Detroit. *Race/Ethnicity: Multidisciplinary Global Contexts*, *5*(1), 13–28. https://doi.org/10.2979/racethmulglocon.5.1.13

286. Wilhelm, J. A., & Smith, R. G. (2018, October 1). Ecosystem services and land sparing potential of urban and peri-urban agriculture: A review. *Renewable Agriculture and Food Systems*, Vol. 33, pp. 481–494. https://doi.org/10.1017/S1742170517000205

287. Wilson, B. R., Koen, T. B., Barnes, P., Ghosh, S., & King, D. (2011). Soil carbon and related soil properties along a soil type and land-use intensity gradient, New South Wales, Australia. *Soil Use and Management*, *27*(4), 437-447. https://doi.org/10.1111/j.1475-2743.2011.00357.x

288. Wiltshire, R., & Geoghegan, L. (2012). Chapter 28 Growing alone, growing together, growing apart? Reflections on the social organisation of voluntary urban food

production in Britain. In A. Viljoen & J. S. C. Wiskerke (Eds.), *Sustainable food planning: evolving theory and practice* (pp. 337–348). https://doi.org/10.3920/978-90-8686-187-3_28

289. Wiskerke, J. S. C., & Viljoen, A. (2012). Chapter 1 Sustainable urban food provisioning: challenges for scientists, policymakers, planners and designers. In *Sustainable food planning: evolving theory and practice*. https://doi.org/10.3920/978-90-8686-187-3_1

290. Wood, C. J., Pretty, J., & Griffin, M. (2016). A case–control study of the health and well-being benefits of allotment gardening. *Journal of Public Health*, Vol 38 No 3, pp.e336-e344.

291. World Food Summit (1996) *Rome Declaration on World Food Security and World Food Summit Plan of Action*. FAO.

292. Wortman, S. E., & Lovell, S. T. (2013). Environmental Challenges Threatening the Growth of Urban Agriculture in the United States. *Journal of Environmental Quality*, *42*(5), 1283–1294. https://doi.org/10.2134/jeq2013.01.0031

293. Zezza, A., & Tasciotti, L. (2010). Urban agriculture, poverty, and food security: Empirical evidence from a sample of developing countries. *Food Policy*, *35*(4), 265–273. https://doi.org/10.1016/j.foodpol.2010.04.007

294. Zhang, X. Q. (2016). The trends, promises and challenges of urbanisation in the world. *Habitat International, 54*(3), 241-252. https://doi-org.sheffield.idm.oclc.org/10.1016/j.habitatint.2015.11.018

295. Zhang, P., Zhang, L., Chang, Y., Xu, M., Hao, Y., Liang, S., & Wang, C. (2019). Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resources, Conservation and Recycling*, *142*, 215–224. https://doi.org/10.1016/j.resconrec.2018.11.018

Supplementary information to chapters

Supplementary Information: Chapter 2

1. Reference list for maps used as source data

Present-day United Kingdom maps

1. OS VectorMap® Local [TIFF geospatial data], Scale 1:10000, Coverage: United Kingdom, Updated: 14 December 2016, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <https://digimap.edina.ac.uk>

2. OS MasterMap Topography Layer [GML geospatial data], Coverage: United Kingdom, Updated: July 2018, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <https://digimap.edina.ac.uk>

3. LandBase, InfoTerra, http://www.infoterra.co.uk/landbase

Index of Multiple Deprivation shapefiles

1. Scottish Index of Multiple Deprivation: https://simd.scot/2016/#/simd2016/BTTTFTT/9/-4.0000/55.9000/ (Accessed 14 September 2019).

2. Index of Multiple Deprivation: https://www.arcgis.com/home/item.html?id=14b9617e617c4ae09c0a5b0cab06044b (Accessed 14 September 2019).

Bristol

1. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: st56ne-5,st56nw-5,st57ne-5,st57nw-5,st57se-5,st57sw-5,st58se-5,st58sw-5,st66ne-5,st66nw-5,st67ne-5,st67nw-5,st67se-5,st67sw-5,st68se-5,st68sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: st56ne-7,st56nw-7,st57ne-7,st57nw-7,st57se-7,st57sw-7,st58se-7,st58sw-7,st66ne-7,st66nw-7,st67ne-7,st67nw-7,st67se-7,st67sw-7,st68se-7,st68sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: st56ne-5,st57ne-5,st57nw-5,st57se-5,st58se-5,st58sw-5,st66nw-5,st67ne-5,st67nw-5,st67se-5,st67sw-5,st68se-5,st68sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: glou-st56ne-4,glou-st56nw-4,glou-st57ne-4,glou-st57nw-4,glou-st57se-4,glou-st57sw-4,glou-st58se-4,glou-st58sw-4,glou-st66ne-4,glou-st66nw-4,glou-st67ne-4,glou-st67nw-4,glou-st67se-4,glou-st67sw-4,glou-st68se-4,glou-st68sw-4,monm-st58se-4,monm-st58sw-4,monm-st68sw-4,some-st56ne-4,some-st56nw-4,some-st57se-4,some-st57sw-4,some-st66ne-4,some-st66nw-4,some-st67se-4,some-st67sw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: glou-st56ne-3,glou-st56nw-3,glou-st57ne-3,glou-st57nw-3,glou-st57se-3,glou-st57sw-3,glou-st58se-3,glou-st58sw-3,glou-st66ne-3,glou-st66nw-3,glou-st67ne-3,glou-st67nw-3,glou-st67se-3,glou-st67sw-3,glou-st68se-3,glou-st68sw-3,monm-st57nw-3,monm-st57sw-3,monm-st58se-3,monm-st58sw-3,monm-st68sw-3,some-st56ne-3,some-st56nw-3,some-st57nw-3,some-st57se-3,some-st57sw-3,some-st58sw-3,some-st66ne-3,some-st66nw-3,some-st67se-3,some-st67sw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Glasgow

1. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: ns45ne-6,ns45se-6,ns55se-6,ns56ne-6,ns56nw-6,ns56se-6,ns56sw-6,ns57se-6,ns65se-6,ns66ne-6,ns66nw-6,ns66se-6,ns66sw-6,ns67se-6,ns67sw-6,ns75ne-6,ns76ne-6,ns76nw-6,ns76se-6,ns76sw-6,ns77sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: ns45ne-5,ns45se-5,ns46ne-5,ns46se-5,ns47se-5,ns55ne-5,ns55nw-5,ns55se-5,ns55sw-5,ns56ne-5,ns56nw-5,ns56se-5,ns56sw-5,ns57se-5,ns57sw-5,ns65ne-5,ns65nw-5,ns65se-5,ns65sw-5,ns66ne-5,ns66nw-5,ns66se-5,ns66sw-5,ns67se-5,ns67sw-5,ns75ne-5,ns75nw-5,ns75se-5,ns75sw-5,ns76ne-5,ns76nw-5,ns76se-5,ns76sw-5,ns77se-5,ns77sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: ns45ne-7,ns45se-7,ns46ne-7,ns46se-7,ns47se-7,ns55ne-7,ns55nw-7,ns55se-7,ns55sw-7,ns56ne-7,ns56nw-7,ns56se-7,ns56sw-7,ns57se-7,ns57sw-7,ns65ne-7,ns65nw-7,ns65se-7,ns65sw-7,ns66ne-7,ns66nw-7,ns66se-7,ns66sw-7,ns67se-7,ns67sw-7,ns75ne-7,ns75nw-7,ns75se-7,ns75sw-7,ns76ne-7,ns76nw-

7,ns76se-7,ns76sw-7,ns77se-7,ns77sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: ns46ne-5,ns46se-5,ns47se-5,ns55ne-5,ns55nw-5,ns55se-5,ns56ne-5,ns56nw-5,ns56se-5,ns56sw-5,ns57se-5,ns57sw-5,ns65nw-5,ns65sw-5,ns66ne-5,ns66nw-5,ns66se-5,ns66sw-5,ns67se-5,ns67sw-5,ns75ne-5,ns75nw-5,ns75se-5,ns75sw-5,ns76ne-5,ns76nw-5,ns76se-5,ns76sw-5,ns77se-5,ns77sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: dumb-023se-4,dumb-023sw-4,dumb-024sw-4,dumb-025ne-4,dumb-032se-4,dumb-033se-4,dumb-033sw-4,lana-005se-4,lana-006ne-4,lana-006nw-4,lana-006se-4,lana-006sw-4,lana-007ne-4,lana-007nw-4,lana-007se-4,lana-007sw-4,lana-008nw-4,lana-008sw-4,lana-010ne-4,lana-010nw-4,lana-010se-4,lana-010sw-4,lana-011ne-4,lana-011nw-4,lana-011se-4,lana-011sw-4,lana-012nw-4,lana-012sw-4,lana-016ne-4,lana-017ne-4,lana-017nw-4,lana-018nw-4,renf-008ne-4,renf-008se-4,renf-012ne-4,renf-012se-4,renf-013sw-4,renf-016ne-4,renf-017nw-4,renf-017sw-4,stir-032se-4,stir-033se-4,stir-033sw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: dumb-02300-3,dumb-02400-3,dumb-02500-3,dumb-03300-3,lana-001se-3,lana-001sw-3,lana-002se-3,lana-002sw-3,lana-003sw-3,lana-005ne-3,lana-006ne-3,lana-006nw-3,lana-006se-3,lana-006sw-3,lana-007ne-3,lana-007nw-3,lana-007se-3,lana-007sw-3,lana-008nw-3,lana-008sw-3,lana-010ne-3,lana-010nw-3,lana-010se-3,lana-010sw-3,lana-011ne-3,lana-011nw-3,lana-011se-3,lana-011sw-3,lana-012sw-3,lana-016nw-3,lana-017ne-3,lana-017nw-3,lana-018nw-3,renf-008ne-3,renf-008se-3,renf-009nw-3,renf-009sw-3,renf-012ne-3,renf-012se-3,renf-013ne-3,renf-013nw-3,renf-013se-3,renf-013sw-3,renf-016ne-3,renf-016se-3,renf-017nw-3,renf-017se-3,renf-017sw-3,stir-03200-3,stir-03300-3,stir-03400-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Leicester

1. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: sk50ne-6,sk50nw-6,sk50sw-6,sk60sw-6,sp59ne-6,sp59nw-6,sp69nw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: sk50ne-5,sk50nw-5,sk50se-5,sk50sw-5,sk60nw-5,sk60sw-5,sp59ne-5,sp59nw-5,sp69nw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: sk50ne-7,sk50nw-7,sk50se-7,sk50sw-7,sk60nw-7,sk60sw-7,sp59ne-7,sp59nw-7,sp69nw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 1st Revision [TIFF geospatial data], Scale 1:10000, Tiles: sk50ne-6,sk50nw-6,sk50se-6,sk50sw-6,sk60sw-6,sp59ne-6,sp59nw-6,sp69nw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: sk50ne-5,sk50nw-5,sk50se-5,sk50sw-5,sk60nw-5,sk60sw-5,sp59ne-5,sp59nw-5,sp69nw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: leic-025se-4,leic-025sw-4,leic-026sw-4,leic-030se-4,leic-031ne-4,leic-031nw-4,leic-031se-4,leic-031sw-4,leic-032nw-4,leic-032sw-4,leic-037ne-4,leic-037nw-4,leic-037se-4,leic-037sw-4,leic-038nw-4,leic-038sw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

7. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: leic-024se-3,leic-025se-3,leic-025sw-3,leic-030ne-3,leic-030se-3,leic-031ne-3,leic-031nw-3,leic-031se-3,leic-031sw-3,leic-037ne-3,leic-037nw-3,leic-037se-3,leic-037sw-3,leic-038nw-3,leic-038sw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

8. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: leic-024se-2,leic-025se-2,leic-025sw-2,leic-026sw-2,leic-030ne-2,leic-030se-2,leic-031ne-2,leic-031nw-2,leic-031se-2,leic-031sw-2,leic-032nw-2,leic-032sw-2,leic-036ne-2,leic-036se-2,leic-037ne-2,leic-037nw-2,leic-037se-2,leic-037sw-2,leic-038nw-2,leic-038sw-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Liverpool

1. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: sd30se-6,sd40se-6,sj27ne-6,sj28ne-6,sj28se-6,sj29se-6,sj37ne-6,sj37nw-6,sj38ne-6,sj38nw-6,sj38se-6,sj38sw-6,sj39ne-6,sj39nw-6,sj39se-6,sj39sw-6,sj47ne-6,sj47nw-6,sj48ne-6,sj48nw-6,sj48sw-6,sj49ne-6,sj49nw-6,sj49se-6,sj49sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: sd20se-5,sd30se-5,sd30sw-5,sd40se-5,sd40sw-5,sj27ne-5,sj28ne-5,sj28se-5,sj29ne-5,sj29se-5,sj37ne-5,sj37nw-5,sj38ne-5,sj38nw-5,sj38se-5,sj38sw-5,sj39ne-5,sj39nw-5,sj39se-5,sj39sw-5,sj47ne-5,sj47nw-

5,sj48ne-5,sj48nw-5,sj48se-5,sj48sw-5,sj49ne-5,sj49nw-5,sj49se-5,sj49sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: sd20se-7,sd30se-7,sd30sw-7,sd40se-7,sd40sw-7,sj27ne-7,sj28ne-7,sj28se-7,sj29ne-7,sj29se-7,sj37ne-7,sj37nw-7,sj38ne-7,sj38nw-7,sj38se-7,sj38sw-7,sj39ne-7,sj39nw-7,sj39se-7,sj39sw-7,sj47ne-7,sj47nw-7,sj48ne-7,sj48nw-7,sj48se-7,sj48sw-7,sj49ne-7,sj49nw-7,sj49se-7,sj49sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: sd20se-5,sd30se-5,sd30sw-5,sd40se-5,sd40sw-5,sj27ne-5,sj28ne-5,sj28se-5,sj29se-5,sj37ne-5,sj37nw-5,sj38ne-5,sj38nw-5,sj38se-5,sj38sw-5,sj39ne-5,sj39nw-5,sj39se-5,sj39sw-5,sj47ne-5,sj47nw-5,sj48ne-5,sj48nw-5,sj48se-5,sj48sw-5,sj49ne-5,sj49nw-5,sj49se-5,sj49sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: ches-006se-4,ches-007ne-4,ches-007nw-4,ches-007se-4,ches-007sw-4,ches-012ne-4,ches-012se-4,ches-013ne-4,ches-013nw-4,ches-013se-4,ches-013sw-4,ches-014sw-4,ches-015sw-4,ches-021ne-4,ches-022ne-4,ches-022nw-4,ches-022se-4,ches-022sw-4,ches-023nw-4,ches-023se-4,ches-023sw-4,flin-006ne-4,lanc-098ne-4,lanc-098nw-4,lanc-098se-4,lanc-098sw-4,lanc-099ne-4,lanc-099nw-4,lanc-099se-4,lanc-099sw-4,lanc-100ne-4,lanc-100nw-4,lanc-100se-4,lanc-100sw-4,lanc-106ne-4,lanc-106nw-4,lanc-106se-4,lanc-106sw-4,lanc-107ne-4,lanc-107nw-4,lanc-107se-4,lanc-107sw-4,lanc-113ne-4,lanc-113nw-4,lanc-113se-4,lanc-113sw-4,lanc-114ne-4,lanc-114nw-4,lanc-114se-4,lanc-114sw-4,lanc-117ne-4,lanc-117se-4,lanc-118ne-4,lanc-118nw-4,lanc-118sw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: ches-006ne-3,ches-006se-3,ches-007ne-3,ches-007nw-3,ches-007se-3,ches-007sw-3,ches-012ne-3,ches-012se-3,ches-013ne-3,ches-013nw-3,ches-013se-3,ches-013sw-3,ches-014sw-3,ches-015sw-3,ches-021ne-3,ches-021se-3,ches-022ne-3,ches-022nw-3,ches-022se-3,ches-022sw-3,ches-023ne-3,ches-023nw-3,ches-023se-3,ches-023sw-3,ches-024nw-3,ches-024sw-3,flin-003se-3,flin-006ne-3,lanc-098ne-3,lanc-098nw-3,lanc-098se-3,lanc-098sw-3,lanc-099ne-3,lanc-099nw-3,lanc-099se-3,lanc-099sw-3,lanc-100ne-3,lanc-100nw-3,lanc-100se-3,lanc-100sw-3,lanc-106ne-3,lanc-106nw-3,lanc-106se-3,lanc-106sw-3,lanc-107ne-3,lanc-107nw-3,lanc-107se-3,lanc-107sw-3,lanc-113ne-3,lanc-113nw-3,lanc-113se-3,lanc-113sw-3,lanc-114ne-3,lanc-114nw-3,lanc-114se-3,lanc-114sw-3,lanc-117ne-3,lanc-117se-3,lanc-118ne-3,lanc-118nw-3,lanc-118sw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Milton Keynes

1. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: sp83nw-6,sp83se-6,sp83sw-6,sp84se-6,sp93nw-6,sp94sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: sp73ne-5,sp73se-5,sp74se-5,sp83ne-5,sp83nw-5,sp83se-5,sp83sw-5,sp84se-5,sp84sw-5,sp93nw-5,sp93sw-5,sp94sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: sp73ne-7,sp73se-7,sp74se-7,sp83ne-7,sp83nw-7,sp83se-7,sp83sw-7,sp84se-7,sp84sw-7,sp93nw-7,sp93sw-7,sp94sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: sp73ne-5,sp74se-5,sp83ne-5,sp83nw-5,sp83se-5,sp83sw-5,sp84se-5,sp93nw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: bedf-020nw-4,bedf-024nw-4,bedf-024sw-4,buck-009ne-4,buck-009se-4,buck-010ne-4,buck-010nw-4,buck-010se-4,buck-010sw-4,buck-014ne-4,buck-014se-4,buck-015ne-4,buck-015nw-4,buck-015se-4,buck-015sw-4,buck-019ne-4,buck-020ne-4,buck-020nw-4,nham-061ne-4,nham-061se-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: buck-009ne-3,buck-009se-3,buck-010ne-3,buck-010nw-3,buck-010se-3,buck-010sw-3,buck-014ne-3,buck-014se-3,buck-015ne-3,buck-015nw-3,buck-015se-3,buck-015sw-3,buck-019ne-3,buck-020ne-3,buck-020nw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

7. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: bedf-020nw-2,bedf-024nw-2,bedf-024sw-2,buck-009ne-2,buck-009se-2,buck-010ne-2,buck-010nw-2,buck-010se-2,buck-010sw-2,buck-014ne-2,buck-014se-2,buck-015ne-2,buck-015nw-2,buck-015se-2,buck-015sw-2,buck-019ne-2,buck-020ne-2,buck-020nw-2,nham-061ne-2,nham-061se-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Newcastle

1. National Grid 1:10 560 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: nz16ne-7,nz16se-7,nz26ne-7,nz26nw-7,nz26se-7,nz26sw-7,nz27se-7,nz36nw-7,nz37se-7,nz37sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: nz16ne-6,nz16se-6,nz17se-6,nz26ne-6,nz26nw-6,nz26se-6,nz26sw-6,nz27se-6,nz27sw-6,nz36ne-6,nz36nw-6,nz36se-6,nz36sw-6,nz37se-6,nz37sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: nz16ne-5,nz16se-5,nz17se-5,nz26ne-5,nz26nw-5,nz26se-5,nz26sw-5,nz27se-5,nz27sw-5,nz36ne-5,nz36nw-5,nz36se-5,nz36sw-5,nz37se-5,nz37sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: nz16ne-7,nz16se-7,nz17se-7,nz26ne-7,nz26nw-7,nz26se-7,nz26sw-7,nz27se-7,nz27sw-7,nz36ne-7,nz36nw-7,nz36se-7,nz36sw-7,nz37se-7,nz37sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: nz16ne-5,nz16se-5,nz17se-5,nz26ne-5,nz26nw-5,nz26se-5,nz26sw-5,nz27se-5,nz27sw-5,nz36ne-5,nz36nw-5,nz36se-5,nz36sw-5,nz37se-5,nz37sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: durh-002se-4,durh-002sw-4,durh-003ne-4,durh-003se-4,durh-003sw-4,durh-004nw-4,durh-004sw-4,nhum-085se-4,nhum-086ne-4,nhum-086se-4,nhum-086sw-4,nhum-087sw-4,nhum-094ne-4,nhum-094nw-4,nhum-095ne-4,nhum-095nw-4,nhum-095sw-4,nhum-096nw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

7. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: durh-00200-3,durh-003ne-3,durh-003se-3,durh-003sw-3,durh-004nw-3,durh-004sw-3,nhum-085ne-3,nhum-085nw-3,nhum-085se-3,nhum-085sw-3,nhum-086ne-3,nhum-086nw-3,nhum-086se-3,nhum-086sw-3,nhum-087nw-3,nhum-087sw-3,nhum-094ne-3,nhum-094nw-3,nhum-094se-3,nhum-094sw-3,nhum-095nw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

8. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: durh-002se-2,durh-002sw-2,durh-003ne-2,durh-003se-2,durh-003sw-2,durh-004nw-2,durh-004sw-2,nhum-080se-2,nhum-080sw-2,nhum-081se-2,nhum-081sw-2,nhum-088ne-2,nhum-088nw-2,nhum-088se-2,nhum-088sw-2,nhum-089ne-2,nhum-089nw-2,nhum-089se-2,nhum-089sw-2,nhum-097ne-2,nhum-097nw-

2,nhum-097se-2,nhum-097sw-2,nhum-098ne-2,nhum-098nw-2,nhum-098sw-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Nottingham

1. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: sk53ne-6,sk53nw-6,sk53se-6,sk54ne-6,sk54nw-6,sk54se-6,sk54sw-6,sk63nw-6,sk64nw-6,sk64sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: sk53ne-5,sk53nw-5,sk53se-5,sk53sw-5,sk54ne-5,sk54nw-5,sk54se-5,sk54sw-5,sk63nw-5,sk63sw-5,sk64nw-5,sk64sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: sk53ne-7,sk53nw-7,sk53se-7,sk53sw-7,sk54ne-7,sk54nw-7,sk54se-7,sk54sw-7,sk63nw-7,sk63sw-7,sk64nw-7,sk64sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: sk53ne-5,sk53nw-5,sk53se-5,sk53sw-5,sk54ne-5,sk54nw-5,sk54se-5,sk54sw-5,sk63nw-5,sk63sw-5,sk64nw-5,sk64sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: derb-056ne-3,nott-037ne-3,nott-037se-3,nott-038ne-3,nott-038nw-3,nott-038se-3,nott-038sw-3,nott-041ne-3,nott-041se-3,nott-042ne-3,nott-042nw-3,nott-042se-3,nott-042sw-3,nott-045ne-3,nott-046ne-3,nott-046nw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: derb-056ne-2,nott-037ne-2,nott-037se-2,nott-038ne-2,nott-038nw-2,nott-038se-2,nott-038sw-2,nott-041ne-2,nott-041se-2,nott-042ne-2,nott-042nw-2,nott-042se-2,nott-042sw-2,nott-045ne-2,nott-046ne-2,nott-046nw-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Sheffield

1. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: derb-011nw-4,derb-012ne-4,derb-012nw-4,derb-012se-4,derb-012sw-4,derb-013nw-4,derb-013sw-4,york-281se-4,york-282se-4,york-282sw-4,york-283se-4,york-283sw-4,york-287ne-4,york-288ne-4,york-288nw-4,york-288se-4,york-288sw-4,york-289ne-4,york-289nw-4,york-289se-4,york-289sw-4,york-293se-4,york-294ne-4,york-294nw-4,york-294se-4,york-294sw-4,york-295ne-4,york-295nw-4,york-295se-4,york-295sw-4,york-298ne-4,york-298nw-4,york-298se-4,york-299nw-4,york-299se-4,york-598ne-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: derb-011ne-3,derb-011nw-3,derb-011se-3,derb-011sw-3,derb-012ne-3,derb-012nw-3,derb-012se-3,derb-012sw-3,derb-01300-3,york-281se-3,york-282se-3,york-282sw-3,york-283se-3,york-283sw-3,york-287ne-3,york-287se-3,york-288ne-3,york-288nw-3,york-288se-3,york-288sw-3,york-289ne-3,york-289nw-3,york-289se-3,york-289sw-3,york-293ne-3,york-293se-3,york-294ne-3,york-294nw-3,york-294se-3,york-294sw-3,york-295ne-3,york-295nw-3,york-295se-3,york-295sw-3,york-298ne-3,york-298nw-3,york-299ne-3,york-299nw-3,york-299se-3,york-598ne-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: derb-011ne-2,derb-011nw-2,derb-011se-2,derb-011sw-2,derb-012ne-2,derb-012nw-2,derb-012se-2,derb-012sw-2,derb-013nw-2,derb-013sw-2,york-281se-2,york-282se-2,york-282sw-2,york-283se-2,york-283sw-2,york-287ne-2,york-287se-2,york-288ne-2,york-288nw-2,york-288se-2,york-288sw-2,york-289nw-2,york-289se-2,york-289sw-2,york-293ne-2,york-293se-2,york-294ne-2,york-294nw-2,york-294se-2,york-294sw-2,york-295ne-2,york-295nw-2,york-295se-2,york-295sw-2,york-298ne-2,york-298nw-2,york-299ne-2,york-299nw-2,york-299se-2,york-598ne-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: sk27ne-6,sk29ne-6,sk29se-6,sk37ne-6,sk37nw-6,sk38ne-6,sk38nw-6,sk38se-6,sk38sw-6,sk39ne-6,sk39nw-6,sk39se-6,sk39sw-6,sk47nw-6,sk48nw-6,sk48sw-6,sk49nw-6,sk49sw-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: sk27ne-5,sk28ne-5,sk28se-5,sk29ne-5,sk29se-5,sk37ne-5,sk37nw-5,sk38ne-5,sk38nw-5,sk38se-5,sk38sw-5,sk39ne-5,sk39nw-5,sk39se-5,sk39sw-5,sk47nw-5,sk48nw-5,sk48sw-5,sk49nw-5,sk49sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: sk27ne-7,sk28ne-7,sk28se-7,sk29ne-7,sk29se-7,sk37ne-7,sk37nw-7,sk38ne-7,sk38nw-7,sk38se-7,sk38sw-

7,sk39ne-7,sk39nw-7,sk39se-7,sk39sw-7,sk47nw-7,sk48nw-7,sk48sw-7,sk49nw-7,sk49sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

7. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: sk28ne-5,sk28se-5,sk29ne-5,sk37ne-5,sk37nw-5,sk38ne-5,sk38nw-5,sk38se-5,sk39ne-5,sk39nw-5,sk39se-5,sk39sw-5,sk47nw-5,sk48nw-5,sk48sw-5,sk49nw-5,sk49sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Southampton

1. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: hamp-056se-3,hamp-057se-3,hamp-057sw-3,hamp-058sw-3,hamp-064ne-3,hamp-064se-3,hamp-065ne-3,hamp-065nw-3,hamp-065se-3,hamp-065sw-3,hamp-066nw-3,hamp-066sw-3,hamp-072ne-3,hamp-073ne-3,hamp-073nw-3,hamp-074nw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: su31se-6,su41ne-6,su41nw-6,su41se-6, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: su30ne-5,su31ne-5,su31se-5,su40ne-5,su40nw-5,su41ne-5,su41nw-5,su41se-5,su41sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

4. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: su30ne-7,su31ne-7,su31se-7,su40ne-7,su40nw-7,su41ne-7,su41nw-7,su41se-7,su41sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: su30ne-5,su31ne-5,su31se-5,su40ne-5,su40nw-5,su41ne-5,su41nw-5,su41se-5,su41sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

6. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: hamp-057se-4,hamp-057sw-4,hamp-058sw-4,hamp-064ne-4,hamp-064se-4,hamp-065ne-4,hamp-065nw-4,hamp-065se-4,hamp-065sw-4,hamp-066sw-4,hamp-073ne-4,hamp-073nw-4,hamp-074nw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

Swansea

1. National Grid 1:10 000 1st Metric Edition [TIFF geospatial data], Scale 1:10000, Tiles: ss69ne-5,ss69nw-5,ss69se-5,ss69sw-5,ss79nw-5,ss79sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. National Grid 1:10 560 1st Imperial Edition [TIFF geospatial data], Scale 1:10560, Tiles: ss69ne-5,ss69nw-5,ss69se-5,ss69sw-5,ss79nw-5,ss79sw-5, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

3. National Grid 1:10 000 Latest Version [TIFF geospatial data], Scale 1:10000, Tiles: ss69ne-7,ss69nw-7,ss69se-7,ss69sw-7,ss79nw-7,ss79sw-7, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

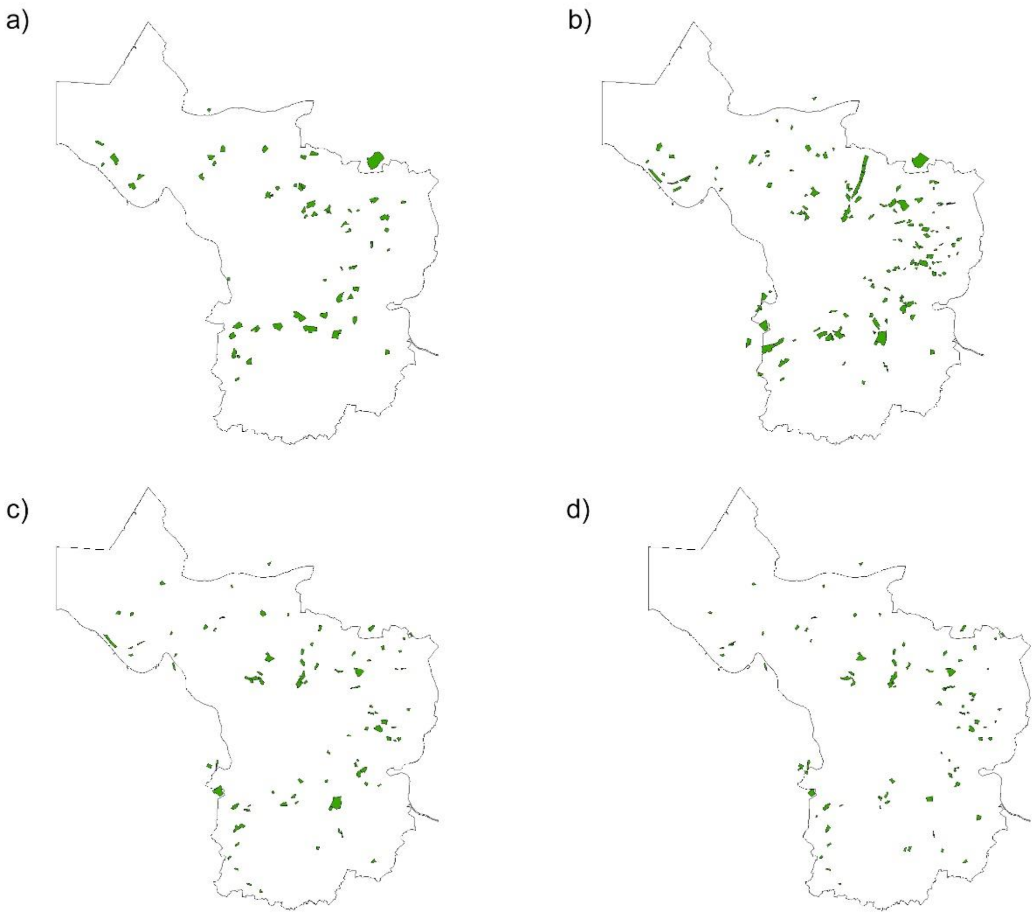
4. 1:10 560 County Series 3rd Revision [TIFF geospatial data], Scale 1:10560, Tiles: glam-014ne-4,glam-014se-4,glam-015ne-4,glam-015nw-4,glam-015se-4,glam-015sw-4,glam-023ne-4,glam-023se-4,glam-024ne-4,glam-024nw-4,glam-024se-4,glam-024sw-4, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

5. 1:10 560 County Series 2nd Revision [TIFF geospatial data], Scale 1:10560, Tiles: glam-014ne-3,glam-014se-3,glam-015ne-3,glam-015nw-3,glam-015se-3,glam-015sw-3,glam-023ne-3,glam-023se-3,glam-024ne-3,glam-024nw-3,glam-024se-3,glam-024sw-3, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

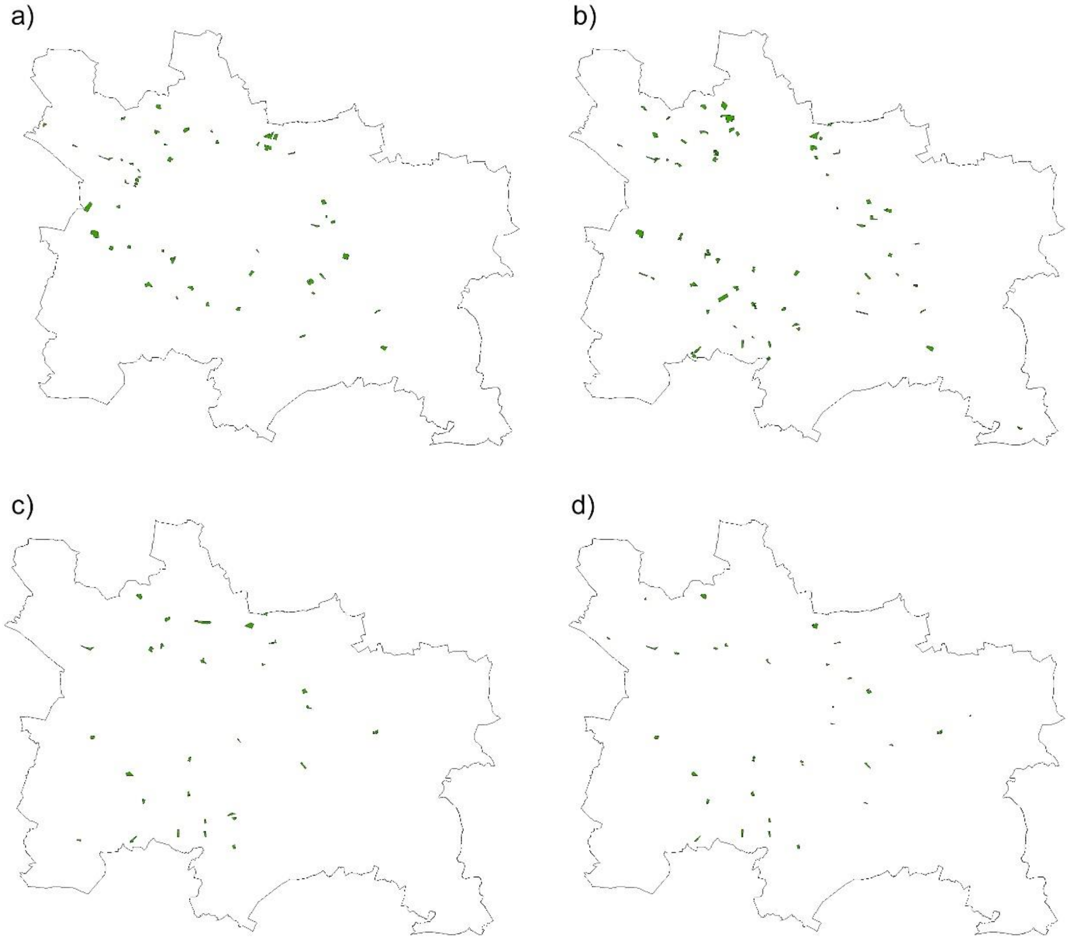
6. 1:10 560 County Series 1st Revision [TIFF geospatial data], Scale 1:10560, Tiles: glam-014ne-2,glam-014se-2,glam-015ne-2,glam-015nw-2,glam-015se-2,glam-015sw-2,glam-023ne-2,glam-023se-2,glam-024ne-2,glam-024nw-2,glam-024se-2,glam-024sw-2, Updated: 30 November 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>

2. Supplementary figures

Supp 1. Change in allotment land provision in Bristol, United Kingdom, over the twentieth century: a) 1920; b) 1950, c) 1970; d) 2016.



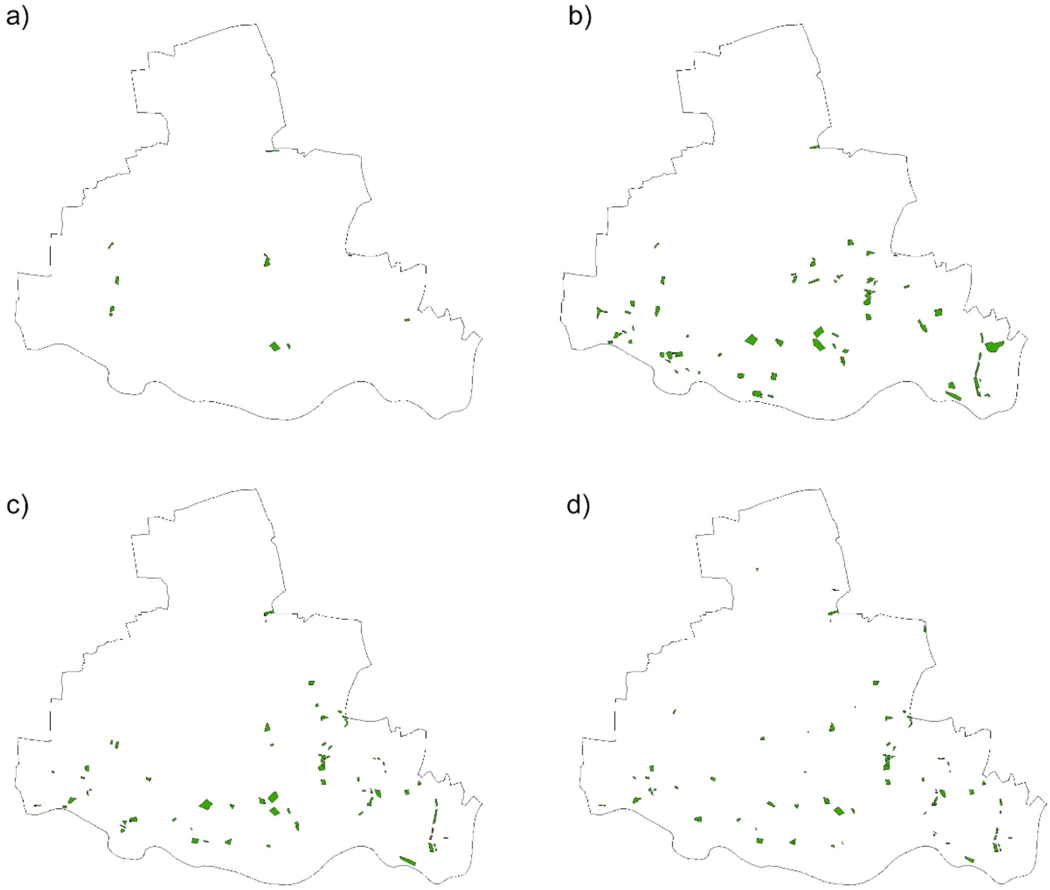
Supp 2. Change in allotment land provision in Glasgow, United Kingdom, over the twentieth century: a) 1940; b) 1950, c) 1970; d) 2016.



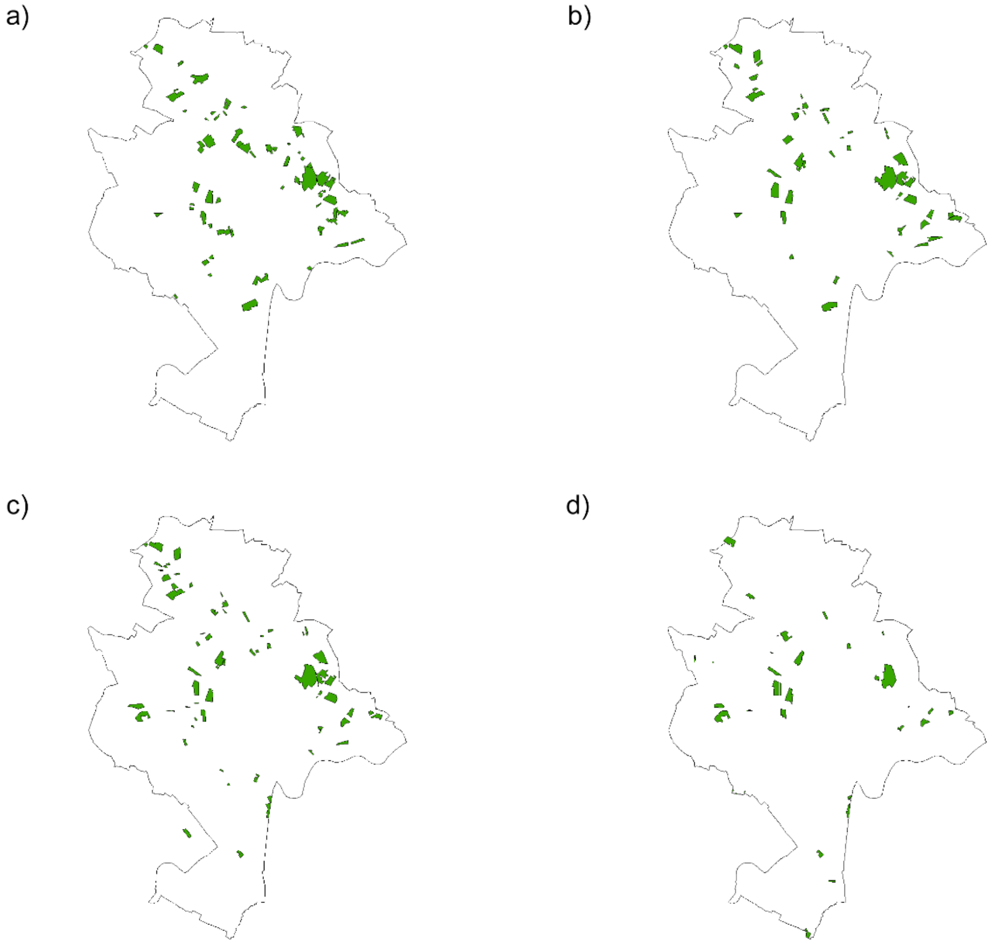
Supp 3. Change in allotment land provision in Liverpool, United Kingdom, over the twentieth century: a) 1930; b) 1950, c) 1970; d) 2016.

Supp 4. Change in allotment land provision in Milton Keynes, United Kingdom, over the twentieth century: a) 1950; b) 1980, c) 2016.

Supp 5. Change in allotment land provision in Newcastle, United Kingdom, over the twentieth century: a) 1920; b) 1950, c) 1970; d) 2016.

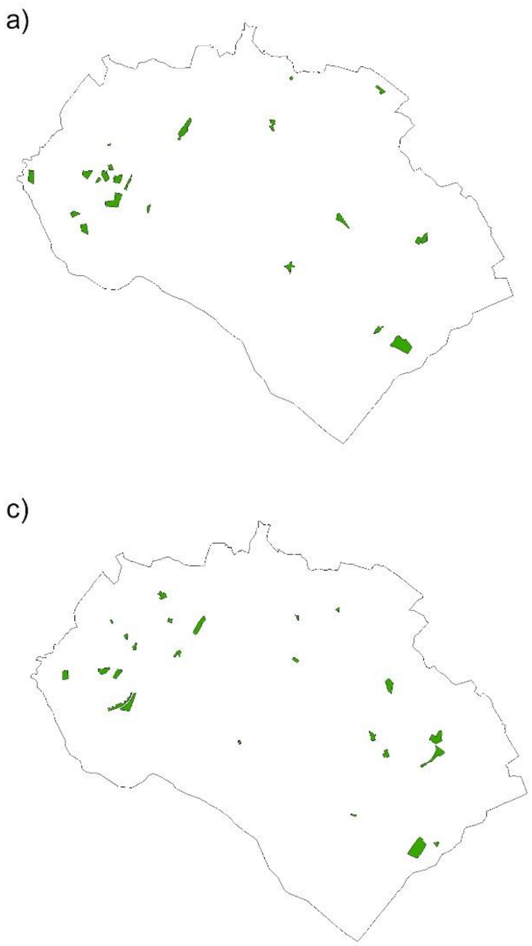


Supp 6. Change in allotment land provision in Nottingham, United Kingdom, over the twentieth century: a) 1910; b) 1950, c) 1970; d) 2016.

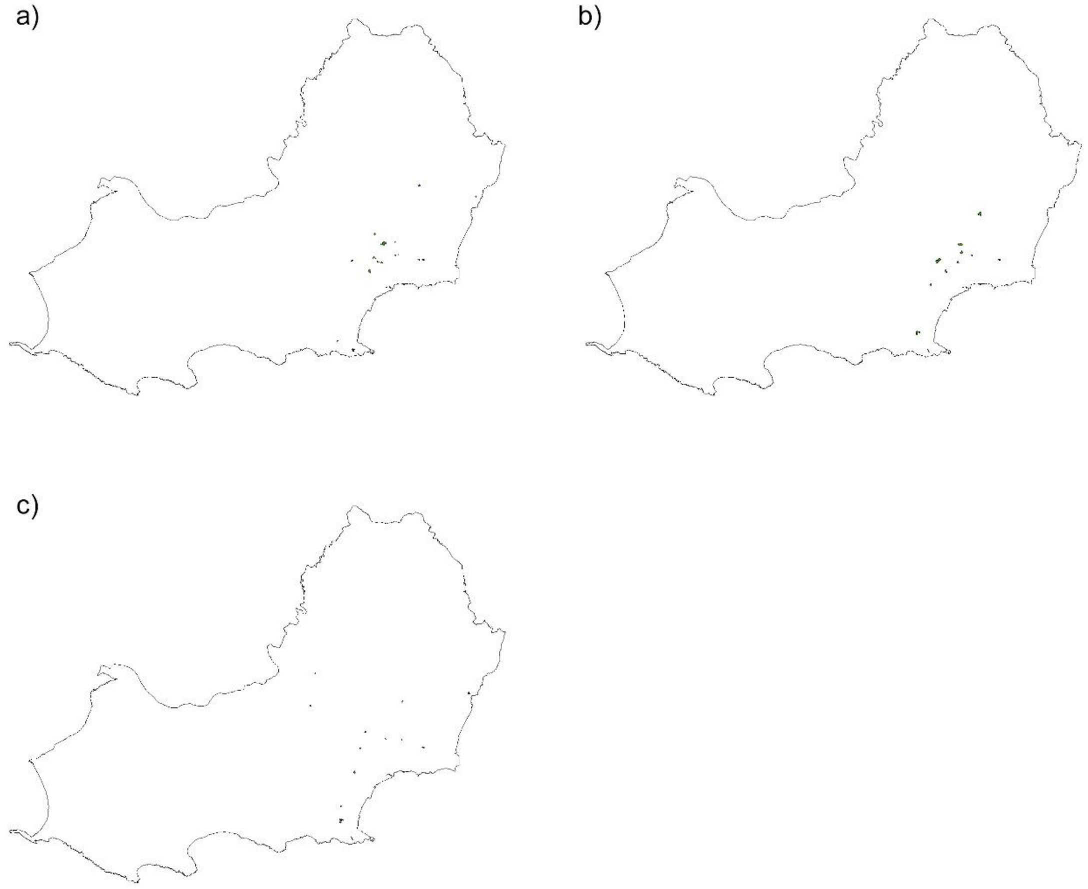


Supp 7. Change in allotment land provision in Sheffield, United Kingdom, over the twentieth century: a) 1910; b) 1930, c) 1950; d) 2016.

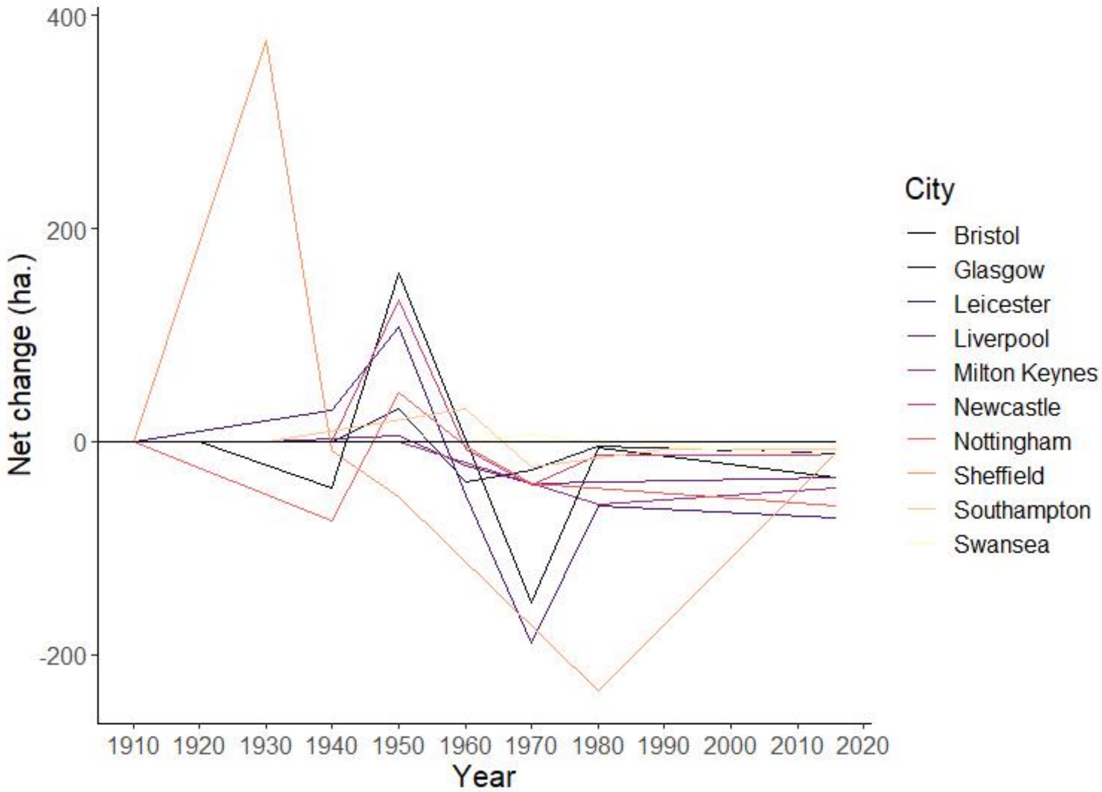
Supp 8. Change in allotment land provision in Southampton, United Kingdom, over the twentieth century: a) 1930; b) 1960, c) 1990; d) 2016.



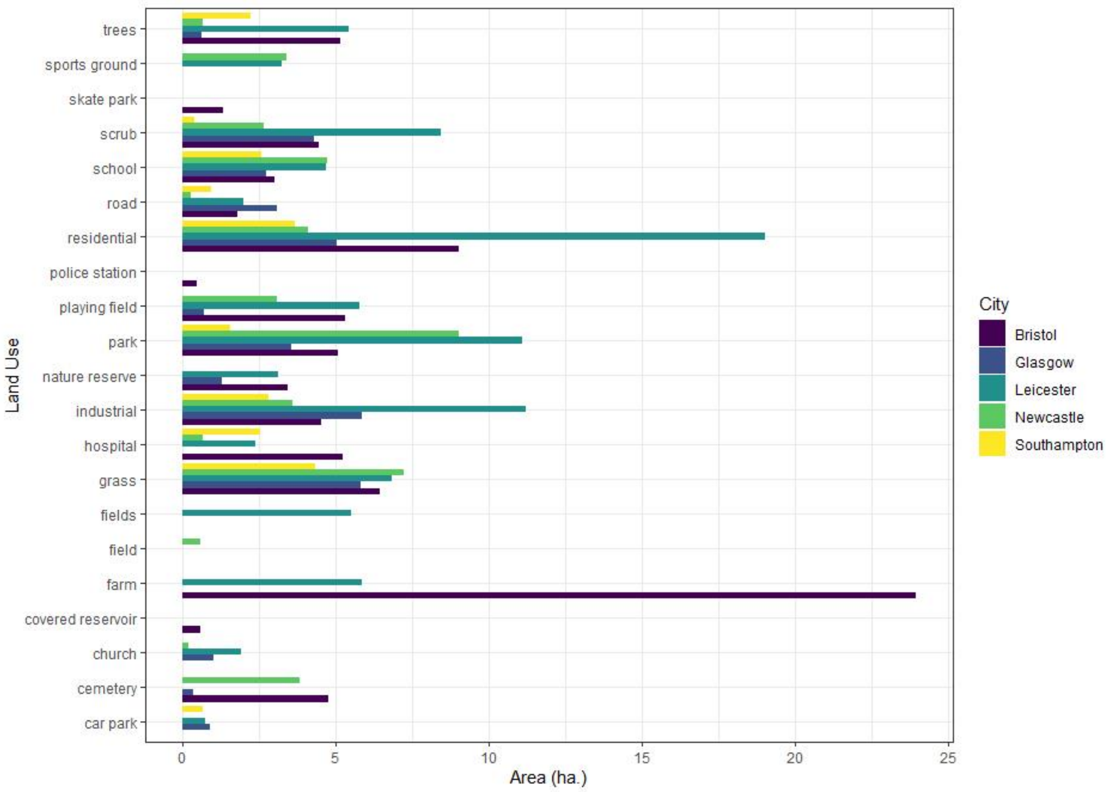
Supp 9. Change in allotment land provision in Swansea, United Kingdom, over the twentieth century: a) 1960; b) 1970, c) 2016.



Supp 10. Net change in allotment land provision throughout the twentieth century for ten case study cities.



Supp 11. Current land uses of former allotment land in Bristol, Newcastle, Glasgow, Southampton and Leicester.



3. Spatial Restriction Criteria

Developed by Grafius *et al*. (2019) for use in identification of potential biofuel production sites, which we have adapted as detailed in the main text for using to identify potential allotment sites.

Class	**Excluded areas**	**Data source**
Water and infrastructure	Water bodies	OS MasterMap
	Pavement	Derived from Landmap CIR via NDVI threshold
	Buildings	OS MasterMap
	Structures	OS MasterMap
Designated areas	Sites of Special Scientific Interest	Natural England, Natural Resources Wales, Scottish National Heritage
	National nature reserves	Natural England, Natural Resources Wales, Scottish National Heritage
	Local nature reserves	Natural England, Natural Resources Wales, Scottish National Heritage
	Special Areas of Conservation	Natural England, Natural Resources Wales, Scottish National Heritage
	Special Protection Areas	Natural England, Natural Resources Wales, Scottish National Heritage
	Ramsar sites	Natural England, Natural Resources Wales, Scottish National Heritage

	Registered Common Land	Natural England, Natural Resources Wales
	Public Rights of Way (PRoW)	Natural England
Cultural and Amenity Areas	Scheduled Monuments	Historic England, Natural Resources Wales
	Registered Battlefields	Historic England
	World Heritage Sites	Historic England
	Sports facilities (incl. playing fields, golf courses, bowling greens, tennis courts and play spaces)	OS OpenGreenspace
	Cemeteries	OS OpenGreenspace
Natural Habitats and Land Cover	Ancient Woodlands	Natural England, Natural Resources Wales, Scottish National Heritage
	National Forest Inventory	Forestry Commission (GB)
	Priority habitats (Lowland heath, lowland calcareous grassland, lowland dry acid grassland, lowland meadow sites)	Natural England
	agricultural land (grade 1-3)	Natural England, James Hutton Institute, Natural Resources Wales
	Woodland/trees	Derived from Environment Agency LIDAR
Land Subject to Existing Grants	Countryside Stewardship Agreement areas	Natural England
	Environmental Stewardship areas	Natural England
	Organic Farming Scheme areas	Natural England
	Woodland Grant Scheme areas	Forestry Commission (Eng/Sco), Natural Resources Wales

Specific to SRC	Site access for vehicles (3m buffer around sites)	Derived in GIS
	Not within 10 m of neighbouring land or residential property	Derived in GIS
	Individual plots at least 0.5 ha	Derived in GIS
	Not private residential garden (‘Multi-surface’ polygons)	OS MasterMap

Supplementary Information: Chapter 3

1. Map of allotment sites where soil sampling took place

2. Frequency of crops sampled for soil quality

Annual		Perennial	
Potato	38	Raspberry	49
Bean (Runner)	26	Rhubarb	36
Onion	21	Apple	24
Courgette	16	Strawberry	16
Tomato	15	Redcurrant	12
Beetroot	12	Pear	11
Bean (French)	8	Plum	11
Leek	7	Gooseberry	7

Chard	5	Blackberry	5
Sweetcorn	5	Blackcurrant	5
Kale	4	Cherry	3
Lettuce	4	Damson	3
Pumpkin	4	Grape	2
Spinach	4	Bare Soil	1
Bean (Broad)	3	Chinese Lantern	1
Carrot	3	Comfrey	1
Cucumber	3	Loganberry	1
Squash	3	Loganberry/Tayberry mix	1
Bean (Borlotti)	2	Mint	1
Bean (Kidney)	2	Whitecurrants	1
Bean (misc.)	2		
Brussel Sprout	2		
Cabbage	2		
Chop Suey Greens	2		
Parsnip	2		
Salad	2		
Brassica (misc.)	1		
Garlic	1		
Globe Artichoke	1		
Lavender	1		
Pea	1		

Purple Sprouting Broccoli	1		
Radish	1		
Rocket	1		
Tomato / Spring Onion (intercropped)	1		

3. Soil management questionnaire

Thank you for answering this questionnaire as part of research taking place at the University of Sheffield. This questionnaire should take a maximum of 10 minutes to complete and asks about allotment management practices as well as the impact of growing food on your life.

Your responses will be paired with the other information we are collecting about your plot; however, you will not be personally identifiable from any of this information.

You are free to refuse to answer any questions you would rather leave blank.

Your participation in this questionnaire is voluntary and you may withdraw at any time if you do not want your data to be used.

This questionnaire and the associated research has received ethical approval from the Department of Animal and Plant Sciences, The University of Sheffield.

Consent form

Please read the following statements and indicate your agreement by checking the boxes below.

I understand that:

☐ My responses to this survey will be kept strictly anonymous, and this survey will not record my name.

☐ This survey will be linked to the other information collected about my plot (e.g. plot map and soil samples).

☐ I am free to leave out any questions I do not feel comfortable answering.

☐ My participation is completely voluntary and I can withdraw from the survey at any time.

I am over 18 years of age and agree to take part in this survey.

☐ Yes

Sometimes information collected for one specific project can be used for other research in the future. Would you be happy for the anonymised survey results to be kept and potentially used for other research in the future?

☐ Yes

☐ No

Signed: ____

What is your home postcode? ____

How old are you?

☐ 18-25

☐ 26-40

☐ 41-60

☐ 61 or over

How would you describe your ethnic background? ________________________________

How long have you been growing at this site? ___________________________________

Have you previously grown food elsewhere, and if so, for how long? __________________

____

How many people work on your allotment? ____

Do you grow anywhere else? *Please check all that apply.*

☐ Home garden

☐ Indoors e.g. windowsill

☐ Community garden

☐ Other: ____

Approximately how many hours per week do you spend managing your growing space?

a. In spring: _________________

b. In summer: _________________

c. In autumn: _________________

d. In winter: _________________

Do you grow organically, i.e. without the use of chemical fertilisers, pesticides or other artificial chemicals?

☐ Yes, 100%

☐ Yes, partially

☐ No

If you do not grow 100% organically, what non-organic inputs do you use? ______________

____

____

____

Do you save seeds?

☐ Yes

☐ No

If you save seeds, do you also share them e.g. with neighbouring plot-holders?

☐ Yes

☐ No

Do you compost

☐ Household kitchen waste e.g. vegetable peelings

☐ Growing waste e.g. old plants

☐ Other: ____

Do you add things to your soil that originate outside your plot?

☐ Animal manure

☐ Organic fertiliser

☐ Non-organic fertiliser

☐ Purchased compost / potting soil

☐ Other: ____

Do you use cover cropping or other forms of winter soil cover e.g. plastic sheeting?

☐ Yes, I use ____

☐ No

Approximately how much do you spend per year on your plot?

- ☐ Under £100
- ☐ From £100 to £249
- ☐ £250 to £500
- ☐ Over £500

What is your yearly allotment rent? ____

4. List and references of R packages used

1. Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67:1, 1-48. https://doi.org/10.18637/jss.v067.i01
2. Firke, S. (2020). janitor: Simple tools for examining and cleaning dirty data. R package version 2.0.1. https://CRAN.R-project.org/package=janitor
3. Fox, J., & Weisberg, S. (2019). A R companion to applied regression, third edition. Thousand Oaks CA: Sage. https://socialsciences.mcmaster.ca/jfox/Books/Companion
4. Gravesm S., Piepho, H-P., & Selzer, L. with help from Dorai-Raj, S. (2019). multcompView: Visualisations of paired comparisons. R package version 0.1-8. https://CRAN.R-project.org/package=multcompView
5. Harrell, F. E. Jr., with contributions from Charles Dupont and many others. (2020). Hmisc: Harrell miscellaneous. R package version 4.4-0. https://CRAN.R-project.org/package=Hmisc
6. Hlavac, M. (2018). stargazer: Well-formatted regression and summary statistics tables. R package version 5.2.1. https://CRAN.R-project.org/package=stargazer
7. Kassambara, A. (2020). ggpubr: ‘ggplot2’ based publication ready plots. R package version 0.3.0. https://CRAN.R-project.org/package=ggpubr
8. Kassambara, A. (2020). rstatix: Pipe-friendly framework for basic statistical tests. R package version 0.6.0. https://CRAN.R-project.org/package=rsatix
9. Kleiber, C., & Zeileis, A. (2008). Applied econometrics with R. New York: Springer Verlag. ISBN 978-0-387-77316-2. https://CRAN.R-rpoject.org/package=AER

10. Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: tests in linear mixed effects models, *Journal of Statistical Software,* 82:13, 1-25. https://doi.org/10.18637/jss.v082.i13

11. Lenth, R. (2020). emmeans: Estimated marginal means, aka least-square means. R package version 1.4.8. https://CRAN.R-project.org/package=emmeans

12. Lüdecke, D., Mokowski, D., Waggoner, P., & Patil, I. (2020). performance: Assessment of regression models performance. R package version 0.4.7. https://CRAN.R-project.org/package=performance

13. Mangiafico, S. (2020). rcompanion: Functions to support extension education program evaluation. R package version 2.3.25. https://CRAN.R-project.org/package=rcompanion

14. Meyer, D., Dimitriadou, E., Hornik, K., Weingessel, A., & Leisch, F. (2019). e1071: Misc functions of the department of statistics, probability theory group (formerly: E1081), TU Wein. R package version 1.7-3. https://CRAN.R-project.org/package=e0171

15. Wickham, H. (2016). ggplot2: Elegant statistics for data analysis. Springer-Verlag New York.

16. Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D'A., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., & Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, 4:43, 1686. https://doi.org/10.21105/joss.01686

17. Wickham, H., François, R., Henry, L., & Miller, K. (2020). dplyr: A grammar of data manipulation. R package version 1.0.0. https://CRAN.R-project.org/package=dplyr

18. Wickham, H., & Henry, L. (2020). tidyr: Tidy messy data. R package version 1.1.0. https://CRAN.R-project.org/package=tidyr

19. Wilke, C. (2019). cowplot: Streamlined plot theme and plot annotations for 'ggplot2'. R package version 1.0.0. https://CRAN.R-project.org/package=cowplot

5. Results of soil management linear mixed models

Variable	Transformation	Model random effects	Type III AOV results	Organic	Winter cover	Manure	Bought compost	Reused compost	Nonorganic fertiliser	Organic fertiliser
Bulk density	None	City	Num DF	2	1	1	1	1	1	1
			Den DF	498.77	501.99	500.87	500.23	500.39	497.88	500.42
			F	2.4223	0.2619	2.8824	7.6307	0.8884	7.0088	0.1047
			p	0.089761	0.609071	0.090171	**0.00595**	0.346354	**0.008368**	0.746446
SOC density	Log	City	Num DF	2	1	1	1	1	1	1
			Den DF	468.02	470.58	471.56	468.25	469.77	466.35	468.96
			F	0.6129	4.1946	0.9224	0.6716	2.6568	0.2099	0.0411
			p	0.542231	**0.041109**	0.337328	0.412901	0.13775	0.64708	0.83948
C Concentration	Log	City	Num DF	2	1	1	1	1	1	1
			Den DF	502.4	505.4	505.57	502.87	504.72	501.08	503.98
			F	1.4151	1.5573	1.7028	3.575	3.0371	1.7006	0.0001
			p	0.24388	0.21264	0.19252	0.05923	0.08199	0.1928	0.99205
N concentration	Square root	City and site	Num DF	2	1	1	1	1	1	1
			Den DF	576.51	571.09	575.64	573.24	570.57	572.27	576.73
			F	0.5203	0.0648	0.8905	1.4554	1.9314	6.2517	0.2951
			p	0.5946	0.79921	0.34574	0.22816	0.16515	**0.01269**	0.58718
C:N ratio	Log	City	Num DF	2	1	1	1	1	1	1
			Den DF	501.09	503.32	503.37	501.39	502.71	500.23	502.21
			F	5.7983	0.9815	2.779	1.0935	3.4515	2.0212	0.1996
			p	**0.00324**	0.322304	0.100477	0.296204	0.063781	0.155745	0.655252
pH	Exp	City and site	Num DF	2	1	1	1	1	1	1
			Den DF	230.518	236.25	236.829	232.736	229.724	229.224	232.582
			F	0.537	0.0002	0.0954	0.1913	0.0509	0.0467	0.4371
			p	0.58525	0.98953	0.75766	0.66226	0.82177	0.82912	0.50918
WHC	Log	City	Num DF	2	1	1	1	1	1	1
			Den DF	228.86	230.86	227.52	229.68	230.83	229.68	228.32
			F	0.4713	0.8239	0.7363	0.0928	0.571	3.427	0.0171
			P	0.624778	0.3679	0.39175	0.7609	0.450605	0.06542	0.8962

6. Organic carbon estimates for each allotment site in Great Britain

This is a large file and is available at https://tinyurl.com/y5c7jhln.

Supplementary Information: Chapter 4

1. General questions asked about allotments

About your plot

Number of years you have had the plot:

What direction does your plot face?

Is your plot on a slope?

Do you know your soil type – if so, what is it?

Do you grow organically?

Do you use peat free compost / topsoil?

How many people work on your plot?

What is your yearly rent?

Any other details?

If you have a MYHarvest username, please enter it here:

____

2. Fertilisers, pest control and weed control methods used by allotment gardeners, with frequency of applications (count of all days applied for all participants)

Weed control

roundup	63
weedkiller	35
bark chipping	40
glyphosate	21
woodchip	21
cardboard	13
black plastic	13
gel weedkiller	5
fleece	4
mesh	4
membrane	3
glycophospate	2
nets	5
weed burner	2
weed fabric	5
black cloth	1
carpet	1
glycophosphate	1

Pest control

slug pellets	525

bug spray	61
washing up liquid	43
netting	33
slug beer traps	26
insecticide	6
nematodes	6
rat poison	6
savona pesticide	4
garlic water	3
nemaslug	3
ant killer	5
fleece	3
ladybirds	2
slug gone	3
wool pellets	5
bug traps	1
caterpillar control	1
CDs	1
chicken wire	1
coffee grounds	1
copper wire	2
eggshell	2
grease bands	1
grit	1

insect powder	1
mildew spray	1
moth trap	1
mouse poison	2
pesticide	1
pheremones	1
pyrethrum	1
rabbit proof fencing	1
salt water for slugs	1
slug spray	2

Fertiliser

chicken manure pellets	254
seaweed	165
fish blood and bone	169
growmore	148
tomorite	100
comfrey	78
general fertiliser	33
tomato fertiliser	29
lime	26
q4	39
tomato feed	16
6x	15

bonemeal	8
miracle grow	7
potato fertiliser	7
sm4	7
sulphate of potash	6
nettle feed	15
ammonia sulphate	5
dry blood	5
maxicrop	5
onion fertiliser	5
potash	5
potato feed	5
q10	5
volcanic dust	5
10:10:10	4
coffee grounds	4
strawberry fertiliser	4
seaweed, iron	4
slow release	4
ammonium sulphate	3
Ca and N	3
composted leaf mould	3
epsom salts	3
green manure	3

lime, chicken manure pellets	3
miracle gro	3
npk	3
tomarite	3
vitax q6	3
wood ash	3
blood fish and bone	2
calcium	2
comfrey feed	2
comfrey feed, epsom salts	2
comfrey, lime	2
ericaceous fertiliser	2
fish blood and bone, 6x	2
fish blood and bone, lime	2
growmore, q4	2
invigorator	2
mychorrhizal fungi	2
organic potato fertiliser	2
phostrogen	2
plant magic	2
potato fertiliser, chicken manure pellets	2
rose fertiliser	2
seaweed, chicken manure fertiliser	2
sm3	2

soil invigorator	2
sulphate of ammonia	2
tomato feed, chicken manure pellets	2
comfrey	1
6x, chicken manure pellets	1
ammonium sulphate, tomato fertiliser	1
baby bio	1
blood fish and bone, chicken manure pellets	1
blood fish and bone, ericaceous liquid	1
blueberry feed	1
bonemeal, lime	1
calcifed seaweed	1
charge, q4	1
chicken manure pellets, coffee	1
chicken manure pellets, growmore	1
chicken manure pellets, potato fertiliser	1
chicken manure pellets, seaweed	1
comfrey feed, nettle feed	1
comfrey feed, nettle feed, tomorite	1
comfrey feed, nettle feed, tomorite, strawberry feed	1
comfrey feed, tomorite	1
comfrey, chicken manure pellets	1
comfrey, seaweed	1
comfrey, tomato feed	1

cucumber feed	1
egg shells	1
ericaceous compost	1
ericaceous feed, chicken manure pellets	1
fish blood and bone, calcified seaweed	1
fish blood and bone, coffee	1
fish blood and bone, comfrey	1
fish bloood and bone	1
granular feed	1
grow organic, volcanic dust	1
growmore, fish blood and bone, sulphate of potash, superphosphate of lime	1
growmore, plant feed	1
growmore, tomorite	1
growmore, vitax q4	1
invigorator spray	1
iron sulphate	1
leaf mould	1
lime, bonemeal	1
lime, invigorator	1
lime, straw	1
liquid feed	1
liquid fruit fertilisers	1
liquid sea weed	1
magnesium	1

michorrhizal funghi	1
molasses	1
mychorrhizal funghi	1
nettle feed, tomorite	1
nitrogen	1
nutrimate	1
onion fertiliser, vitax q4	1
organic soil conditioner	1
phosphogen	1
plant feed	1
plant magic, 6x	1
potash, ammonia	1
potassium sulphate	1
q4, fish blood and bone	1
q4, potash	1
q4, seaweed	1
rock dust	1
rose feed	1
seaweed, bonemeal	1
seaweed, chicken manure pellets, tomorite	1
seaweed, growmore	1
seaweed, lime	1
seaweed, potash	1
seaweed, rock phosphate, potash	1

slow release, grow organic	1
sm4, nettle feed	1
sm6	1
soil improver	1
strawberry fertiliser	1
sulphate of ammonia, chicken manure pellets	1
sulphate of ammonia, epsom salt	1
sulphate of iron, chicken manure pellets	1
sulphate of phosphate	1
sulphate of potash, ericaceous fertiliser	1
sulphate of potash, growmore	1
tomato fertiliser, phosphate	1
tomato fertiliser, seaweed	1
tomorite, comfrey feed, nettle feed, epsom salts	1
tomorite, growmore	1
urine	1
vitax q4, growmore	1
vitax q4, liquid fertiliser	1
vitax q4, rock fertiliser	1
volcanic dust, chicken manure pellets	1
volcanic dust, mychorrizhal funghi	1

Supplementary Information: Chapter 5

1. List of comments

ID	Date	Note	Type 1	Type 2	Emotion
39	27/12/2017	Suffering from bronchial infection - emergency work on greenhouse prior to gales.	health	Weather	n
39	14/01/2018	Allotment Association Working Party with 5 helpers.	Organisation		
164	14/01/2018	Fox sitting at gate - resident on site. Sleepy wasps in gloves in shed !!!	Wildlife		p
99	15/01/2018	Donated 4 spare kale seedlings to sister's garden	Surplus	Social	p
58	17/01/2018	Pigeons have taken purple sprouting broccoli :(	Wildlife		n
349	27/01/2018	Absolutely freezing rain but v excited. Waist high weeds - history of allotment - gardened by one gent who passed away taken on by a young man who rotivated and planted for a 1/3 of the year then never came back	Weather	Emotion	n
68	28/01/2018	Pruned neighbours grapevine. Sprouts really are a waste of space!	Social		p
37	29/01/2018	Worms, lots of worms :)	Wildlife	Emotion	p
22	01/02/2018	Given 140 packets of flower seeds. Use some later and share rest. Bee hives on site.	Sharing	Wildlife	p
127	05/02/2018	Brought tea and scones and watched birds and horses	Wildlife	Relaxation	p
243	09/02/2018	Plot sheltered so felt good. Sat for a while and enjoyed peace.	Emotion		p

204	12/02/2018	Lots of wildlife around, really nice	Wildlife		p
313	14/02/2018	Fair bit of chatting went on! For the first time in ages other people were on the site and there was a lot of catching up to be done.	Social		p
22	15/02/2018	Pottered about	Relaxation		
240	15/02/2018	This was a clear very sunny day but still very cold. -1 sat in the sunshine. Had a hot drink in greenhouse.	Weather		p
164	15/02/2018	Mr Fox - as usual	Wildlife		p
76	18/02/2018	Grandchildren "helped"	Social		p
240	21/02/2018	Helped [fellow plotholder] clear out his frog pond and transferred four frogs to my pond. He is building another pond.	Social	Wildlife	p
349	24/02/2018	It snowed and was freezing. We must be mad!!! 'Beast from the East'	Weather	Emotion	n
164	24/02/2018	No fox :(Snow forecast for 2 wks!!!	Wildlife		n
112	24/02/2018	With [child] (4 years old) put worm in soil - made new home for toad in community garden	Wildlife	Social	p
219	24/02/2018	Fed robin and set up wildlife camera - always see badger	Wildlife		p
388	04/03/2018	Went for walk to take a friend to see the allotment she keeps hearing about. Sent her home with the cabbage!	Social	Sharing	p
246	05/03/2018	Spent a lot of time gawping at red kites doing their mating thing - gripping talons high up, whirling round while dropping down	Wildlife		p

126	07/03/2018	I order a lot of seeds from Dobbies to be given free to anyone on the allotments, who wants to grow them, paid for from allotment funds. They are flowers I have chosen to attract beneficial insects to the allotments. Took them today with a list of all the varieties and left them in a place where everyone goes (the toilet)	Social	Wildlife	p
37	08/03/2018	Photograph example			
127	09/03/2018	Spoke to three other allotmenteers and watched wildlife. Discussed issues with earth toilet.	Social	Wildlife	p
127	11/03/2018	Still ill. Only went to allotment to enkoy company and wildlife. Only one or two allotmenteers present.	Social	Wildlife	p
322	13/03/2018	Helped sort out seed potatoes in the shop = main reason for visit. Put up notices re volunteers for working party, shop opening & shop rota	Organisation		
127	21/03/2018	Was visited by fellow allotmenteer much chatting, tired and went home! Spent most r at least half eating lunch or chatting.	Social		p
293	23/03/2018	The council came to the plot and asked that I reduce the height of an "old" apple tree to 6 feet! The inspector admitted knowing nothing about allotment history.	Emotion		n
191	23/03/2018	Chatted to [friend] about a favourite painting she did - I will call to see it. Chated to [friend #2] and gave her daffodils	Social	Sharing	p
172	24/03/2018	Territorial black birds newaly flew into my head! Spent about an hour helping [friend] with poorly hen	Wildlife	Social	p

31	25/03/2018	Hurt my back :(	health		n
204	27/03/2018	Really nice to see that the plot has a baby slow worm	Wildlife		p
293	31/03/2018	Dictatorial council inspected the allotments!!	Emotion		n
172	31/03/2018	[Friend's] hen died on Tuesday	Wildlife		n
219	31/03/2018	Killed 150 slugs	Wildlife		n
93	06/04/2018	Polytunnel door won't open!!!	Emotion		n
322	07/04/2018	Working party to clear plot for re-letting	Social	Organisation	
10	08/04/2018	Lovely day	Emotion		p
191	08/04/2018	Great help from 11 year old grandson	Social		p
79	08/04/2018	It must be Spring, we're having fresh salad for tea.	Weather		p
196	09/04/2018	Frog spawn in pond :)	Wildlife		p
322	10/04/2018	Watering polytunnel and enjoying time to reflect. My allotment is a place for me to sit and muse/reflect	Emotion		p
196	12/04/2018	Dead frog :(	Wildlife		n
76	13/04/2018	Found the bowl of a clay pipe. How long have these allotments been used I wonder?	Knowledge		
126	15/04/2018	Last week, a wagon delivering soil to another allotment got stuck in my onion bed. The wheels sunk into the bed. It took a recovery vehicle 6 hours to get it out. It has left the bed in a mess. Edging flags along the front got squashed into the bed and some wer ebroken. Spent the time trying to repair the damage.	Emotion		n

15	15/04/2018	Nephew came to help. Gave PSB to sister & neighbour.	Social	Sharing	p
347	18/04/2018	Far too tempting to sit in the sun, I must do some work!	Weather		p
31	19/04/2018	Only there to assess a break-in at the plot. Shed door ripped off, some toold stolen - fairly minor and unimportant tools, but irritating! LATER (2 May). Recovered stolen tools... Result!!	Emotion		n
31	20/04/2018	Pooped now. Time for a beer!	Relaxation		p
256	20/04/2018	Gave neighbour 4 Shirley tomato plants	Sharing		p
344	20/04/2018	Hottest April day since records began!	Weather		n
271	21/04/2018	Brought tray of green broccoli plants from home to plot greenhouse. Gave some away to plot neighbours.	Sharing		p
388	21/04/2018	Allotment Tenants Coffee Morning today 10.30-12	Social	Organisation	
15	21/04/2018	Dad brought old pool table frame… Much warmer, more people around	Social	Sharing	p
243	21/04/2018	Picnic lunch and sat in Sun.	Weather		p
434	21/04/2018	Weed control sheets had been disturbed, probably by a fox chasing a rat as a dead rat was found nearby. The body was buried.	Wildlife		n
395	22/04/2018	Cherry and plum and pear blossom beautiful	Emotion		p
322	22/04/2018	Mainly resolving plotolder issues	Organisation	Social	
15	22/04/2018	Taking PSB to work. Dad brought old window from conservatory. Will use to help grow melons.	Sharing		p

127	22/04/2018	Lots of chatting and two mugs of tea	Social		p
240	22/04/2018	Hope I get some more frogs	Wildlife		p
22	23/04/2018	Hailstorm encouraged me to leave early.	Weather		n
39	26/04/2018	Called to sort out leaking water pipes	Organisation		
60	26/04/2018	Fig tree donated by friend in autumn has new leaves	Sharing		p
243	29/04/2018	Sat in sun and surveyed my domain :)	Emotion	Weather	p
127	03/05/2018	Met new allotmenteers. Showed them my strimmer - light - good value for money - showed [them] that my compost was already heating up with addition of veg scraps and shredded paper	Social	Knowledge	p
353	03/05/2018	Guerilla seed sowing on wasteland. Honey bees extremely busy.	Wildlife		p
37	04/05/2018	Two seagulls fighting over scrap of food. A crow joined in like a boxing referee. The gulls fought so much they dropped the food and the crow nipped in and stole it! You had to be there.	Wildlife		p
164	04/05/2018	We also have fox cubs :)	Wildlife		p
271	05/05/2018	Took a walk around the allotment sit eto show a friend the place and just to enjoy it in its spring glory!	Social	Emotion	p
15	05/05/2018	Nephew came to help. Sat and chat with 2 neighbouring allotmenteers. Beautiful blue sky.	Social	Weather	p
46	05/05/2018	Temperature has SHOT up - from around 10 earlier in the week to around 23	Weather		n

39	06/05/2018	Resigned from committee therefore much discussion. Cabin open for coffee and cake.	Organisation	Social	
240	06/05/2018	Just visited the allotment with a friend. We sat in the sunshine and saw a frog in the new pond. Lovely. Don't know where he came from. Hope he stays.	Social	Wildlife	p
112	06/05/2018	Afternoon tea in the pavillion	Social		p
22	06/05/2018	Spent 1.5 hours watering from 18.00 hours	Weather		n
204	06/05/2018	Really nice seeing a bird that I have not seen before	Wildlife		p
341	07/05/2018	Very warm 26C and it's brought lobsters onto the plot!! Also sunhats :)	Weather	Emotion	p
169	07/05/2018	Sat and look around the very quiet site because it was a bank holiday. It was lovely all the fruits are coming on the apple and pear trees. Gooseberries forming everything looks fantastic, the sun is shining and the birds are singing - what more could you want?	Wildlife	Emotion	p
218	08/05/2018	Hoe when you can't see a weed and you will never see a weed	Knowledge		
55	08/05/2018	The season has moved on suddenly with the warmth. Like nature is trying to catch up.	Wildlife	Weather	p
395	09/05/2018	Helped? By 5 year old grandson	Social		p
39	11/05/2018	Given 20 romanesco plants	Sharing		p
388	11/05/2018	14 kites means someone locally is regularly putting out food for them	Wildlife		p

395	12/05/2018	Lovely to be able to spend a good long time there	Emotion		p
81	13/05/2018	Long discussion with [friend] - he thinks it is centipedes that make holes in the potatoes, I think it's wireworm or slugs	Social	Knowledge	
172	15/05/2018	This was the day oney bees started nesting in our chimney so this visit was relaxing albeit brief	Wildlife		p
353	18/05/2018	Honeybee hives frantic! 1 hive swarm :(	Wildlife		n
311	19/05/2018	Was at site to help wit annual plant sale to raise funds for site.	Social	Organisation	p
75	19/05/2018	Watched blue tits which had nested in an old bird box on top of a compost bin flying in and on feeding chicks.	Wildlife		p
280	20/05/2018	As a member of the committee - covered a vacant plot with tarpaulin to prevent weeds spreading. Also tidied up a bit of rubbish. It's amazing what some plotolders dump!	Organisation		n
164	20/05/2018	Bunting made out of gloves	pride		
112	20/05/2018	BBQ with family	Social		p
169	20/05/2018	Followed by an afternoon tea (12 attended and supply the food). Usual plot holders turn up for work and tea.	Social		p
311	22/05/2018	Neighbour gave me an early crop of rhubarb	Sharing	Surplus	p
126	22/05/2018	Left all my dahlia tubers in a box near the allotment gates with a note saying "For anyone who wants them"	Sharing		p

345	22/05/2018	Lots of people working on plots - all very social!	Social		p
204	25/05/2018	Bitten by red ant	Wildlife		n
345	27/05/2018	Allotments open to public tomorrow bank holiday - lots of gardeners and for local International Aid charity	Social	Organisation	
311	27/05/2018	Annual BBQ on allotment site. Slugs have eaten pea seedlings :(	Social	Wildlife	p
10	27/05/2018	First rain for ages	Weather		p
293	27/05/2018	The council have destroyed much of the allotment hedgerow through complete ignorance and much of the wildlife in the way of birds has disappeared	Wildlife	Emotion	n
345	28/05/2018	Plenty of social interaction with fellow plotters! Lots of chat	Social		p
79	29/05/2018	My Birthday!	Emotion		p
224	31/05/2018	Assissted by 17m toddler	Social		p
20	31/05/2018	Not seen goldfish for a while hope they are ok under the weed	Wildlife		p
437	02/06/2018	Spinach thinnings in salad, yum	Pride		p
388	02/06/2018	Spent some time talking to new tenants about tenants group and the waterless loo. Gave them contact information for the committee (nothing to do with council)	Social	Organisation	
193	02/06/2018	Monthly allotment coffee morning, lots of chat and plant swapping	Social	Sharing	p
267	02/06/2018	Visits from [friends]	Social		p
68	02/06/2018	I HATE red ants.	Wildlife	Emotion	n

55	02/06/2018	Not as much birdsong this year as I remember previously	Wildlife		n
395	03/06/2018	Gradually getting on top of it again. Plant swap at hut, a great success, heaps of people. Hut is where our allotment association trades. Also meet to give support.	Social	Organisation	p
160	03/06/2018	BBQ and socialising	Social		p
68	03/06/2018	Kiwi flowers opened! This is a first…	Weather		p
313	03/06/2018	Each visit I'm surrounded by bird song but I don't always actually see anything!	Wildlife		p
55	04/06/2018	Beginning to have to take water from home to garden for greenhouse	Weather		n
126	06/06/2018	Found a dead chicken and a lot of feathers. Probably the work of a fox.	Wildlife		n
277	07/06/2018	Noted no leek seed germinated, sent complain to seed company via email.	Emotion		n
288	07/06/2018	Mole keeps digging in brassicas bed!!	Wildlife		n
283	07/06/2018	Slowworms found on manure stack. Relocated to a cold compost bin for their own safety.	Wildlife		p
79	08/06/2018	Have a cold - huh :(	Emotion		n
310	09/06/2018	Enough strawberries to give away three large punets to neighbours	Sharing	Surplus	p
311	10/06/2018	Walked round allotment to look at other plots. Must plant some flowers to make my plot a bit brighter and attract wildlife	Knowledge		
427	12/06/2018	Arrived to find mains water pipe along length of allotment. Stand pipe at one end and splitter to water trough on the other.	Emotion		n

		No notification whatsoever. Went home and cried.			
423	13/06/2018	Rain forecast tonight and tomorrow, we will see!! (No rain, no surprise)	Weather		n
400	15/06/2018	Also watered neighbour's plot again	Sharing		p
37	15/06/2018	Still no rain so very dry & watering now major issue.	Weather		n
293	16/06/2018	Today was a sad day. I helped [another plotholder] to bury his pet dog at the bottom of his allotment.	Emotion	Social	n
423	16/06/2018	Still no rain, potatoes limp, needed a lot of watering. Who needs the gym!! I'm 70 next year!!!	Health	Weather	p
81	16/06/2018	STILL NO RAIN - everything very dry. Really need to water more.	Weather		n
243	17/06/2018	LACK OF WATER CRITICAL to strawbs and raspberries	Weather		n
345	18/06/2018	Lots of song birds around in air. Clutch of partiridge eggs in neighbours strawberry path. Fear abandoned. Delivered some surplus black nero kale and brussel sprouts plants to other plots - organised through our allotment Facebook page!	Wildlife	Surplus	p
39	19/06/2018	3 hours on site - time taken dealing with Association issues over possible fly-tipping and blocking access roads, over and hour! Forgot to water new plantings.	Organisation		n
388	21/06/2018	Watered someone elses as they are on holiday. I thought the plants were coming after 27th but arrived today!! Panic to get bed ready.	Social		

293	22/06/2018	Toady help my allotment neighbours with the construction of a shed. Got it half completed today. My neighbour goes into hospital on the 4th July so it is important to get as much of the self made shed completed before then.	Social	Organisation	p
368	22/06/2018	The drought continues! BBC TV were on an adjacent allotment filming a ... programme	Weather	Social	n
102	22/06/2018	All water butts empty	Weather		n
347	23/06/2018	Looking forward to our first cooked meal using our own veg this year	Emotion		p
164	23/06/2018	Competition judging on 27th. We're up for best 10 rod! :)	Pride		p
174	23/06/2018	Husband watered plot. Day of Great Get Together picnic on communal plot.	Social		p
192	24/06/2018	Mini kiwi fruit now 7'!	Pride		p
402	24/06/2018	Getting ready for allotment competition being judged next week - we won last year!	pride		p
224	24/06/2018	No-one can remember when it last rained.	Weather		n
311	25/06/2018	Made lovely (even though I say it myself) blackcurrant jam and a rhubarb crumble	Emotion		p
354	25/06/2018	Wildlife: 2 children with watering cans!	Social		
348	25/06/2018	Very dry. Plant wilting. Grass brown.	Weather		n
345	26/06/2018	Lots of tidying ready for RHSociety It's Your Neighbourhood judging of site on 5/7 and I go away in 2 days time for 3 weeks! Plot does look very good	Organisation		p

10	28/06/2018	Very, very hot. Went there are 0530 to avoid [heat]… Desperate for rain to promote growth	Weather		n
160	28/06/2018	The pond is completely dry now	Weather		n
145	29/06/2018	It hasn't rained properly for about 8 weeks	Weather		n
327	29/06/2018	Water butts almost empty. Collceting water from river.	Weather		n
22	30/06/2018	Just looked around	Relaxation		
427	30/06/2018	Very hot! Hot! Hot!	Weather		n
10	01/07/2018	A thunderstorm. First rain in weeks, hooray!	Weather	Emotion	p
37	01/07/2018	Photograph example - a harvest			
69	02/07/2018	Frog being stalked by a cat! - Cat shooed away and frog escorted to wild area! :)	Wildlife		p
44	03/07/2018	People take water from the butt however they are not filling it up afterwards so I took water from the river.	Organisation		n
169	03/07/2018	Neighbour on allotment did an excellent job looking after my plot. Big thanks.	Social		p
79	04/07/2018	No rain since 30th May - none forecast in next 10 days.	Weather		n
93	04/07/2018	No rain now for many weeks	Weather		n
423	05/07/2018	Please, RAIN!!!	Weather	Emotion	n
313	05/07/2018	The prolonged dry weather is taking its toll but at least there's no sign of slug damage and the grass doesn't need mowing!	Weather		p
102	06/07/2018	Spinach and loads of courgettes which we put outside the house "Help Yourself!"	Surplus		p

427	07/07/2018	We are definitely having a heatwave	Weather		n
169	08/07/2018	Cut a cucumber for a friend on another plot. Drank a bottle of sparkling apple juice and had a laugh with two fellow allotmenteers!	Social	Surplus	p
55	09/07/2018	Many plotholders have run out of water and are having to use the river	Weather		n
55	10/07/2018	Tomatoes doing really well in greenhouse, temperates 110C! [maybe means F]	Pride		p
81	10/07/2018	So very very dry - no rain still, not a lot of pollinators in sight, no bees probably little nectar in such dry weather	Weather	Wildlife	n
246	10/07/2018	Still no rain since the end of May. I have been reduced to watering potatoes, which I seldom do.	Weather		n
349	10/07/2018	NO RAIN! - for over a month. Dry as a bone… peas suffering loosing sweetness	Weather		n
37	10/07/2018	Rumours of an adder spotted on plot! Note 15 July - identified as grass as expected.	Wildlife		p
361	11/07/2018	Judges from City Council and RHS were on site a.m.	Organisation		
319	12/07/2018	Made a fantastic supper with the above [harvest] :)	Emotion		p
374	12/07/2018	Not many weeds and grass not growing - so no mowing needed - RESULT!	Emotion		p
402	12/07/2018	Can't remember what rain feels like	Weather		n
427	13/07/2018	Spoke to chair of Parish Council last night. Contacted my solicitor this am.	Organisation		n

423	13/07/2018	I don't think it will EVER rain again!!	Weather		n
427	14/07/2018	Stand pipe has been resited off my allotment. Pipe still along edge. Unable to cut path edge grass.	Emotion		n
199	14/07/2018	We entered the Village Produce Show with produce grown on our allotment. We won 5 first prizes, 8 second prizes, 5 third prizes. We also won 3 trophies for most points in the horticultural section, most points overall and most points for a Gardening Club ember, along with the RHS Banksian Medal for most points in the Horticultural Section (the second time we have won this - you can only win it every 3 years). It just goes to show that all the hard work of having an allotment certainly pays off.	Pride	Social	p
313	15/07/2018	Both vacant plots have been allocated to young, enthusiastic, energetic families. Here's hoping they make a go of it. Empty plots are depressing.	Social		p
15	15/07/2018	Since last record, we have had no rain and has been v. hot. Have been watering almost every day… Everything tinder dry.	Weather		n
93	15/07/2018	Still no rain for 12 weeks!	Weather		n
259	15/07/2018	Just SO dry	Weather		n
180	16/07/2018	Still no rain!	Weather		n
220	16/07/2018	Pump still broken. NO RAIN.	Weather		n
259	17/07/2018	Still NO rain	Weather		n
386	18/07/2018	Two grandsons did all the harvesting. I just supervised.	Social		

224	18/07/2018	No rain for at least 2 months	Weather		n
112	19/07/2018	had a beer on [friend's] plot	Social		p
280	19/07/2018	The cooler weather is much more comfotable to work in and will be better for the crops I think.	Weather		p
383	20/07/2018	Had time to sit quietly at the allotment. It was then that all the birds appeared. Don't see so many when watering and mowing.	Emotion	Wildlife	p
400	21/07/2018	All the harvested veg are for a weekend lunch party for 12 people	Sharing		p
293	21/07/2018	The council has imposed quite rightly a 'bonfire' ban across the allotment site. The weather being very dry and the temperatures in the high twenties.	Weather		n
145	21/07/2018	RAINED OVER NIGHT :)	Weather		p
89	22/07/2018	Plot vandalised - onion tops chopped off, one sweetcorn plant pulled down. First incident in 20 years. Ten plots vadalised	Organisation		n
313	23/07/2018	Granddaughter (10) was helping so we got lots done in the time!	Social		p
86	23/07/2018	Everything under loads of stress (including me) due to hot weather	Weather	Emotion	n
180	23/07/2018	Still no rain. Soil is now rock hard and some crops have stopped growing e.g. carrots	Weather		n
224	23/07/2018	Plants are dying	Weather		n
311	24/07/2018	Took my 1.5 year old granddaughter to get her used to seeing food growing	Social	Knowledge	p
79	24/07/2018	The need to water constantly feels impossible now. Please let it rain soon.	Weather	Emotion	n

230	25/07/2018	Had a picnic :)	Social		p
37	25/07/2018	Water butts (x5) all now completely dry.	Weather		n
286	25/07/2018	Deer has eaten the lettuces and courgettes! V hot 25C no rain	Wildlife	Weather	n
31	26/07/2018	Granddaughters (7 and 8) helping with watering cans and picking blackberries (ate most of them!!)	Social		p
75	26/07/2018	With other plot holders picked flowers for a local wedding on Saturday	Social		p
313	26/07/2018	[Granddaughter's] last day. I have strict instructions to send photos of the lettuce we planted. Also of the grapes and the sweet corn when they are ripe.	Social		p
46	26/07/2018	It rained! Very hard for a short time but it made weding much easier	Weather		n
283	26/07/2018	Watered first thing (6.50am). Retired inside by 11.00 am. Hoping for cooler weather soon.	Weather		n
423	26/07/2018	Rain is forecast for tomorrow, but we've been disappointed before, so not getting too excited, and have watered regardless! 11 weeks with no rain and hot temperatures	Weather		n
423	27/07/2018	WE HAVE RAIN, LOTS, PLUS THUNDER!! The 3 month drought has broken. I am NOT watering my allotment today!!	Weather		p
388	28/07/2018	Only went for afternoon walk on first day for ages that was cool enough for me not to feel hot, ill and exhausted. All we need now is a share of the rain some people have had.	Health	Weather	p

293	28/07/2018	Didn't do anything on my plot today and it was the clubs AGM and BBQ day. A window day which managed to blow the gazebo into the air and wreck the frame.	Social	Weather	n
427	28/07/2018	Hoping for rain!! Yeeeeees A good heavy shower	Weather		p
349	29/07/2018	Rain, rain, lovely rain!	Emotion	Weather	p
68	30/07/2018	Finally! Proper rain yesterday.	Weather		p
219	30/07/2018	RAINED AT LAST!!	Weather		p
272	30/07/2018	Some rain yesterday - at last! But some areas of soil still bone dry	Weather		p
46	01/08/2018	Apple tree fell over	Weather		n
246	02/08/2018	Going on holiday for a fortnight. Praying for rain while I am away.	Weather		n
310	02/08/2018	Total 10.5mm 26/7 ro 1/8! So dry!	Weather		n
311	04/08/2018	All veg for dinner were from plot. Beans, courgettes and kale :)	Emotion		p
277	04/08/2018	Too dry to dig, ground cracking open due to heat/ no rain.	Weather		n
369	04/08/2018	IT'S RAINING!	Weather	Emotion	p
388	05/08/2018	Too tired. Slept badly too hot. So gave up and went picking. Back by 7.25. going to try to sleep now! 72 years old and hot weather do not go happily together!	Weather	Emotion	n
39	06/08/2018	Laying slabs for disabled access to cabin	Social	health	
389	06/08/2018	The ground is so hard that my neighbour has resorted to using a mattock to dig up his potatoes!	Weather		n
93	07/08/2018	AT LAST RAIN!! All day	Weather		p

39	08/08/2018	Help from grandchildren - good with berries but short concentration span	Social		p
313	09/08/2018	What a satisfying thing the composting business is!	Emotion		p
192	09/08/2018	Educating children of visiting family re allotment culture	Social	Knowledge	p
240	09/08/2018	Little drawing of the frog	Wildlife		p
395	11/08/2018	Still not sure about funny courgettes, if they're squashes or not. Only time will tell.	Knowledge		
10	11/08/2018	Deer broke in again, 2nd line of defence held	Wildlife		n
427	13/08/2018	No need for watering anything WOW	Emotion	Weather	p
347	14/08/2018	Lovely sunset, think it's time to go home	Emotion		p
75	14/08/2018	Dug up some leek seedlings to give to my sister	Social		p
68	15/08/2018	Will I get ANY grapes? Wasps and birds? Does this mean they are ripe? In August? Surely not	Weather		n
76	15/08/2018	Just read a book called "Buzz" about wild bees. I'm probably spotting more bumblebees that I would previously have overlooked.	Wildlife	Knowledge	p
374	16/08/2018	AT LAST - IT RAINED THIS MORNING - A USEFUL AMOUNT	Weather		p
428	17/08/2018	I am growing kale for a friend who eats it every day to keep macular[?] degeneration at bay. It seems to work	Social	Sharing	p

313	18/08/2018	A friend from the opposite plot is watering while I'm away (reciprocal arrangements)	Social		p
388	19/08/2018	Today the council provided a BBQ for the tennants. It is an annual event.	Social	Organisation	p
46	19/08/2018	WE NEED RAIN!	Weather	Emotion	n
311	20/08/2018	Overheard "argument" about boundaries on adjacent plots. 2 men who should know better! Upset the calmness of my visit!!	Emotion		n
249	20/08/2018	Enjoyed a chat with 2 allotment acquaintances - one of the bonuses of allotmnet life!	Social		p
44	20/08/2018	Buzzard on its own being chased by seagulls	Wildlife		p
169	22/08/2018	Given lots of our harvest to neighbours	Surplus		p
164	22/08/2018	Plot looking very very sad. Worst yield of most of our crops in the past 8 years!	Weather	Emotion	n
427	24/08/2018	Letter sent out from solicitor re removal of pipe	Organisation		n
434	24/08/2018	We were informed that we had won the prize for 'Best Newcomers' covering all 4 allotments within Wokington Town Council area (cup and £25 garden voucher)	Pride		p
344	24/08/2018	Also doing some work for neighbouring plot holder who has had heart attack. Dug and cleared a raised bed.	Social		p
271	25/08/2018	Met our new Artist in Residence at the plot, which she is using as a base for her	Sharing	Social	p

		year's residency. Gave her a pile of produce to take home.			
50	25/08/2018	Not anoter sole in sight. More tomatoes and beans than I can cook or give away.	Sharing	Surplus	p
79	25/08/2018	NB Good theory as to why we have so many seagulls in [this area] suddenly: repairs to [local] reservoirs mean they've been drained. Lots to take to our daughter's [house] tomorrow.	Wildlife	Surplus	p
272	26/08/2018	First day of decen rain for months	Weather		p
293	27/08/2018	The council continue to "badger" plot holders for no apparent reason. They have "stripped" many plots of fruit trees and bushes where people have given up their plots and this in turn has caused many bitter plot holders to leave because of the ruthless actions of the council	Organisation	Emotion	n
240	27/08/2018	Picked beans, corn, appled, beetroot. Will take this to my sister.	Sharing	Surplus	p
402	27/08/2018	Hops harvest 4 kilos from 2 plants. We are members of Farnham hoppers and get beer in return for hops. Lovely big flowers best yet	Social		p
54	28/08/2018	Didn't pick veg because too much waiting in the kitchen to be eaten already!	Surplus		p
374	30/08/2018	Really glorious day - feels like the 1st touch of autmn	Emotion		p
427	01/09/2018	Pipe removed yesterday. Splitter forced open and water gushing. Repair did not work. Water turned off.	Organisation		n
89	02/09/2018	Allotment show. Won first prize with my sweetcorn.	Social	Pride	p

404	02/09/2018	Our summer BBQ! Lots of activity. 80 people!	Social		p
249	04/09/2018	I love my allotment! And just now I'm getting on top of things…	Emotion		p
39	04/09/2018	Long discussion with fellow tenant illegally keeping bees after letter from council	Social		n
37	04/09/2018	"Grumpy cat"!	Wildlife		p
127	05/09/2018	Spoke to new allotmenteer. Offered him spinach seedlings he was pleased and said he'd dig some for himself	Social	Sharing	p
240	05/09/2018	Sept, and its still lovely and warm. Spent time sitting by the frog pond with [friend] talking.	Weather	Social	p
31	05/09/2018	Bitten by venomous spider! Serious swelling of Right Hand overnight. Trip to A & E. Horse-strength antibiotics for a week. Bloomin' painful too :(	Wildlife	Emotion	n
193	06/09/2018	Went to the Museum of Garden History in London, sadly rather disappointing	Emotion		n
402	06/09/2018	We have won best plot on west stre*et al*lotments	Pride		p
280	06/09/2018	There are signs of hedgehog activity - 'poo' :)	Wildlife		p
388	08/09/2018	Planted courgettes that arrived through the post while I was away! Husband left them in a box in kitchen for 48 hours because he didn't know what to do with them!! Must have had his hearing aid switched off when I told him to pass them next door to my friend who would look after	Emotion		n

		them i.e. open box and put them in a little water!			
319	08/09/2018	Autumn show 4 bunches herbs - 3rd, carrot - 2nd, sweetcorn - 1st place, melon - 1st place, sugar snap peas - 3rd. Proud day :)	Pride	Organisation	p
219	08/09/2018	Socialised. 1st prize for flowers…	Social		p
388	10/09/2018	Some of the time was spent cleaning the eco-toilet - remind me to stop volunteering for things!!	Organisation		
345	11/09/2018	Just walked there and back as pat of getting back to fitness! No work	health		p
75	14/09/2018	Together with other members of the Allotments committee, gathered produce for a display at the Village Show held tomorrow.	Organisation		
311	14/09/2018	Picked the veg for a meal with friends today. Tasted lovely :)	Social		p
249	16/09/2018	Sadly on 19/9/18 I had a stroke and spent 6 weeks in hospital. 1 April 19 now and I have had to abandon my plot.	health		n
240	16/09/2018	Today we had an apple pressing day. 3 presses were set up and people collected apples in wheelbarrows and brought them to the press. A lovely social afernoon. Soeme people on chopping apples, some on the crusher and some on the press. All the cores and anything not for the press were taken to the composts. We then had a bar-b-q and cake to finish off the day.	Social	Organisation	

191	17/09/2018	Every Japanese person living locally has tried to grow edamame - and failed! So my daughter in law is very impressed!	Social	Pride	p
288	19/09/2018	The "April" cabbage seed I planted are ready to move on. I will have far more than I need so will share!	Sharing	Surplus	p
427	20/09/2018	Very dry. Splitter system out today. Hooray!!	Emotion		p
37	21/09/2018	Photograph example - pumpkins etc harvested			
145	25/09/2018	Got given apples :) For compost and eating	Surplus		p
193	26/09/2018	Socialising is quite an important part of life on the allotment - contributes to well-being!	Social		p
229	28/09/2018	3 hour thunderstorms last two nights. 1st rain for 8 weeks	Weather		p
193	02/10/2018	Had to eat a picnic lunch in the shed as new floor being put down at home and I wasn't allowed in!	Relaxation		
353	04/10/2018	1x small melon fell off. The only melon.	Emotion		n
263	09/10/2018	A neighbouring allotmenteer gave us a dried loofah gourd	Sharing		p
93	12/10/2018	Allotment Bench STOLEN!!	Emotion		n
293	13/10/2018	It was a bit of an odd day today. Most of it was spent scavenging from another allotment further down the track. One of the allotmenteers has literally walked away from his allotment because of the council's attitude towards the allotmenteers. He has told others to help themlseves to whatever they want, and	Organisation	Emotion	n

		that was what I was doing for most of the day at various times.			
272	13/10/2018	Warmest October day 24C. Tenants of adjacent allotment have given it up and left it in a poor state. Started some clearing before re letting.	Weather		n
311	14/10/2018	Gave my neighbour some roofin felt for his shed. He will repair wood on my shed in return for felt.:)	Social	Sharing	p
22	14/10/2018	B****** squirrel. It had all my cobnuts & 80% of my apples.	Wildlife	Emotion	n
288	17/10/2018	Peregrine falcon flew over! BRILL	Wildlife		p
204	20/10/2018	Brambles prickles hurt hands	health		n
193	20/10/2018	The secretary of the site asked me to take a prospective family around my allotment as a demonstration!	Organisation	Pride	p
293	21/10/2018	in hospital for 14 weeks with prostrate cancer. He came to the plot today for fresh air and to see how he could cope. He acknowledged he has a few months to go before even thinking of being active again.	Health		n
311	22/10/2018	My neighbour has repared and strengthened my shed and printed it! What a man!	Sharing	Social	p
437	23/10/2018	Mostly chatting. Been unwell and no one has seen me! Had to ask neighbour to drop stuff off for me as I couldn't carry it all!	Social	Surplus	p
246	27/10/2018	Rain stopped play, also I was knackered anyway.	Weather		n

127	28/10/2018	Spent the morning 11am-1300 at my old allotment site encouraging them to vote	Social	Organisation	p
112	28/10/2018	Sat in warm greenhouse talking to friend Jackie	Social		p
281	30/10/2018	Got apples from John Campbell made 2 gallons cider	Social	Sharing	
20	02/11/2018	Allotment looking good some panes in greenhouse need reinforcing inside after storm damange.	Pride	Weather	p
388	04/11/2018	Village bonfire party!! Hundred of people. But alothough it looked clean the gulls were finding plenty to eat!	Social		p
388	05/11/2018	Can't do more than 2 hours digging even though I have many stops for hot chocolate - I have a big flask! Takes a little more than 1 pint - delicious	Emotion		p
311	05/11/2018	Neighbour gave me some chrysanths to bring home to put in vase. Lovely weather, bright usn with no wind. Perfect allotment day!	Social	Sharing	p
22	08/11/2018	9 flocks of paraqueets ~ 160 birds	Wildlife		p
172	09/11/2018	Don't plan to come back for a while - our baby is long overdue!	Social		
39	10/11/2018	2 piles of weeds "donated" to a neigboour for his chickens	Sharing		p
423	10/11/2018	Dear rat found in green manure!! Given a burial under peach tree. Found dead rat last year in green manure. Maybe they like to hide in the vegetation when they feel poorly.	Wildlife		p
388	12/11/2018	Only really went for the walk today	Health		p

347	12/11/2018	Spent too much time talking and not enough gardening! Must try harder tomorrow	Social	p
310	18/11/2018	A lovely morning: just right to be down on the allotments!	Emotion	p
9	18/11/2018	Two of the red kites were fighting!	Wildlife	p
126	26/11/2018	I am losing half of my allotment next year. I am taking home any plants from this half that I want to keep and replant them	Emotion	n
355	08/12/2018	The brussel sprouts are not going to be ready for Christmas!	Emotion	n
219	15/12/2018	Slow due to broken toe	health	n
79	18/12/2018	Went over just before 9 as rain forecast and surprised 2 foxes on the main paht, both ran but 1 vanished and the other turned after a short distance to return and kept watching me from a distance - very [coy?] as jumped when a crow croaked but stared after me as I left very interestedly.	Wildlife	p
313	19/12/2018	I had an operation on my shoulder 8/11 and a strong 13/11. This is the first time I'm been able to drive to the plot and work for a while. And very good it felt!	Emotion	p
160	23/12/2018	Went with police to ceck for damage after night of vandalism - my plot OK but many others not	Emotion	n
55	25/12/2018	Bump into another plotholder also gathering veg for Christmas Dinner!	Social	p

313	27/12/2018	Saw another plot holder and had a chat. They've been very supportive and kind during my period of illness.	Social		p
240	27/12/2018	My freezer is full. I've had a good year on the allotment. The food will last until the next year's crop is in.	Surplus		p
112	31/12/2018	Read back the year's diary. Sat + reflected upon the year. The plot is my safe place. It’s my mental health balancer. Peaceful, but sociable, accepting, a place to connect, to disconnect. A place to grow, to write, to accept that things die and turn to compost. To be me without being judged. To eat and share food, drink + friendship. Not tidy or regimented, it changes + develops. It flowers and envelopes blossoms and blooms or freezes and browns. The bird song at all times, the outside industrial noises of the docks, roads, next door's motorbike, generator, chainsaw, rotavator, strimmer, friends, but mostly... it's mine. It's my little piece of earth, the planet. I aim for no chemicals, using rainwater, last year's seeds, cuttings, pots donated, second hand stuff made into plant containers. A calm place to listen, to cry, to eat, to welcome friends, to walk around + know deep in my heart here, I feel connected, balanced (despite the wobbly deckchair) and recharged. I'm drawn here in the winter to the stark, bareness of it all. Stripped back to the structure, paths + beds defined, perennials on show, spring bulbs daring to peek out... It's time for soup. Thank you for this	Social	Health	p

		diary. It helps me to write so some days you've helped my mental health.			
145	01/01/2019	Don't have car so moved my post stakes to allotment shed (took 3 journeys) in my shopping trolley. Beautiful day :)	Weather		p
224	02/01/2019	Cat nearly got planted	Wildlife		p
388	06/01/2019	Getting back into the swing of things. Can't go again for a couple of days possibly. Today's session was punctuated by stops for refreshments and a memorable 1/4 hour helping a dog walker catch her dog that had run off with a dead bird she found under a tree! Useless info but may raise a smile!!	Social		p
353	16/01/2019	Greenhouse - seedlings I grew in october have stayed v small so removed them and I'm disillusioned about winter crops.	Emotion		n
169	19/01/2019	Note. Don't let my husband use that stepstool again. He fell off face first into wood chippings on ground	Social		n
347	27/01/2019	5C, hail, blowing a gale and cloudy. Us allotmenteers are a tough bunch.	Weather	Emotion	n
423	01/02/2019	Come to the end of a year of allotment-growing. A challenging year, and still have cabbages, leeks and sprouts to harvest, and a freezer full of fruit and veg, which is what its all about!	Pride		p
388	23/02/2019	3 new cloches arrived at home. Sadly self-assembly. Impossible for one to do so ended up with 3 of us with lots of complaining. Took 1 1/2 hours!!!	Social		p

437	24/02/2019	Netted gooseberries. Scratched to bits. How stupid am i? In short sleeves and shorts. Very mild.	Weather	health	n
349	25/02/2019	Note to self - do not put sheds up in snow storms	Weather	Emotion	n
193	NA	In these uncertain times the more we can grow ourselves the better!... I enjoyed participating enormously	Emotion		p
22	NA	Thanks for the opportunity in showing me how long I spend on the plot.	emotion		p

Supplementary Information: Chapter 6

1. Questionnaire

Please see Supplementary Information 3 for Chapter 3.

2. Test results (Kruskal – Wallis)

Feature	**Chi-Sq**	**D.F.**	***p***
Greenhouse	130.38	116	0.1708
Shed	119.57	116	0.3913
Polytunnel	114.14	116	0.5313
Pond	114.56	116	0.5204
Compost	128.76	116	0.5204
Weeds / wild	110.01	116	0.6392
Grass	109.81	116	0.6442
Ornamental	124.54	116	0.2773
Water storage	111.34	116	0.605
Livestock	105.4	116	0.7499

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Urban food cultivation in the United Kingdom: Quantifying loss of allotment land and identifying potential for restoration

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ABSTRACT

Urban agriculture contributes to food security and human wellbeing and is associated with a wide range of environmental benefits. In the United Kingdom, a substantial proportion of urban agriculture occurs in allotment gardens, and these are a historically significant part of the landscape. However, allotment land provision has declined significantly since its mid-twentieth century peak. Here, we examine the magnitude and nature of this decline using a GIS analysis of historic Ordnance Survey maps covering ten British urban areas from the beginning of the twentieth century to the present. We find there has been a 65% decline in allotment land from its peak to 2016, a pattern also reflected in per capita provision, which declined by 62%, demonstrating a long-term trend across the case study areas, and the loss of food provisioning land for an average of 6% of the urban population. We also show that the most at-risk areas for food insecurity have faced eight times the level of allotment closures than the least deprived areas. Assessing subsequent land-use of former allotments, we show that 47% of allotment land is now part of the urban built infrastructure, and 25% is other forms of urban greenspace. Restoration of these greenspace sites to allotments has the potential to meet up to 100% of the current levels of demand for new allotments by residents of our case study areas. Our results demonstrate that whilst a significant amount of urban agricultural land has been lost, opportunities for restoration exist on a substantial scale.

1. Introduction

The global urban population has increased significantly in past decades and forecasts predict this trend will continue. According to the United Nations, by 2050 68% of the global population will be urban residents, a figure rising to 90% in the United Kingdom (United Nations, 2019). Impacts of urbanisation on food systems, and food security, can occur at local, national and international levels. Urban areas, which are forecast to increase in global land cover by 1.2 million km^2 by 2030 compared to the turn of the century (Seto, Guneralp, & Hutyra, 2012), often expand into agricultural land (Martin, Clift, & Christie, 2016), itself a limited resource facing increasing problems of soil degradation (Graves et al., 2015; Lal, 2015). The density of urban populations also means that the agricultural land requirements of cities are vastly greater than their areal extent (Eigenbrod & Gruda, 2015). This creates an inherent reliance on food imports for urban populations, with associated risks for food security. This is a growing issue of concern in the global North where, for example, undernourishment affects 2.5% of the British population, and 11.1% of American households experienced food insecurity at some point during 2018 (Food and Agriculture Organisation, 2017; Coleman-Jensen, Rabbitt, Gregory, & Singh, 2019).

Against this background, researchers and policymakers have shown a renewed interest in the potential contribution to food supply which can be made by food grown in urban areas, or urban agriculture (Grewal & Grewal, 2012; Taylor & Lovell, 2012; Horst, Mcclintock, & Hoey, 2017; Edmondson et al., 2019). It is estimated that 25–30% of urban residents participate in urban agriculture to some degree (Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013), although this varies in form and prevalence across the world. Urban agriculture is practiced not only for food security, but also for leisure, wellbeing and mental health (Blair, Giesecke, & Sherman, 1991; Andersson, Barthel, & Ahrné, 2007). A growing body of research supports this, demonstrating that urban agriculture can provide multiple benefits which go beyond food provision. These include providing cultural ecosystem services (Webber, Hinds, & Camic, 2015; Robert & Yengué, 2017; Langemeyer, Camps-Calvet, Calvet-Mir, Barthel, & Gómez-Baggethun, 2018) and benefits to human health through supporting exercise and healthy diets (Altieri et al., 1999; Leake, Adam-Bradford, & Rigby, 2009; Zezza & Tasciotti, 2010; McClintock, Cooper, & Khandeshi, 2013). Further to this, urban agriculture can also help to enhance biodiversity (Lin, Philpott, & Jha, 2015; Speak, Mizgajski, & Borysiak, 2015; Aerts, Dewaelheyns, & Achten, 2016; Borysiak, Mizgajski, & Speak, 2017); increase food system resilience to international economic or climatic shocks (Goldstein, Hauschild, Fernández, & Birkved, 2016; Seguí, Mackiewicz, & Rosol, 2017); reduce food miles and waste (Howe &

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Wheeler, 1999; Lovell, 2010); support plant genetic diversity (Barthel, Folke, & Colding, 2010; Eigenbrod & Gruda, 2015); mitigate urban heat island effects (Oberndorfer et al., 2007; Lovell, 2010; Lin et al., 2015); regulate stormwater runoff (Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2013; Lin et al., 2015; Goldstein et al., 2016); and maintain soil carbon stocks and other aspects of soil quality (Edmondson, Davies, Gaston, & Leake, 2014; Lorenz, 2015). In the global South, urban agriculture traditionally contributes primarily to food security and poverty alleviation (Zezza & Tasciotti, 2010). In the global North, whilst motivations for participation are more likely to be recreational (Mok et al., 2014), urban agricultural participation and access to food growing space has been shown to have important potential for the alleviation not only of food insecurity in low income communities but empowerment, education and improvement in quality of life (Traveline & Hunold, 2010; Milbourne, 2012; Carney et al., 2012; Poulsen et al., 2014; Horst et al., 2017).

In the global North, urban food production is practiced in a variety of forms, predominantly focusing on fruit and vegetable production (Orsini et al., 2013). For example: allotments (see below; Crouch & Ward, 1997; Acton, 2011; Edmondson et al., 2014); private domestic gardens (Foster, Bennett, & Sparks, 2017); community gardens (Kulak, Graves, & Chatterton, 2013; Martin et al., 2016); and commercial market gardens (Kulak et al., 2013; Schmutz, Kneafsey, Sarrouy Kay, Doernberg, & Zasada, 2018).

Allotment sites are 'small parcels of rented land, in rural and urban locations, used for growing fruits and vegetables for personal consumption' (Acton, 2015). Allotments form a large proportion of the area of urban agricultural land across Europe (Speak et al., 2015) and their use varies, but in the United Kingdom they are almost wholly dedicated to food production, with plot tenancy dependent on maintaining a minimum cultivation level, typically between two-thirds and three-quarters of the area of the plot. An individual allotment garden is a plot of land, generally around 250 m^2, rented from a local council in a larger allotment site comprising anything from fewer than ten to over two hundred individual plots. There are around 333,000 allotment plots in the United Kingdom (Campbell & Campbell, 2013) covering 135 km^2 of land. As demand for allotments fluctuated throughout the twentieth century, many sites were closed, particularly in the decades following the Second World War, and, nationally, levels of provision fell from an estimated 1,400,000 plots during the war to 300,000 in 2009 (Crouch & Ward, 1997; Acton, 2015). However, whilst general estimates can be made of the overall national trend across this period, the available data are limited, both temporally and spatially, and as a result we have little understanding of precisely when and where these closures occurred, or the subsequent fate of the land.

There have been multiple drivers for allotment closures over the twentieth century, including post-war prosperity and the rise of convenience food leading to a decrease in demand for food growing areas; and pressures from urban development taking precedence over allotments in land use allocation (Acton, 2011). Whilst some closures have been generally accepted by tenants and local residents, others have been contested. Recent examples in Bristol (Morris, 2015) and Watford (Siddique & Topping, 2016) demonstrate a tension that exists between the legal obligation of councils to provide allotments sufficient to meet demand and planners' needs to prioritise or consider other forms of urban infrastructure. Over the past twenty years, a cultural revival in interest in "grow your own" food practices, has led to an increase in demand for allotments. For example, in England demand has risen from fewer than ten people waiting per one hundred plots in 1996, to more than fifty per one hundred plots in 2013 (Campbell & Campbell, 2013).

The consequences of loss of allotments for the full range of ecosystem service provision depends not just on the extent of allotment loss, but also on what happens to the land afterwards. This may also be an important determinant of the scope to reinstate allotment provision, in response to new demand, in the future, as well as contributing to addressing food insecurity in cities through the provision of growing space. Understanding the extent of allotment closures over the course of the twentieth century, and the subsequent fate of allotment sites, would help us understand both historic changes in urban food production and other ecosystem services, and help to inform future decisions about allotment provision where demand necessitates their expansion. Here, we use historic maps to quantify the change in allotment provision, in relation to population, for ten cities across the United Kingdom over periods of between 50 and 100 years. We analyse change in allotment provision over time, identify what former allotment sites have now become, identify the potential for former sites to be re-converted to allotment usage to help meet waiting list demand, and examine the potential impact of closures on food security, discussing how this has affected the food provision capacity of the most food insecure urban areas.

2. Methods

2.1. Case study areas

We selected ten case study urban areas, geographically distributed across mainland Great Britain: Bristol, Glasgow, Leicester, Liverpool, Milton Keynes, Newcastle, Nottingham, Sheffield, Southampton and Swansea. These cover a range of population sizes and densities, demographics, and land-use histories (Fig. 1; Table 1). With one exception all are major British cities, which have been substantial urban settlements with significant industrial or maritime activity for at least the last 150–200 years. Milton Keynes is the exception, being a new town created in a previously non-urban location in 1967. We analysed all case study areas according to their 2016 administrative boundaries to ensure a consistent geographical area of investigation across the time period studied. Population data were taken from the 2011 census, the closest census year to that for which the boundary data could be obtained.

2.2. Historic and present-day mapping of allotment provision

The Ordnance Survey (OS) is the United Kingdom's national mapping agency, and has been surveying and producing printed maps of the entire country, at a range of scales, since 1791, with complete coverage first completed in 1870 (Owen & Pilbeam, 1992). For urban areas OS mapping is available at larger scales, with delineation of buildings, and distinctions made among a range of land covers. For each urban area, we obtained digital scans of historic Ordnance Survey maps from EDINA Digimap (http://digimap.edina.ac.uk) in the form of georeferenced raster "tiles" (see Supplementary Material for a full reference list of maps used in this paper). For the identification of allotments, a scale of 1:10,000 or 1:10,560 such as the National Grid or County Series mapping produced by OS is fine scale enough for areas of allotment land to be delineated on the map tiles. The time periods for which maps were available at this resolution varied between case study areas, but for all areas we were able to generate data for at least three, and up to seven, different time points, hereafter referred to by the decade during which the maps used were published for all historic maps, and by 2016 for the present-day map (Table 1). The present-day map used was the OS "VectorMap" layer of October 2016.

Allotment areas were digitised as polygons for each land parcel labelled as "Allotment Gardens" or "Allot. Gdns" on the original maps. Despite stylistic changes in mapping over the twentieth century, labelling of allotments remained consistent enabling unambiguous identification of allotments for all decades studied. Where uncertainty arose, the previous decade's and next decade's maps were checked to ensure consistency throughout a time period, ensuring no allotments "disappeared" for a decade only to reappear ten years later; if this was the case, continuous existence of the site was assumed. For the present day, the OS mapping was validated by cross-checking the GIS polygon data with aerial images and information provided online by local

Fig. 1. Locations of case study areas within the United Kingdom. From North to South: Glasgow, Newcastle, Liverpool, Sheffield, Leicester, Nottingham, Milton Keynes, Swansea, Bristol and Southampton.

councils. To account for population variation, both over time and between cities, the absolute change in total allotment area over time was converted to change in per capita provision over time using census data for the nearest decade to when mapping occurred (the British population census occurs decennially).

The typical allotment was originally designed as such to be large enough to feed a family of four on fruit and vegetables for a year (National Society of Allotment and Leisure Gardeners Ltd., 2012). Recent research in Leicester, one of our case study cities, found that the actual current productive capacity of an allotment is around 1.8 kg m^{-2} $year^{-2}$, or a "five-a-day" provision of fruit and vegetables for about four people (Edmondson, Childs, et al., 2020). We used these figures, along with the typical allotment plot size of 250 m^2 with 18% of total site area used for infrastructure rather than food production (Edmondson, Childs, et al., 2020), to calculate how the productive capacity of allotments have changed, and the change in the number of people that could be fed with current provision levels compared to those of the decade of peak provision.

2.3. Land use change and waiting list demand

For a subset of five case study cities (Bristol, Glasgow, Leicester, Newcastle and Southampton; which maintained our geographic range throughout the country), the digitised layer of polygons for all allotment sites that had been closed at some point throughout the twentieth century was overlaid on the Ordnance Survey VectorMap (2016) backdrop mapping. Sites were then characterised according to their present-day land use as greenspace or built environment, and greenspace areas were further categorised to type (park, nature reserve, cemetery, scrub, etc.) using Google Earth to ensure accuracy of this fine detail categorisation. Where a former allotment site had multiple present-day uses, polygons were split to reflect this.

In order to calculate the potential of former allotment land to meet current waiting list demand, waiting list data was obtained from Campbell and Campbell (2011) for four of the five case study areas: Bristol, Leicester, Newcastle, and Southampton (with waiting list data for Glasgow unavailable). We followed an approach developed by Grafius, Hall, McHugh, and Edmondson (2019), originally for the identification of potential biofuel production sites, which has been adapted by Edmondson, Cunningham, et al. (2020) for use in urban agriculture. This applies a spatial restriction criteria to land parcels to identify their suitability for a purpose and excludes, for example, Sites of Special Scientific Interest, nature reserves, buildings, ancient woodlands, sites inaccessible by vehicle, and playing fields or sports grounds (see Supplementary Material). We then applied a further allotment-specific spatial restriction: the site had to be large enough to have four full-size allotments plus infrastructure. Anything below this was deemed too small to be considered a viable site. The potential number of plots was then expressed as a percentage of the total numbers on the waiting list to analyse the extent to which demand could be met by the reconversion of former allotment land which met the criteria above. We used the above data on allotment productivity to calculate the number of people that could be fed through land reconversion.

Table 1
Case study areas listed in declining order of population size according to 2011 United Kingdom census data, as well as administrative area in hectares (Office for National Statistics; National Records of Scotland, 2016), and availability of Ordnance Survey historic maps.

Case study area	2011 UK census population	Administrative area (hectares)	Decades for which mapping was available
Glasgow	593,245	20,956	1940, 1950, 1960, 1970, 1980, 2016
Sheffield	552,698	36,793	1910, 1930, 1940, 1950, 1980, 2016
Liverpool	466,415	13,353	1930, 1950, 1960, 1970, 2016
Bristol	428,234	11,223	1920, 1940, 1950, 1970, 1980, 2016
Leicester	329,839	7331	1910, 1940, 1950, 1960, 1970, 1980, 2016
Nottingham	305,680	7461	1910, 1940, 1950, 1960, 1970, 2016
Newcastle	280,177	11,510	1920, 1940, 1950, 1960, 1970, 1980, 2016
Milton Keynes	248,821	30,863	1950, 1980, 2016
Swansea	239,023	42,120	1960, 1970, 1980, 2016
Southampton	236,882	5639	1930, 1960, 1970, 1990, 2016

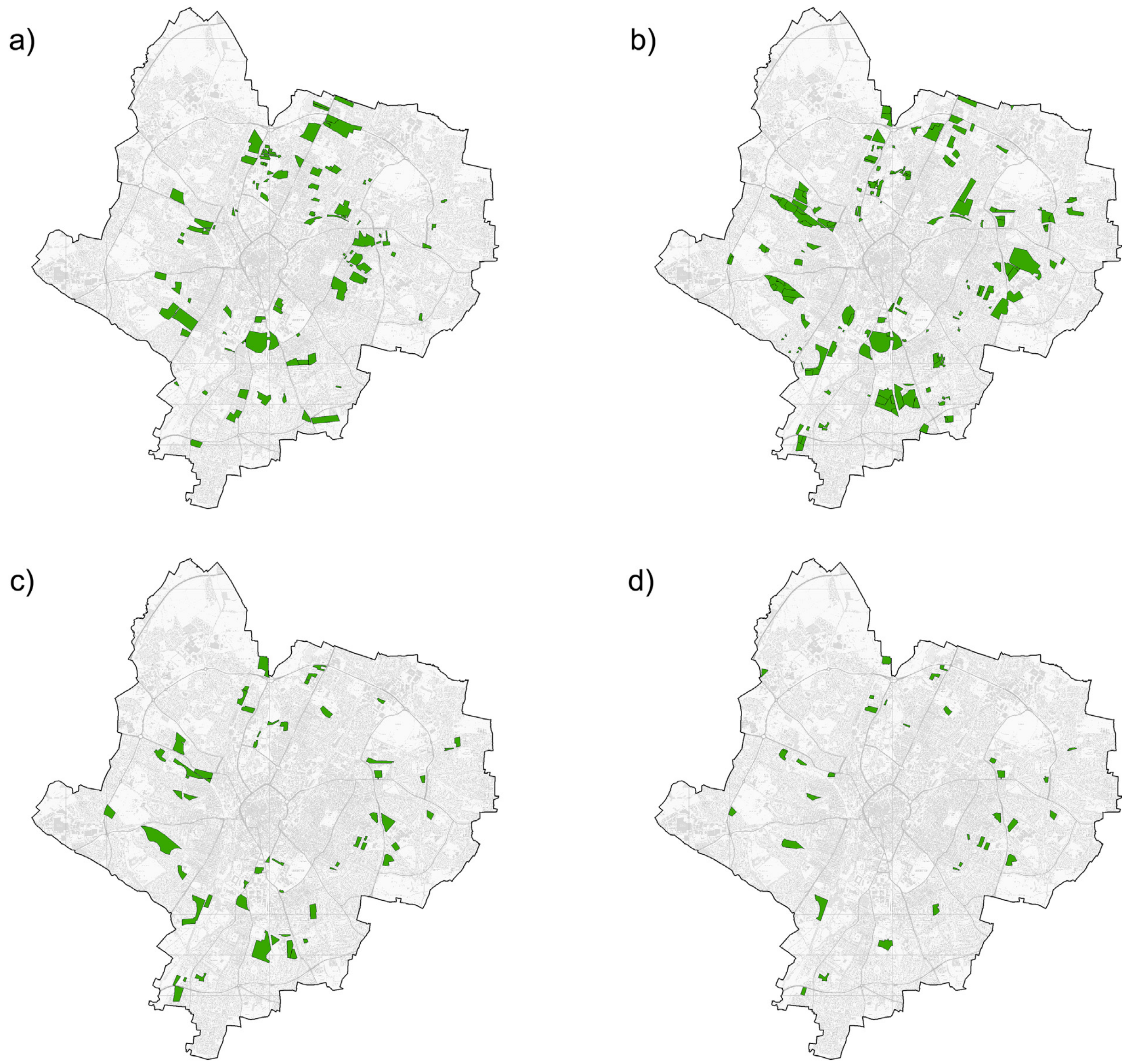

Fig. 2. Change in allotment land provision in Leicester, United Kingdom, over the twentieth century: a) 1910, b) 1950, c) 1970, d) 2016.

2.4. Socio-demographic correlates of allotment site closures

The English and Scottish Indices of Multiple Deprivation (IMD) measure relative deprivation for small areas of the United Kingdom, known as Lower Level Super Output Areas (LLSOA), with a mean population of 1500 people per area. We used this data to determine the current deprivation levels of areas in which allotment sites had been closed for our subset of five case study cities to quantify how much allotment land had been closed in each IMD decile, on a scale of 1 being the most deprived areas to 10 being the least deprived. Deprivation patterns within British cities have stayed relatively static over time (Rae, Hamilton, Crisp, & Powell, 2016), so we made the assumption that, in the majority of cases, a historic allotment closure in a current deprivation category would also have been in a similarly deprived area at the time it took place. Where a land parcel overlapped a LLSOA border, we used the IMD decile in which most of the land parcel lay. Smith, Thompson, Harland, Parker, and Shelton (2018) found a strong positive correlation between IMD level and risk of food insecurity, suggesting that the IMD can provide a good index of potential food insecurity, allowing us to test whether changes in access to food growing space as a result of allotment land closures impacts disproportionately on the most food insecure communities in our case study cities. We combined this data with the spatial restriction criteria outlined above to show which IMD categories would benefit most from a conversion of former allotment land back to allotments.

3. Results

3.1. Change in allotment provision over time

The spatial distribution, area, and changes through time in allotment provision are illustrated for a single urban area, Leicester, in Fig. 2. Patterns for other locations are broadly similar. Absolute allotment land provision varied between our case study sites, as would be expected from the variation in size of the urban areas themselves, but there are also marked differences in per capita provision suggesting that variation does not simply reflect population size (Fig. 3). The main trend through time is a major decline since peak allotment provision in the 1950s (Figs. 2 and 3; see also Supplementary Material Figs. 1–9). This trend was found in all areas studied: whilst the decade of absolute peak provision and peak provision per capita varied somewhat, each case study area had reached its peak provision on both counts by 1960. For every city both absolute and per capita provision in 2016 was lower than that for the preceding date with available data. This is also

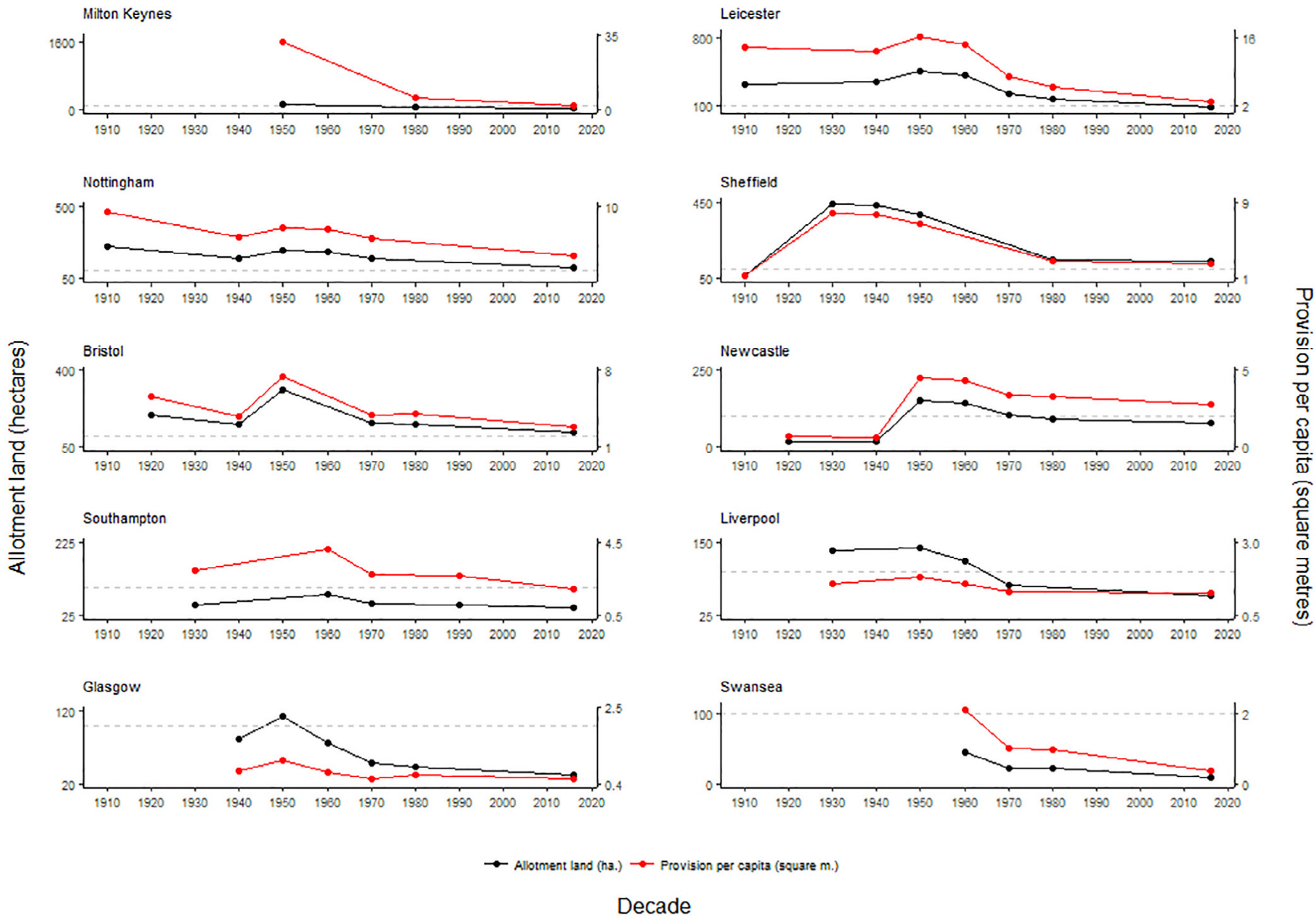

Fig. 3. Plots showing the trend in allotment land provision for ten urban areas in the United Kingdom, both in absolute provision per hectares, and in per capita provision accounting for population change over the twentieth century. Urban areas are arranged in declining order of peak total provision. Provision in hectares is shown in black, and provision per capita in red. The grey, dashed line indicates 100 ha and 2 m^2 per capita to allow comparison between plots, as the scale of allotment provision varies between urban areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

reflected in the net change on a decade-to-decade basis (see Supplementary Material Fig. 10), which demonstrates the greatest loss of allotment land between the 1950s and 1970s, followed by a more gradual decline to the end of the twentieth century.

Over the twentieth century, the mean decline in allotment land area experienced from peak provision to the present day was 65% (s.e. = 4%) and the mean decline experienced in provision per capita was 62% (s.e. = 7%). This demonstrates a comparable percentage decline between locations despite variation in absolute levels of decline expressed in terms of hectares lost. For every city except Newcastle and Sheffield, allotment provision per capita in the present day is less than it was in the first decade for which historic maps were available (Newcastle had particularly low provision prior to the 1950s, where in one decade provision increased from 0.6 m^2 per capita to 4.5 m^2 per capita, and Sheffield had low levels of provision at 1.3 m^2 per capita in the 1910s which had dramatically increased to 7.9 m^2 per capita in the 1930s). In the case of Milton Keynes, the high levels of provision per capita in the 1950s is due to low population prior to the creation of the town, and the existence of large rural allotment sites which subsequently became urban sites within Milton Keynes when the population density rose dramatically following the town's creation (Fig. 3; see Supplementary Material for the complete list of decade-by-decade area changes for each city).

Changes from the decade of peak provision to current levels have impacted on the number of people citywide able to be fed from a city's allotment land. Using population levels from the most recent UK census (2011, see Table 1), loss of food provision ranged from provision for 0.7% of the population of Swansea to 13.8% of the population of Leicester, with the mean loss at 4.7% (s.e. = 1.1). Regarding total loss of yields, this ranged from 241 tonnes of food production per year in Swansea (1.28 kg per person on 2011 population levels) to 6700 tonnes per year in Leicester (25.9 kg per person), with a mean of 2500 tonnes (s.e. = 628).

3.2. Land use change

For our subset of five case study cities, by 2016 of all areas that were recorded as allotments in the historic data, just 26.7% (s.e. = 12.6%) was still allotment land, while 47.9% (s.e. = 14.2%) had become built infrastructure and 25.3% (s.e. = 6.7%) was other types of greenspace (Figs. 4 and 5). Of the former allotment land that remained as greenspace, 75.7% (s.e. = 18%) was suitable for reconversion to agricultural cultivation based on our spatial restriction criteria, with a range from 57.2% in Bristol to 100% in Southampton (Fig. 6).

This represents a substantial increase in the potential number of city residents able to be fed by a reconversion of former allotment land to agriculture. With every plot providing for four people, as detailed above, an extra 14,107 people (3.27% of the 2011 population) per year could be fed in Bristol; 4521 (0.76%) in Glasgow; 14,462 (4.38%) in Leicester; 4260 (1.52%) in Newcastle; and 3037 (1.28%) in Southampton.

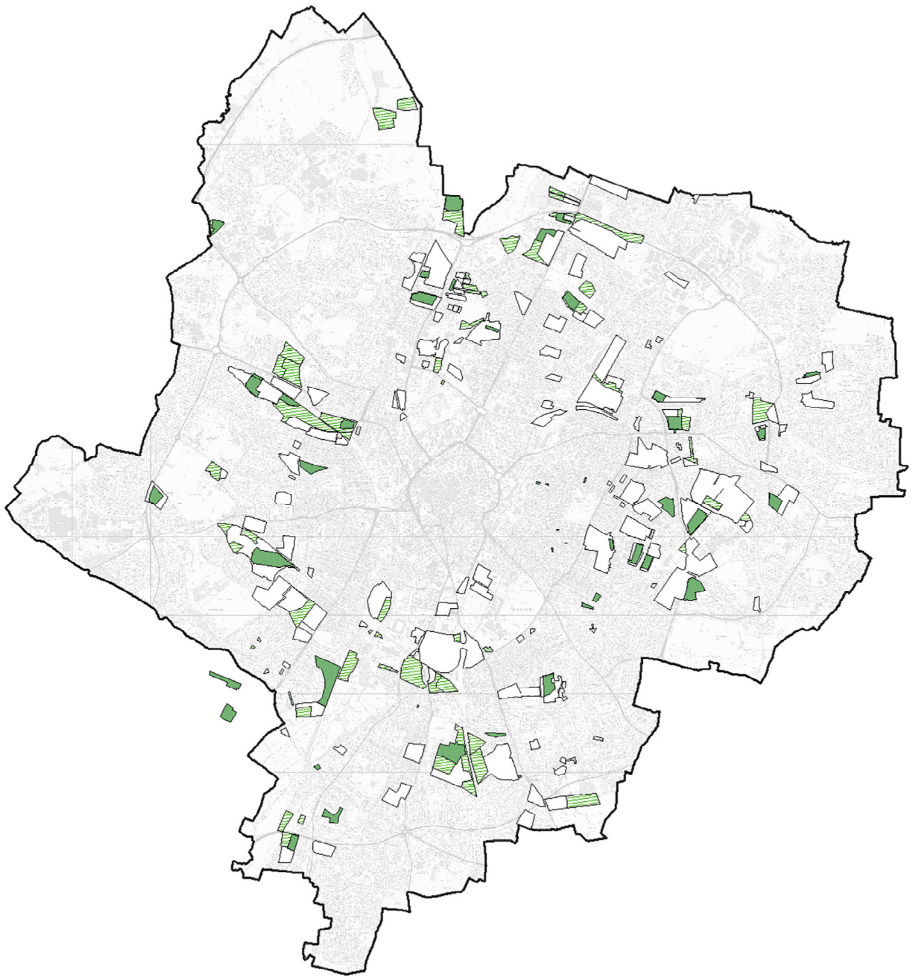

Fig. 4. Current (2016) land uses of sites in Leicester which were allotments during the twentieth century. Solid fill indicates allotments, hollow is built infrastructure, and hatched is greenspace.

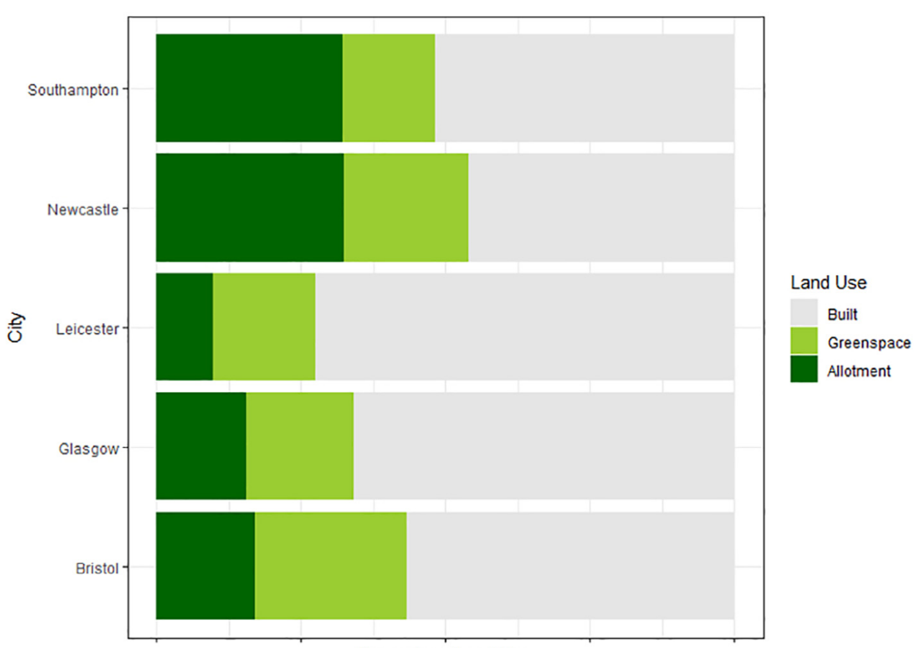

Fig. 5. Proportional land-use change of different types in twentieth-century allotment sites for five urban areas in the United Kingdom. Dark green indicates sites still in use as allotments in 2016; light green indicates sites converted to other forms of greenspace; and grey indicates sites converted to the built urban environment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

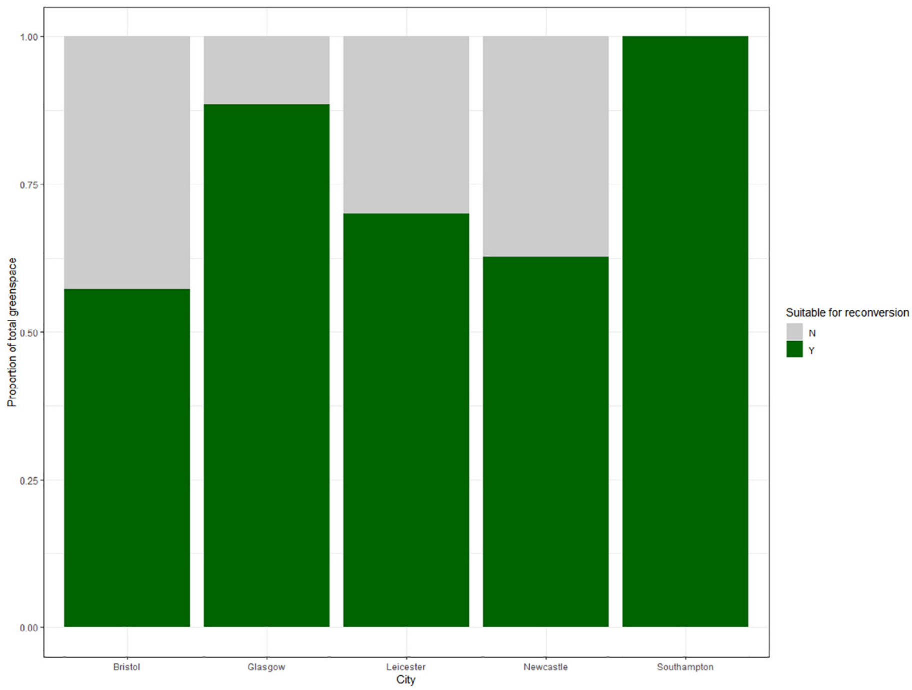

Fig. 6. The proportion of former allotment greenspace with potential suitability for reconversion to use as food production for five urban areas in the United Kingdom based on spatial restriction criteria. Green indicates suitability; grey is unsuitable land. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3. Waiting list demand

For the cities for which waiting list data was available (Southampton, Newcastle, Leicester and Sheffield), all except Southampton would, in principle, be able to fully meet current demand by restoring suitable greenspace sites which were formerly allotments to their prior use. Of these cities, Newcastle would need to convert 75.1% of this land, Bristol would need 41.8%, and Leicester would need 6.6%. In Southampton, a full restoration of all suitable former allotment sites would meet 55.4% of waiting list demand.

3.4. Socio-demographic trends

Across the five cities, the more deprived IMD deciles experienced greater absolute allotment land loss than the least deprived deciles (Fig. 7; Table 2). This suggests that the most food insecure areas are also those that have, historically, lost the greatest amount of allotment land. For all five cities, despite variation in the absolute levels of loss within each decile within the cities, deciles 1–4 (the most deprived) faced substantially greater levels of allotment loss than the more affluent areas. Many of the more deprived areas in cities contain land changed from use as allotments to commercial and industrial buildings; in more affluent areas, which tended to be primarily residential, such land use change was rare.

When applying the spatial restriction criteria to discover where former allotment greenspace has the potential for reconversion to use as allotments, almost half of suitable land occurs in IMD deciles 1 and 2, the most deprived areas (Fig. 8). This suggests that the most food insecure communities stand to gain the greatest benefit from a restoration of former allotment land in terms of providing access to food growing space where it has historically been lost. Using the above measures of potential people fed from restoration of land, over four times as many people in IMD decile 5 and below would be fed on a five a day diet as in the upper deciles with a full restoration of potentially suitable former allotment land.

4. Discussion

Our results demonstrate a significant loss of allotment provision in the United Kingdom from its mid-twentieth century levels of peak provision: a decline by almost two-thirds in both absolute land area and land area per capita. The fact that there has been a decline in the amount of allotment land available to be cultivated on a nationwide scale has previously been reported in aggregate by major works on the subject's history (Crouch & Ward, 1997; Acton, 2015). Our city by city analysis demonstrates how this overall change is realised on the ground. Despite the variation in absolute provision of allotments, we see similar trends, country-wide, of mid-century increase to peak provision in the immediate post-Second World War period, following rationing and the Dig For Victory campaign, to a decline throughout the second half of the century resulting in the lowest recorded levels of provision occurring in the present day. This supports the nationwide general historic trend identified by Crouch and Ward (1997) and Acton (2011). In terms of the number of people that own-growing on allotments could provide fruit and vegetables for, our analysis shows that there has been a substantial loss in the capacity of urban allotments to feed a city's population on their "five a day" fruit and vegetable diet, and a substantial overall loss in yield in absolute and per capita kilograms of fruit and vegetables produced each year. A continuation of this downward trend is increasingly at odds with the public desire for access to allotments, as evidenced by waiting lists. From 2004, waiting list numbers began to rise across the UK following a resurgence in interest in allotment gardening, and national demand continues to be high (Acton, 2011; Campbell & Campbell, 2013); however, we have demonstrated that reconversion of suitable former allotment land to urban agriculture would be sufficient to meet waiting list demand in four of our five case study sites.

Our results also demonstrate that areas that are in the lowest (most deprived) deciles for deprivation, and as a result are at the greatest risk of food insecurity (Smith et al., 2018), have faced the highest levels of allotment closure throughout the twentieth century. Whilst reasons for site closures vary, the cumulative effect is that access to food growing space is more limited in areas where the need is potentially greatest. Food security has not been found to be a primary concern of allotment gardeners, who tend to discuss own-growing in terms of the social and cultural ecosystem services it provides (Acton, 2011); however the potential contribution to food security own-growing can and does make is well-documented, if not conclusively quantified, by a growing body

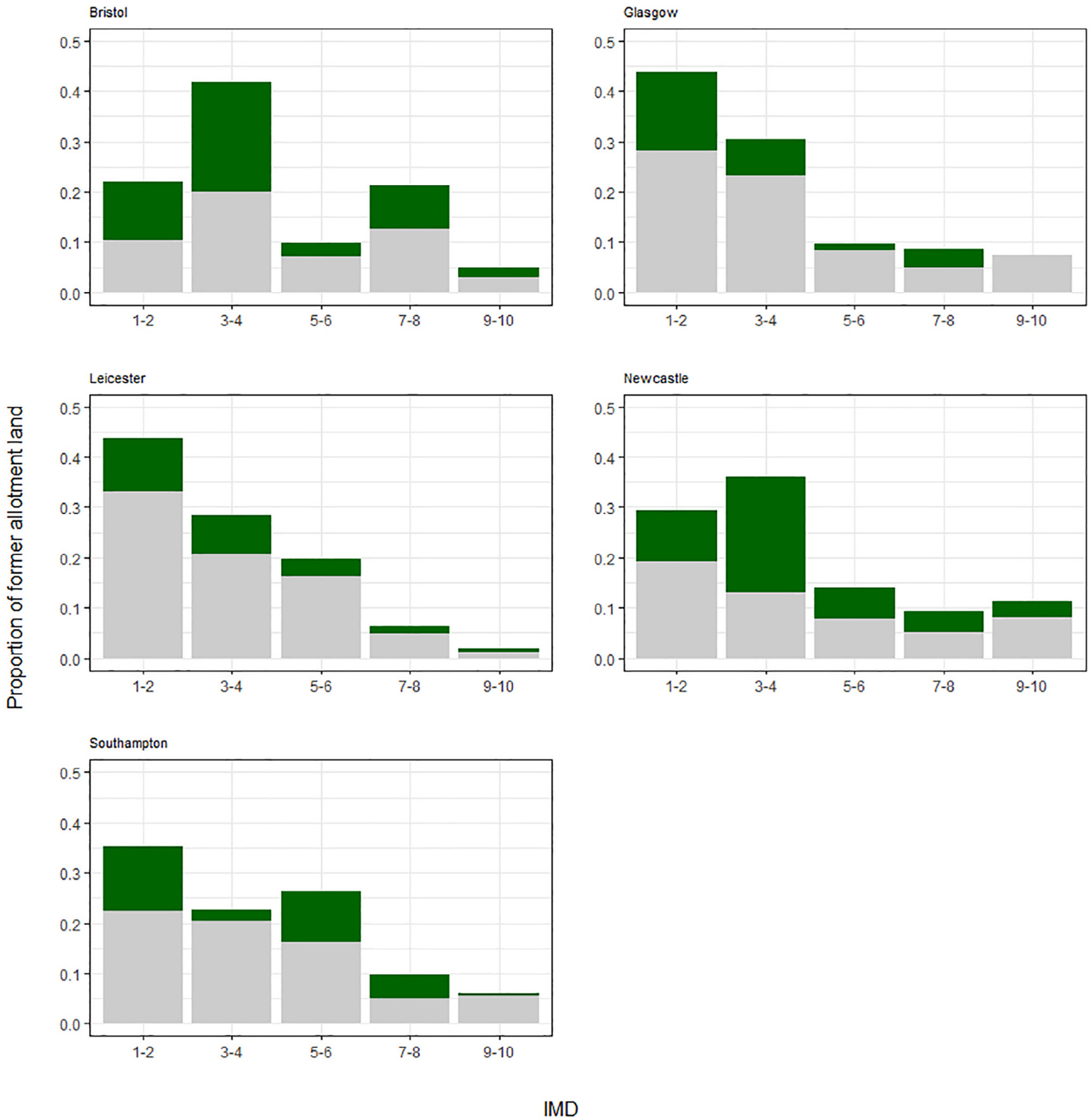

Fig. 7. Allotment closures throughout the twentieth century in different Index of Multiple Deprivation deciles for five urban areas in the United Kingdom. Grey indicates sites closed that are now part of the built environment; green indicates sites closed that remain as greenspace. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of literature (Orsini et al., 2013; Mok et al., 2014; Badami & Ramankutty, 2015; Eigenbrod & Gruda, 2015; Opitz, Berges, Piorr, & Krikser, 2016). An increase in access to food growing space in more deprived areas could play a significant role in reducing food insecurity in vulnerable communities, and concurrently contributing associated wellbeing and health benefits.

Whilst the primary pressure on urban land comes from the development of the built environment, our results suggest that a substantial area of land formerly used as allotment gardens has not been developed for this purpose but now comprises other forms of urban greenspace, from unused or vacant land through to school playing fields and nature reserves. Whilst we have demonstrated that the amount of former allotment greenspace is, in the majority of cases, sufficient, or nearly so, to meet current waiting list demand, the heterogeneity of types of greenspace land cover on former allotment sites provides a significant caveat. It is clearly not the case that all former allotment land could, or should, be converted back to its use for food growing. In many cases the current land use is also of high value in either a social or environmental capacity, and waiting list demand may be spatially variant within cities such that past allotment locations are no longer the best places for future provision. What the results do demonstrate is that not all former allotment land has been converted to land uses now unsuitable for urban agriculture. Our method, using the spatial restriction criteria developed by Grafius et al. (2019), along with further restrictions to identify viable allotment sites, easily identifies cases where land could be at least considered for such a purpose, with the added benefit that former use as allotments suggests potential suitability (e.g. soil quality) for the same purpose. As allotment waiting list numbers continue to

Table 2
Occurrences of allotment closures throughout the twentieth century for five British cities, arranged by Index of Multiple Deprivation decile, where 1 is most deprived and 10 is least deprived.

IMD Decile	Area closed (hectares)	Percent of total closed area in this IMD	Percent of total former and current allotment land in this IMD
1	253.28	18.45	21.33
2	239.02	17.41	18.45
3	214.25	15.61	10.87
4	236.08	17.20	15.39
5	165.26	12.04	16.08
6	50.41	3.67	3.60
7	100.96	7.36	3.96
8	53.77	3.92	2.66
9	29.26	2.13	2.19
10	30.26	2.20	3.55

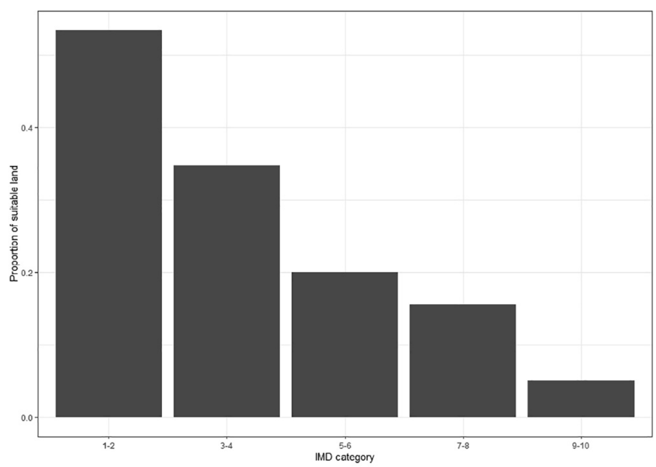

Fig. 8. Proportion of land suitable for reconversion to allotment gardening purposes, categorised by Index of Multiple Deprivation, for five urban areas in the United Kingdom.

rise, and urban food security maintains its status as a pressing issue, the identification of land parcels suitable for urban agriculture, in any of its forms, is of great importance. Higher spatial resolution data on waiting list numbers and trends in site closures within a city would enable investigation into the optimum locations for the creation of new sites to meet waiting list demands.

The method we have used here provides a simple technique for the identification of land parcels formerly in use as urban agriculture and suitable for reconversion to such a purpose. Whilst there are some limitations with the use of LLSOA areas (primarily, people travelling across LLSOA boundaries to access an allotment site in a different IMD decile), the trends we found were consistent across the UK, suggesting the robustness of the approach. The specific issue of allotments and their closures may be unique to the United Kingdom, but urban land across the world faces the challenges of being a limited resource, subject to demands for housing, transport, and other infrastructure, with which the use of urban land for food production and delivery of associated ecosystem services must compete. The extent to which waiting list demand could be met – in four fifths of cases, completely – by reconverting former land proves the surprising extent to which this land exists, and such a result seems likely to hold for other similar urban areas in the global North. In the future, issues of access to land for food production, as well as those of food justice and inequalities of resources (financial and time-related) to engage in food growing must also be considered by any project, in the public sector or in civil society, looking to expand the availability of urban agricultural land (Siegner, Sowerwine, & Acey, 2018).

5. Conclusions

Current research into urban agriculture focuses on the ability and capacity of urban agricultural land to provide urban ecosystem services and food for urban residents. However setting provision into its historic context, as we have done here, is a key part of building the bigger picture of urban agriculture, demonstrating the scale of past food growing space in cities and the long-term trends in such space, and illustrating the consequences of site closures in the face of competing demands on urban land and food security issues faced by deprived communities. This investigation is an important first step in the identification of areas where food growing projects, and not just allotments, have the potential to be successful based on historic land use, and present-day need for access to food growing spaces for deprived communities. With the increasing urbanisation of populations, feeding urban communities equitably and sustainably is a pressing question. Our findings strengthen the case for retaining those sites that remain today, and increasing the distribution of urban agricultural land across all deciles of urban deprivation or affluence to ensure access to food growing spaces, and their associated environmental and health benefits, for all.

CRediT authorship contribution statement

Miriam C. Dobson: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Jill L. Edmondson:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Philip H. Warren:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2020.103803.

References

Acton, L. (2011). Allotment gardens: A reflection of history, heritage, community and self. *Papers from the Institute of Archaeology, 21*, 46–58. https://doi.org/10.5334/pia.379.
Acton, L. (2015). *Growing space: a history of the allotment movement.* Nottingham: Five Leaves Publications.
Aerts, R., Dewaelheyns, V., & Achten, W. M. J. (2016). Potential ecosystem services of urban agriculture: A review. *Peer J Preprints, 4*, 1–6. https://doi.org/10.7287/peerj.preprints.2286v1.
Altieri, M., Companioni, N., Cañizares, K., Murphy, C., Rosset, P., Bourque, M., & Nicholls, C. (1999). The greening of the "barrios": Urban agriculture for food security in Cuba. *Agriculture and Human Values, 16*(2), 131–140. https://doi.org/10.1023/A:1007545304561.
Andersson, E., Barthel, S., & Ahrné, K. (2007). Measureing social-ecological dynamics behind generation of ecosystem services. *Ecological Applications, 17*(5), 1267–1278. https://doi.org/10.1890/06-1116.1.
Badami, M. G., & Ramankutty, N. (2015). Urban agriculture and food security: A critique based on an assessment of urban land constraints. *Global Food Security, 4*, 8–15. https://doi.org/10.1016/j.gfs.2014.10.003.
Barthel, S., Folke, C., & Colding, J. (2010). Social–ecological memory in urban gardens—Retaining the capacity for management of ecosystem services. *Global Environmental Change, 20*(2), 255–265.
Blair, D., Giesecke, C. C., & Sherman, S. (1991). A dietary, social and economic evaluation of the Philadelphia urban gardening project. *Journal of Nutrition Education, 23*(4),

161–167.
Borysiak, J., Mizgajski, A., & Speak, A. (2017). Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. *Urban Ecosystems, 20*(2), 323–335. https://doi.org/10.1007/s11252-016-0595-4.
Campbell, M., & Campbell, I. (2011). Allotment waiting lists in England 2011. Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom. http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2011.pdf.
Campbell, M., & Campbell, I. (2013). Allotment waiting lists in England 2013. Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom. http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2013.pdf.
Carney, P. A., Hamada, J. L., Rdesinski, R., Sprager, L., Nichols, K. R., Liu, B. Y., & Shannon, J. (2012). Impact of a community gardening project on vegetable intake, food security and family relationships: A community-based participatory research study. *Journal of Community Health, 37*(4), 874–881. https://doi.org/10.1007/s10900-011-9522-z.
Coleman-Jensen, A., Rabbitt, M. P., Gregory, A. C., & Singh, A. (2019). Household Food Security in the United States in 2018. ERR-270, U.S. Department of Agriculture, Economic Research Service.
Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M. (2013). Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography, 37*(1), 2–28. https://doi.org/10.1177/0309133312461032.
Crouch, D., & Ward, C. (1997). *The allotment: Its landscape and culture.* Nottingham: Five Leaves Publications.
Edmondson, J. L., Davies, Z. G., Gaston, K. J., & Leake, J. R. (2014). Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. *Journal of Applied Ecology, 51*(4), 880–889. https://doi.org/10.1111/1365-2664.12254.
Edmondson, J. L., Blevins, R., Cunningham, H., Dobson, M. C., Leake, J., & Grafius, D. (2019). Grow your own food security? Integrating science and citizen science to estimate the contribution of own growing to UK food production. *Plants, People, Planet, 2019*, 1–5. https://doi.org/10.1002/ppp3.20.
Edmondson, J. L., Childs, D. Z., Dobson, M. C., Gaston, K. J., Warren, P. H., & Leake, J. R. (2020). Feeding a city – Leicester as a case study of the importance of allotments for horticultural production in the UK. *Science of the Total Environment, 705*(135930), https://doi.org/10.1016/j.scitotenv.2019.135930.
Edmondson, J. L., Cunningham, H., Tingley, D. D., Dobson, M. C., Grafius, D., Leake, J., ... Cameron, D. (2020). The hidden potential of urban horticulture. *Nature Food, 1*, 155–159. https://doi.org/10.1038/s43016-020-0045-6.
Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities. A review. *Agronomy for Sustainable Development, 35*(2), 483–498. https://doi.org/10.1007/s13593-014-0273-y.
Food and Agriculture Organisation. (2017). Prevalence of Undernourishment – % of Population (United Kingdom). Retrieved from https://data.worldbank.org/indicator/SN.ITK.DEFC.ZS?end=2017&locations=GB&start=2017&view=bar.
Foster, G., Bennett, J., & Sparks, T. (2017). An assessment of bumblebee (Bombus spp) land use and floral preference in UK gardens and allotments cultivated for food. *Urban Ecosystems, 20*(2), 425–434. https://doi.org/10.1007/s11252-016-0604-7.
Goldstein, B., Hauschild, M., Fernández, J., & Birkved, M. (2016). Testing the environmental performance of urban agriculture as a food supply in northern climates. *Journal of Cleaner Production, 135*, 984–994. https://doi.org/10.1016/j.jclepro.2016.07.004.
Grafius, D., Hall, S., McHugh, N., & Edmondson, J. L. (2019). How much heat can we grow in our cities? Modelling UK urban biofuel production potential. *GCB Bioenergy, 00*, 1–15. https://doi.org/10.1111/gcbb.12655.
Graves, A. R., Morris, J., Deeks, L. K., Rickson, R. J., Kibblewhite, M. G., Harris, J. A., ... Truckle, I. (2015). The total costs of soil degradation in England and Wales. *Ecological Economics, 119*, 399–413. https://doi.org/10.1016/j.ecolecon.2015.07.026.
Grewal, S. S., & Grewal, P. S. (2012). Can cities become self-reliant in food? *Cities, 29*(1), 1–11. https://doi.org/10.1016/j.cities.2011.06.003.
Horst, M., Mcclintock, N., & Hoey, L. (2017). The intersection of planning, urban agriculture, and food justice: A review of the literature. *Journal of the American Planning Association, 83*(3), 277–295. https://doi.org/10.1080/01944363.2017.1322914.
Howe, J., & Wheeler, P. (1999). Urban food growing: The experience of two UK cities. *Sustainable Development, 7*(1), 13–24. https://doi.org/10.1002/(SICI)1099-1719(199902)7:1 < 13::AID-SD100 > 3.0.CO;2-B.
Kulak, M., Graves, A., & Chatterton, J. (2013). Reducing greenhouse gas emissions with urban agriculture: A life cycle assessment perspective. *Landscape and Urban Planning, 111*(1), 68–78. https://doi.org/10.1016/j.landurbplan.2012.11.007.
Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability, 7*(12), 5875–5895. https://doi.org/10.3390/su7055875.
Langemeyer, J., Camps-Calvet, M., Calvet-Mir, L., Barthel, S., & Gómez-Baggethun, E. (2018). Stewardship of urban ecosystem services: Understanding the value(s) of urban gardens in Barcelona. *Landscape and Urban Planning, 170*, 79–89. https://doi.org/10.1016/j.landurbplan.2017.09.013.
Leake, J. R., Adam-Bradford, A., & Rigby, J. E. (2009). Health benefits of "grow your own" food in urban areas: Implications for contaminated land risk assessment and risk management? *Environmental Health: A Global Access Science Source, 8*(SUPPL. 1), S6. https://doi.org/10.1186/1476-069X-8-S1-S6.
Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and Applied Ecology, 16*(3), 189–201. https://doi.org/10.1016/j.baae.2015.01.005.
Lorenz, K (2015). Organic urban agriculture. *Soil Science, 180*(4/5), 146–153. https://doi.org/10.1097/SS.0000000000000129.
Lovell, S. T. (2010). Multifunctional urban agriculture for sustainable land use planning in the united states. *Sustainability, 2*(8), 2499–2522. https://doi.org/10.3390/su2082499.
Martin, G., Clift, R., & Christie, I. (2016). Urban cultivation and its contributions to sustainability: Nibbles of food but oodles of social capital. *Sustainability, 8*(5), 409. https://doi.org/10.3390/su8050409.
McClintock, N., Cooper, J., & Khandeshi, S. (2013). Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landscape and Urban Planning, 111*(1), 46–58. https://doi.org/10.1016/j.landurbplan.2012.12.009.
Milbourne, P. (2012). Everyday (in)justices and ordinary environmentalisms: Community gardening in disadvantaged urban neighbourhoods. *The Internaitonal Journal of Justice and Sustainability, 17*(9), 943–957. https://doi.org/10.1080/13549839.2011.607158.
Mok, H. F., Williamson, V. G., Grove, J. R., Burry, K., Barker, S. F., & Hamilton, A. J. (2014). Strawberry fields forever? Urban agriculture in developed countries: A review. *Agronomy for Sustainable Development, 34*(1), 21–43. https://doi.org/10.1007/s13593-013-0156-7.
Morris, S. (2015). Bristol bus protesters take to the trees. The Guardian. Retrieved from https://www.theguardian.com/uk-news/2015/feb/02/bristol-bus-protesters-trees-european-green-capital-2015.
National Society of Allotment and Leisure Gardeners Ltd. (2012). Creating a new allotment site. Retrieved from https://www.nsalg.org.uk/wp-content/uploads/2012/09/A5_Creating_a_new_allotment_site_LR.pdf.
Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., ... Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. *BioScience, 57*(10), 823–833. https://doi.org/10.1641/B571005.
Opitz, I., Berges, R., Piorr, A., & Krikser, T. (2016). Contributing to food security in urban areas: Differences between urban agriculture and peri-urban agriculture in the Global North. *Agriculture and Human Values, 33*(2), 341–358. https://doi.org/10.1007/s10460-015-9610-2.
Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development, 33*(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z.
Owen, T., & Pilbeam, E. (1992). *Ordnance Survey: Map-makers to Britain since 1791.* Southampton: Ordnance Survey.
Poulsen, M. N., Hulland, K. R. S., Gulas, C. A., Pham, H., Dalglish, S. L., Wilkinson, R. K., & Winch, P. J. (2014). Growing an urban oasis: A qualitative study of the perceived benefits of community gardening in Baltimore, Maryland. *Culture, Agriculture, Food and Environment, 36*(2), 69–82. https://doi.org/10.1111/cuag.12035.
Rae, A., Hamilton, R., Crisp, R., & Powell, R. (2016). Overcoming deprivation and disconnection in UK cities. Joseph Rowntree Foundation. https://www4.shu.ac.uk/research/cresr/sites/shu.ac.uk/files/overcoming-deprivation-disconnection-uk-cities.pdf.
Robert, A., & Yengué, J. L. (2017). When allotment gardens become urban green spaces like others, providing cultural ecosystem services. *Environment and Ecology Research, 5*(6), 453–460. https://doi.org/10.13189/eer.2017.050606.
Schmutz, U., Kneafsey, M., Sarrouy Kay, C., Doernberg, A., & Zasada, I. (2018). Sustainability impact assessments of different urban short food supply chains: Examples from London, UK. *Renewable Agriculture and Food Systems, 33*(6), 518–529. https://doi.org/10.1017/S1742170517000564.
Seguí, A. E., Mackiewicz, B., & Rosol, M. (2017). From leisure to necessity: Urban allotments in Alicante province. *Spain in times of crisis. Acme, 16*(2), 276–304.
Seto, K. C., Guneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109.
Siddique, H., & Topping, A. (2016). Watford allotment campaigners lose high court battle to save site. The Guardian. Retrieved from https://www.theguardian.com/lifeandstyle/2016/nov/02/watford-allotment-campaigners-lose-high-court-battle-to-save-site.
Siegner, A., Sowerwine, J., & Acey, C. (2018). Does urban agriculture improve food security? Examining the nexus of food access and distribution of urban produced foods in the United States: A systematic review. *Sustainability (Switzerland), 10*(9), 2988. https://doi.org/10.3390/su10092988.
Smith, D., Thompson, C., Harland, K., Parker, S., & Shelton, N. (2018). Identifying populations and areas at greatest risk of household food insecurity in England. *Applied Geography, 91*, 21–31. https://doi.org/10.1016/j.apgeog.2017.12.022.
Speak, A. F., Mizgajski, A., & Borysiak, J. (2015). Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. *Urban Forestry and Urban Greening, 14*(4), 772–781. https://doi.org/10.1016/j.ufug.2015.07.007.
Taylor, J. R., & Lovell, S. T. (2012). Mapping public and private spaces of urban agriculture in Chicago through the analysis of high-resolution aerial images in Google Earth. *Landscape and Urban Planning, 108*(1), 57–70. https://doi.org/10.1016/j.landurbplan.2012.08.001.
Traveline, K., & Hunold, C. (2010). Urban agricultural and ecological citizenship in Philadelphia. *The International Journal of Justice and Sustainability, 15*(6), https://doi.org/10.1080/13549839.2010.487529.
United Nations (2019). Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision. (ST/ESA/SER.A/420).
Webber, J., Hinds, J., & Camic, P. M. (2015). The well-being of allotment gardeners: A mixed methodological study. *Ecopsychology, 7*(1), 20–28. https://doi.org/10.1089/eco.2014.0058.
Zezza, A., & Tasciotti, L. (2010). Urban agriculture, poverty and food security: Empirical evidence from a sample of developing countries. *Food Policy, 35*(4), 265–273. https://doi.org/10.1016/j.foodpol.2010.04.007.

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An assessment of urban horticultural soil quality in the United Kingdom and its contribution to carbon storage

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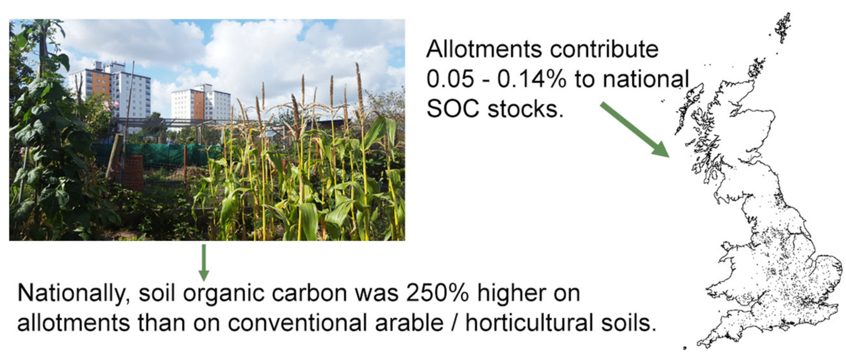
HIGHLIGHTS

- We investigated the quality of urban horticultural soils in the United Kingdom.
- Soil was analysed for indicators including organic carbon and bulk density.
- We estimate of the contribution of allotment soils to national carbon stocks.
- Allotment soils were of higher quality than commercial horticultural soils.
- Urban horticulture can enhance ecosystem services provided by soils in cities.

GRAPHICAL ABSTRACT



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ABSTRACT

As participation in urban horticulture grows, understanding the quality of urban horticultural soils is of increasing importance. Until now, case studies of individual cities or gardens have limited the potential of such studies to draw generalised conclusions. Here, we present the first national scale assessment of soil quality in allotments, a dominant form of urban horticulture in the United Kingdom. We sampled soils in 200 allotments in 10 urban areas across Great Britain. We assessed a range of soil quality indicators (carbon and nitrogen concentration, C:N ratio, bulk density, carbon density, pH) comparing them to the quality of soils in rural arable and horticultural land. We present the first estimate of nationwide carbon storage on allotments. We found that allotment gardeners consistently employ management practices conducive to high soil quality. Allotment soil quality differed significantly between soil types but in general soils were of a high quality: low bulk density (0.92 g cm^{-3}) and high soil organic carbon concentration and density (58.2 mg g^{-1} and 58.1 mg cm^{-3} respectively). Allotment soil organic carbon concentration was 250% higher than in the surrounding arable and horticultural land. Covering only 0.0006% of Great Britain, allotments contribute a disproportionate 0.05–0.14% of nationwide total organic carbon stocks. This national-scale study provides compelling evidence that small-scale urban horticultural production, unlike conventional horticulture, does not degrade soil quality. Indeed, allotments hold a small but previously unaccounted for carbon stock nationally. Urban horticultural land is a vital part of the urban landscape with effectively functioning soils that should be protected. As public demand for urban horticultural land rises and policy-makers from local to trans-national levels of governance advocate for urban food production, our findings demonstrate that urban horticulture can protect or enhance the ecosystem services provided by soils in cities and towns where the majority of people live.

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1. Introduction

A growing global urban population has brought with it increasing concern about issues of urban sustainability and food security. Recent research attention has turned to possibilities presented by urban horticulture (UH) to contribute to meeting the nutritional demands of urban residents, predicted to comprise over two-thirds of the global population by 2050 (United Nations, 2019). Urban horticulture is increasingly viewed by international organisations as a facet of ensuring future food security (Mbow et al., 2018), and studies have demonstrated that it has the potential to provide at least 15%, and up to 122%, of a city's residents with fruit and vegetables if all available land was cultivated (Edmondson et al., 2020a; Mcdougall et al., 2020), or thirty days of provision for a city's residents at current levels of cultivation (Grafius et al., 2020).

In addition to providing fruit and vegetables to urban residents, UH is important for ecosystem service provision (Speak et al., 2015; Church et al., 2015; Goldstein et al., 2016; Benis and Ferrão, 2017). This includes services supported by UH soils, such as food production (Beniston and Lal, 2012); regulation of climate and floods (Rawlins et al., 2013); storage of organic carbon (Bretzel et al., 2018); nutrient cycling (Lorenz, 2015); and biodiversity support (Tresch et al., 2018). Soils are the foundation for many ecosystem services, but globally face challenges from degradation, land-use change and climate change (Wiskerke and Viljoen, 2012; Eigenbrod and Gruda, 2015). Traditionally, it was assumed that urban soils on the whole are of poor quality, storing limited or no soil organic carbon (SOC) (Pouyat et al., 2006). However, this has been challenged by research demonstrating that they contain internationally significant stocks of SOC, and that not all urban soils are sealed or degraded to the point of being inconsequential in SOC estimates (Pouyat et al., 2006; Edmondson et al., 2012; Edmondson et al., 2014b). In addition, urban greenspace soils contribute to runoff and flood control, mitigate the urban heat island effect, support biodiversity, and improve air quality (Morel et al., 2015; Mbow et al., 2018). SOC is a good indicator of soil quality, being positively associated with water and nutrient holding capacity, and negatively associated with soil compaction (Franzluebbers, 2002; Edmondson et al., 2014b). It is also positively associated with crop yields and ecosystem service delivery (Lal, 2010; Powlson et al., 2011). Globally, soil degradation and land-use change have released ~78 Gt SOC into the atmosphere, and changes in SOC concentration are a major contributor to greenhouse gas emissions (Lal, 2004; Emmett et al., 2010; Batjes, 2014). However, national SOC inventories do not, typically, account for urban SOC stocks (Bradley et al., 2005; de Brogniez et al., 2014).

Previous research has found that good soil management is key for the improvement of UH soils to increase yields as well as maximise ecosystem service provision (for example: Lorenz, 2015; Eigenbrod and Gruda, 2015; Tresch et al., 2018). Research addressing the influence of management on urban horticultural soil quality is still relatively young (Lorenz, 2018; Tresch et al., 2018); however, practical guidelines for gardeners exist in many forms, for example having been produced by the European Cooperation in Science and Technology framework (COST, 2019), as overall understanding of how to sustainably manage agricultural soils is a mature and comprehensive body of literature. Many common practices such as composting and manure addition contribute to improving UH soils (Edmondson et al., 2014a). However, urban soils are particularly heterogeneous with a large degree of spatial variability (Lal, 2018), and different underlying soil types can have significantly different properties (Wilson et al., 2011). Case studies in individual cities, which form the bulk of previous research into UH soil quality, whilst presenting some common findings, need corroborating with a nationwide understanding. For example, there is now a body of international literature assessing UH soil quality and the influence of management on UH soil: for example in Pisa, Italy (Bretzel et al., 2018); California, USA (Egerer et al., 2018); Zurich, Switzerland (Tresch et al., 2018); Cotonou, Benin (Brock and Foeken, 2006); and Buenos Aires (González et al., 2010). However, to date no nationwide surveys have been undertaken.

In the UK, allotment gardening is the predominant land-use devoted to UH (Crouch and Ward, 1997; Acton, 2015). Allotment plots are rented land parcels for the purpose of food production, usually around 250 m^2, and form part of larger sites comprised of a varying number of plots. Current UK provision of allotment plots does not meet demand: there are approximately 330,000 allotment plots, covering 135 km^2, however, there were 100,000 people on waiting lists in the last decade (Campbell and Campbell, 2013), and demand for plots is rising (Dobson et al., 2020) particularly in response to the Covid-19 pandemic (Smithers, 2020). Previous research on allotment soils in Leicester, UK, found they had a 32% higher SOC concentration than in regional arable soils (Edmondson et al., 2014a), suggesting that UH occurs without the degradation of soils seen in conventional agricultural systems.

In this paper, we establish the first assessment of soil quality on allotment gardens throughout the Great Britain. As well as investigating SOC density and SOC concentration, which as detailed above is one of the primary indicators of overall soil health (Franzluebbers, 2002), we also look at other soil quality indicators associated with the provision of regulating and supporting ecosystem services in the soil (Dominati et al., 2010). These are bulk density (BD), a key measure of soil compaction (Emmett et al., 2010); soil total nitrogen (N) concentration and the carbon to nitrogen (C:N) ratio (an important control of soil nutrient cycling; Powlson et al., 2011); pH; and water holding capacity (WHC). Additionally, we use a questionnaire study with plotholders to determine soil management practices and investigate whether these have a significant influence on soil quality. For each of our study cities, we investigate SOC concentration in comparison to their surrounding arable and horticultural rural land, allowing us to compare the quality of UH soils to overall arable and horticultural soil quality in the UK. Further to this, we produce the first estimate of the contribution of allotment soils to British SOC stocks.

2. Methods

2.1. Site selection

We selected ten case study urban areas, geographically distributed across Great Britain: Bristol (B), Cardiff (CA), Edinburgh (ED), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO) (Fig. 1). This north-south gradient captured a range of climatic conditions, with average annual rainfall varying from 620 mm to 991 mm, and average annual temperature varying from 8.5 °C to 10.6 °C (Climate-Data.org, 2021; Table 1).

Each urban area was split into four quadrants with an allotment site selected for field sampling randomly from each quadrant in a Geographic Information System (ArcGIS 10.4.1.; Supplementary Information S1 for sites), to give four study sites per city. Within each allotment site five allotment plots were selected for soil sampling. Soils were sampled in 200 allotment plots in 40 sites over the 2017–2018 growing seasons. In addition, for each plot, a map was produced detailing all features present, e.g. cropped areas, grass, impermeable surface, greenhouses.

Whilst urban areas are spatially heterogenous in regard to soil properties, we were able to identify the general soil type of each site using the NatMap Vector "soilscapes" dataset (National Soil Resources Institute, 2001). Edinburgh sites had no available soil type data. Allotment sites in the remaining nine urban areas existed on ten different soil types: freely draining floodplain soils (FDFS), freely draining lime rich loamy soils (FSLLS), freely draining slightly acid loamy soils (FSALS), freely draining slightly acid sandy soils (FDSASS), lime rich loamy and clayey soils with impeded drainage (LLCSID), loamy and clayey floodplain soils with naturally high groundwater (LCFNHG), loamy and clayey soils of coastal flats with naturally high groundwater

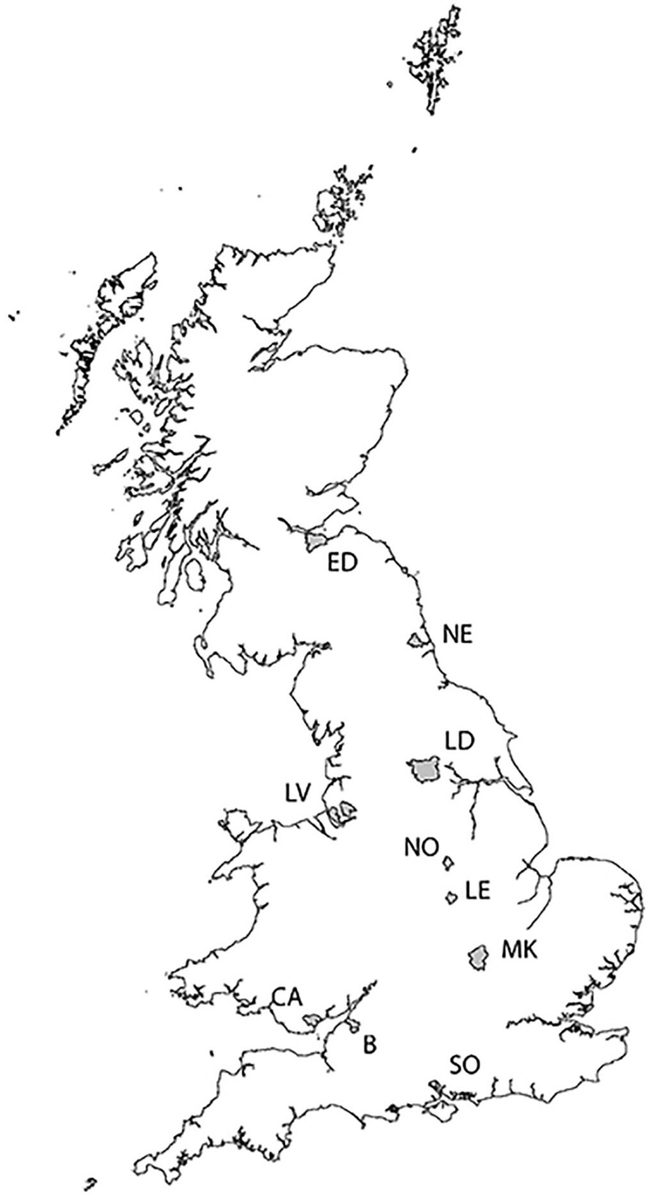

Fig. 1. Location of study cities within Great Britain: Edinburgh (ED), Newcastle (NE), Leeds (LD), Liverpool (LV), Nottingham (NO), Leicester (LE), Milton Keynes (MK), Cardiff (CA), Bristol (B), and Southampton (SO).

(LCCNHG), slightly acid loamy and clayey soils with impeded drainage (SALCSID), slowly permeable seasonally wet acid loamy and clayey soils (SPSWALC), and slowly permeable seasonally wet slightly acid but base rich loamy and clayey soils (SPSWABLC; Fig. 2).

Table 1
Climatic conditions of study cities.

City	Avg. annual rainfall (mm)	Avg. annual temperature (°C)
Bristol	819	9.8
Cardiff	991	10.3
Edinburgh	706	8.5
Leeds	697	9.5
Leicester	620	9.7
Liverpool	796	9.4
Milton Keynes	631	9.6
Newcastle	655	8.5
Nottingham	648	9.8
Southampton	774	10.6

2.2. Soil sampling methods

At each allotment plot (n = 200), soil was sampled under one perennial and one annual crop due to the undisturbed nature of soils beneath perennial crops as opposed to beneath annual crops where crop rotation occurs, in order to assess whether soil properties differed based on this. In plots where there were only annuals or perennials then soils were sampled beneath two different annual or perennial crops. Soils were sampled using two methods. Firstly, at two depth increments (0–10 cm and 10–20 cm) using a specialist bulk density corer (Eijkelkamp Ring Kit C; Edmondson et al., 2012). Secondly, triplicate auger samples were taken to 20 cm depth.

2.3. Soil analysis

Soil samples were dried at 105 °C for 24 h, weighed, ball-milled to homogenise and passed through a 1 mm sieve (Edmondson et al., 2012). Material >1 mm was weighed and removed from soil total weight; this material was then volumetrically measured using water displacement and the volume removed from total volume to calculate soil BD (g cm^{-3}). Inorganic carbon was removed from samples with 5 M HCl, and the remaining soil was analysed for SOC and N in an elemental analyser (Vario EL Cube; Isoprime, Germany). SOC density (mg cm^{-3}) was calculated individual samples using SOC concentration (mg g^{-1}) and BD prior to the removal of the volume of >1 mm material (g cm^{-3}) (Edmondson et al., 2012).

Auger samples were air dried and analysed for water holding capacity (WHC) and pH. Soil pH was determined in 1:10 (v:w) ratio with 0.01 M $CaCl_2$ suspension (Houba et al., 2000). Prior to WHC analysis, auger samples were passed through a 9 mm sieve. The "European" maximum water holding capacity method of Gardner (1986) was used to determine WHC based on the weight of water held by soil as a percentage of the dry weight of the soil.

2.4. Soil management questionnaire

Questionnaires were conducted with 184 of the 200 allotment plotholders on whose plots soil samples were taken. Participants were asked a variety of questions related to plot and soil management practices, such as organic growing, manure use, winter coverings, and composting of plot waste (Supplementary Information S3).

2.5. Agricultural soil carbon concentration

LandCover Map 2015 (Rowland et al., 2017) was used to identify areas of arable and horticultural land surrounding each urban area. Ten locations were selected at random (in ArcGIS 10.4.1; for Cardiff and Liverpool, only nine were available) within this agricultural land surrounding each urban area. At each location (n = 88) a topsoil organic carbon value was extracted from NatMap Vector (National Soils Resources Institute, 2001). Comparison was conducted on this geographic basis rather than by soil type in order to compare soil quality between places that had similar climatic conditions; however, soil type was comparable within and without study cities, and all arable and horticultural locations selected matched the underlying soil texture of their closest allotments according to the NatMap Vector data. This was not possible in Edinburgh as NatMap Vector does not extend into Scotland.

2.6. Allotment contribution to nationwide SOC stocks

For each soil type sampled, we converted the median SOC density (mg cm^{-3}) for 0–10 cm and 10–20 cm to give SOC storage (kg m^{-2}) to 20 cm. We used the Ordnance Survey Greenspace map (Ordnance Survey, 2017) to identify all allotment sites in Great Britain and combined this with the NatMap Vector dataset to identify the soil type for each allotment site. For all allotments in Scotland (where no soil type

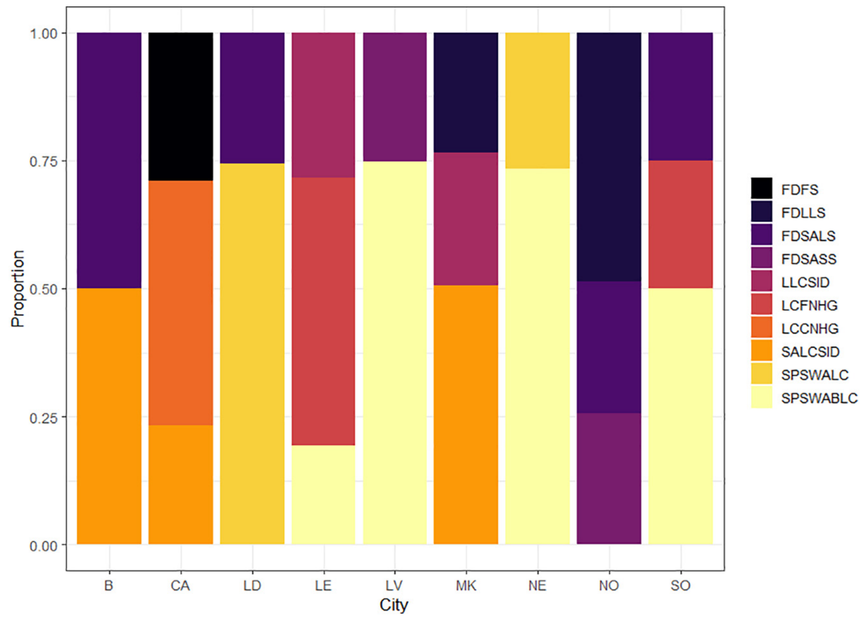

Fig. 2. Distribution of soil types on allotments in case study urban areas (n = 20 per urban area): Bristol (B), Cardiff (CA), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO).

data was available), and for allotment sites on soil types unrepresented in the allotment soil survey, we applied a minimum, maximum and mid-range estimate for SOC storage to 20 cm in kg m^{-2} based on our minimum, maximum and median measurements for SOC in national-scale allotment survey.

To prevent over-estimation of SOC we accounted for land area within allotment sites that is not used for cultivation. Communal infrastructure that can seal soil covers 18% of allotment sites and so was assumed to hold no SOC (Edmondson et al., 2020b). Average area of land used on an allotment plot for impermeable surface area, horticultural production soil, or other permeable surfaces such as grass paths were calculated using plot maps. Average impermeable area per plot was also removed from each allotment site.

We used the Land Cover Map 2015 GB Vector (Rowland et al., 2017) alongside the NatMap Vector soil type data and NatMap Vector carbon map to deduce the soil type and SOC value of each arable and horticultural land parcel. NatMap Vector SOC, estimated to 30 cm, was converted to an estimate to 20 cm to align with our field values. For Scottish land parcels, which did not have NatMap Vector coverage, we applied an overall median of SOC storage estimation. For each allotment land parcel across the country, estimates for the potential minimum, maximum and mid-range SOC storage were calculated twice: firstly, on the assumption that all permeable surface on allotments maintains equal SOC values to the cropped areas; secondly, on the assumption that all permeable surface on allotments that is uncropped has SOC storage equal to rural arable and horticultural land rather than allotment crop area. This gave us two possible estimates for SOC storage overall on allotments.

2.7. Statistical analysis

Statistical analysis was conducted in R version 4.0.0. (R Core Team, 2020; see Supplementary Information S4 for a full list of R packages used). The mean of the two replicated samples was taken for each allotment plot, to give one result per plot depth per crop type (annual or perennial), except for pH and WHC, where only one depth was sampled.

We examined the influence of soil type, crop type and depth (for pH and WHC, depth was excluded) on our measured soil quality indicators. Data were transformed where necessary to improve the fit to assumptions of normality at $p \geq 0.05$ using Shapiro-Wilk tests, and linear mixed effects models were built to include the influence of city or allotment site as random effects using the R package *lme4* (Bates et al., 2015). Using Akaike's information criteria (AIC) values and 95% confidence intervals, the most parsimonious model for each variable was built. The package *lmerTest* (Kuznetsova et al., 2017) was used to generate *p*-values for the models using Satterthwaite's approximation. Linear mixed effects models were also used to investigate the influence of management practices on soil quality. A paired sample *t*-test was used to analyse differences between allotment and arable and horticultural SOC concentration.

3. Results

3.1. Allotment soil management

Plotholders had managed their plots for a median length of 7 years, ranging from two weeks, to 61 years. Previous growing experience prior to taking on their allotment ranged from none to a lifetime of growing, but the majority (76%) had no experience of growing food before taking up their plot. When a plotholder's previous experience was added to the length of their plot occupancy, plotholder median food growing experience increased to 11 years.

Forty-three percent of respondents self-reported growing organically, 43% grew mostly organically, and 13% were non-organic. Fifty-four percent of questionnaire respondents used winter covering on their beds, most commonly black plastic, Geotex membrane and green manure. The most common soil additions were garden waste compost (92%) and manure (82%) with addition of other material less common (Table 2).

3.2. Allotment soil quality

Overall, the median properties of allotment soils were BD of 0.92 g cm^{-3} (0.22–1.52 g cm^{-3} range); SOC density of 58.1 mg cm^{-3} (16.7–191.8 mg cm^{-3} range); SOC concentration of 58.2 mg g^{-1} (14.0 to 305.6 mg g^{-1} range); N concentration of 3.7 mg g^{-1} (0.75–7.95 mg g^{-1} range); C:N ratio of 16.0 (7.0–40.0 range); pH of 6.5 (4.8 to 7.2 range), and WHC of 71.8% (44.6 to 105.7% range). Most soil properties varied by urban area (Fig. 3). The greatest SOC density, SOC concentration, C:N ratios and WHC were found in Cardiff; Leicester

Table 2
Inputs to allotment plots by survey respondents.

Additions to plot	Yes %	No %
Home kitchen waste compost	67	33
Compost from allotment organic matter waste	92	8
Purchased compost	69	31
Other compost[a]	33	67
Manure	82	18
Fertiliser (organic)	38	62
Fertiliser (non-organic)	27	73

[a] For example: cardboard, livestock straw, ash.

had the lowest SOC density and WHC. Milton Keynes had the lowest SOC concentration and C:N ratio, and the highest BD. pH was lowest in Edinburgh (Fig. 3).

For all soil properties measured the most parsimonious models included depth (where applicable), crop type, and soil type, except for N concentration where no fixed effects were included (Table 3). Soil type significantly affected SOC density (df = 9, 566.4, F = 2.1, p = 0.027), C:N ratio (df = 9, 603.7, F = 2.0, p = 0.034), and WHC (df = 9, 184.8, F = 5.4, $p < 0.0001$) (Fig. 4). There was a significant interaction effect between crop type and soil type on pH (df = 9, 92.5, F = 2.7, p = 0.005). Depth did not influence any soil property. Soil type was the most important factor effecting soil properties (Fig. 4; Table 3). When plot management practices were included, there was no improvement in model performance, suggesting that there were no significant effects of management on soil quality (Supplementary Information S5).

3.3. Organic carbon in allotment soils compared to arable and horticultural soils

Median SOC concentration in arable and horticultural soils was 23.5 mg g^{-1}, compared to 58.15 mg g^{-1} for allotment soils across Great Britain. Allotment SOC concentration was significantly higher than that of arable or horticultural soil from the surrounding region (t = 7.80, df = 8, $p < 0.0001$, Fig. 5).

3.4. Soil organic carbon storage contribution of British allotments

National median SOC storage to 20 cm depth in land cultivated for food production in allotments was 11.5 kg m^{-2}. Highest SOC storage (24.4 kg m^{-2} 20 cm depth) occurred in loamy and clayey floodplain soils with naturally high groundwater and in freely draining floodplain soils storage was estimated to be lowest (6.7 kg m^{-2} 20 cm depth; Fig. 6). See Supplementary Information S6 for estimates of SOC storage for all British allotment sites identified by Ordnance Survey. Our field mapping found that 14.4% ± 2.7% of allotment plots are impermeable surface; 31.9% ± 2.1% is uncultivated permeable surface such as grass paths, and 53.4% ± 1.5% is cultivated (crops and ornamental planting).

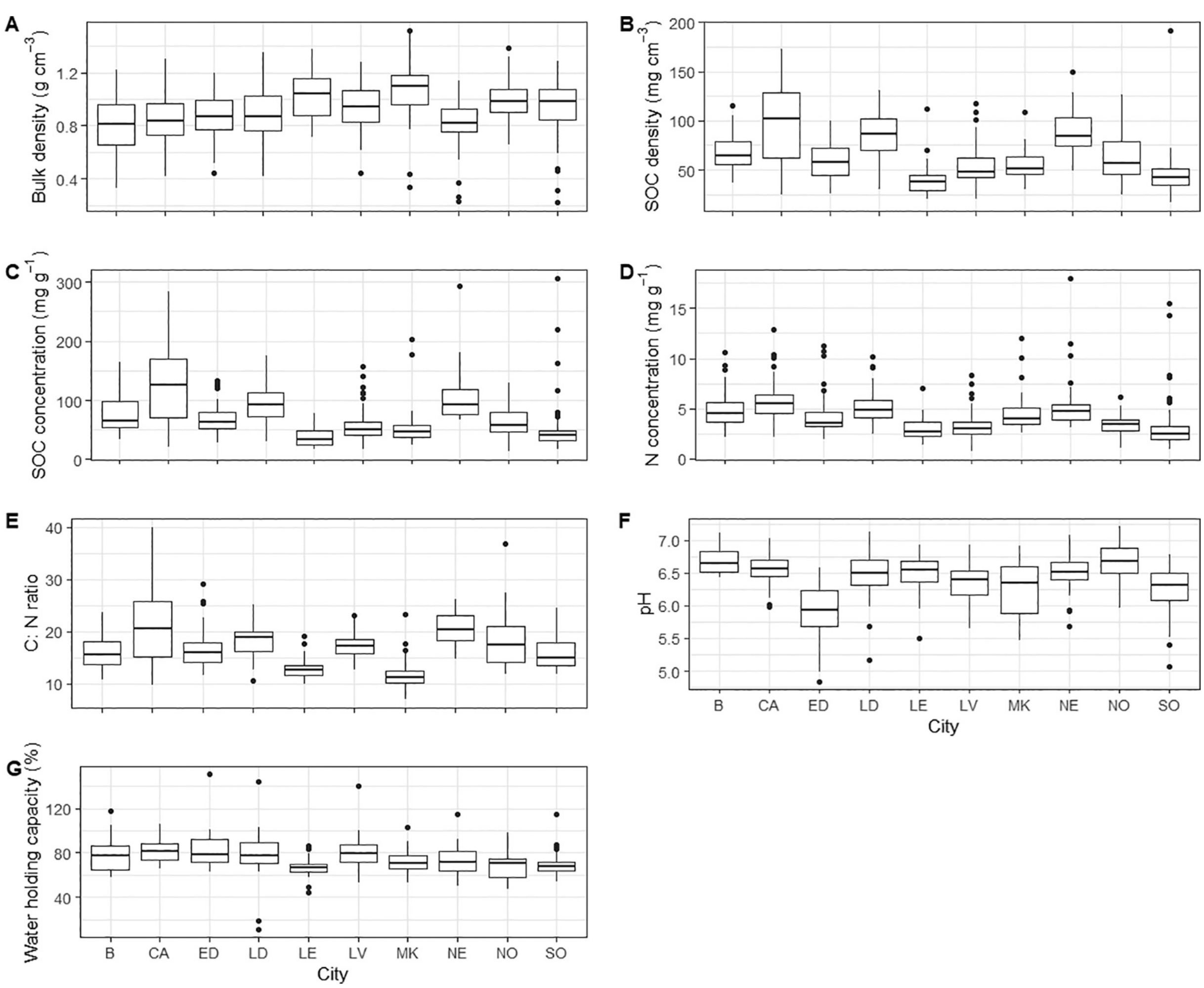

Fig. 3. Graphs showing medians, interquartile ranges and outliers for soil quality indicators on allotments sampled in ten British urban areas: Bristol (B), Cardiff (CA), Edinburgh (ED), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO) and Southampton (SO). A: Bulk density, B: SOC density; C: OC concentration; D: N concentration; E: C:N ratio; F: pH; and G: water holding capacity.

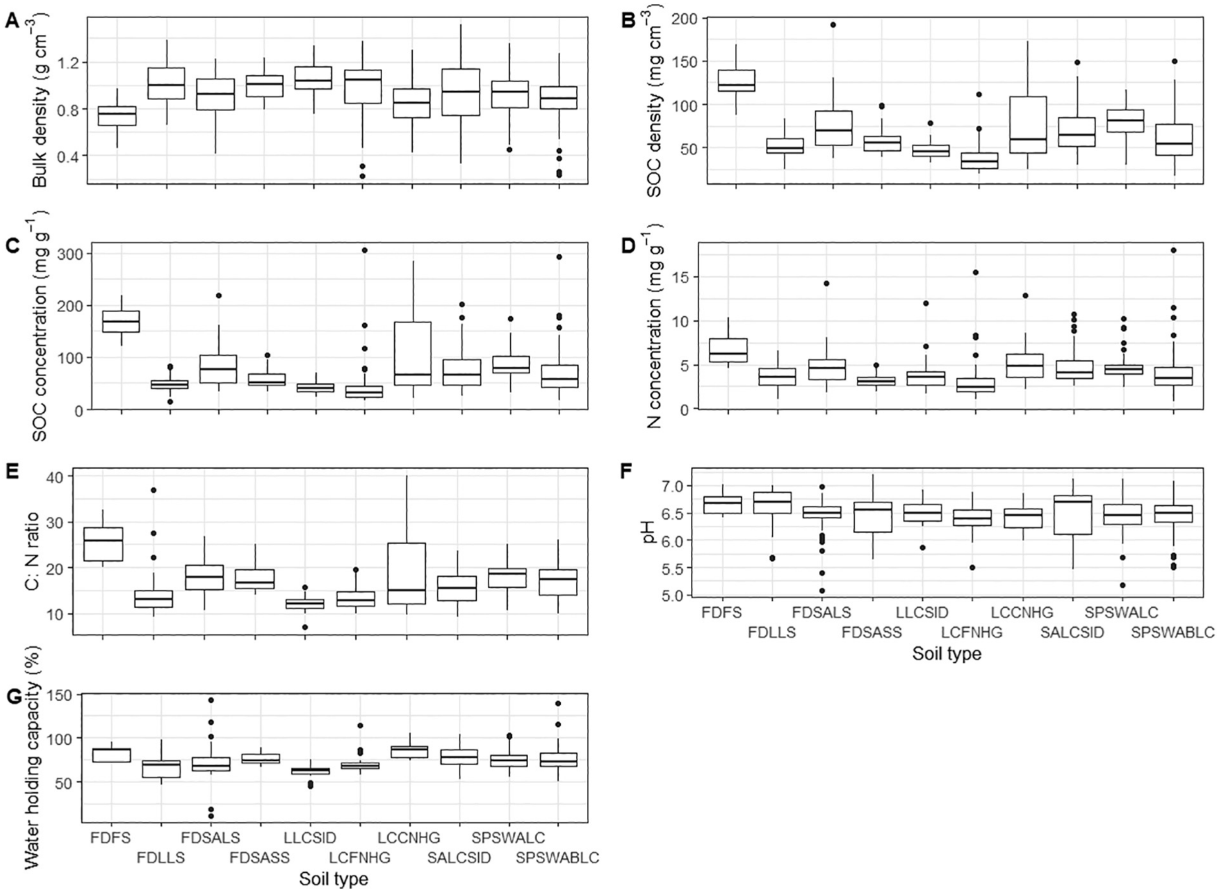

Fig. 4. Graphs showing medians, interquartile ranges and outliers for soil quality indicators on allotments according to soil type: A: Bulk density, B: SOC density; C: OC concentration; D: N concentration; E: C:N ratio; F: pH; and G: water holding capacity. Soil types abbreviated as follows: freely draining floodplain soils (FDFS), freely draining lime rich loamy soils (FSLLS), freely draining slightly acid loamy soils (FSALS), freely draining slightly acid sandy soils (FDSASS), lime rich loamy and clayey soils with impeded drainage (LLCSID), loamy and clayey floodplain soils with naturally high groundwater (LCFNHG), loamy and clayey soils of coastal flats with naturally high groundwater (LCCNHG), slightly acid loamy and clayey soils with impeded drainage (SALCSID), slowly permeable seasonally wet acid loamy and clayey soils (SPSWALC), and slowly permeable seasonally wet slightly acid but base rich loamy and clayey soils (SPSWABLC).

We estimate allotment SOC storage (Tg to 20 cm) in Great Britain ranges from 1.35–2.15 Tg if permeable surfaces on allotments maintain the same SOC levels as cultivated areas, and 0.86–1.37 Tg if permeable uncultivated areas have an SOC storage level the same as rural arable and horticultural land (Table 4).

4. Discussion

Previously, site-specificity of research limited our understanding of the nature and properties of UH soils (Borysiak et al., 2017). Whilst, globally, research into the quality of UH soils has been increasing in recent years and is drawing up a positive international picture regarding UH worldwide (Brock and Foeken, 2006; González et al., 2010; Bretzel et al., 2018; Egerer et al., 2018; Tresch et al., 2018), to date no nationwide surveys have been undertaken. Here, using data at a national scale, we can assess overall properties of allotment soils, and compare their SOC concentrations with those of arable and horticultural land. We find that UH soils in allotments maintain levels of SOC across Great Britain that are significantly higher than those found arable and horticultural soil.

SOC is one of the most important overall indicators of soil health (Franzluebbers, 2002). The most recent Countryside Survey, a national-scale survey that includes measures of soil health across Great Britain (Emmett et al., 2010), found that average SOC concentration for arable and horticultural land was 30.7 mg g^{-1}. This is higher than the 23.5 mg g^{-1} we found, but still substantially lower than the average allotment SOC concentration of 58.2 mg g^{-1}. Allotment SOC concentrations from our field data were similar to improved grassland, which had an SOC concentration of 56.9 g kg^{-1} (Emmett et al., 2010).

Bulk density on allotments was 0.92 g cm^{-3}, compared to 1.23 g cm^{-3} for arable and horticultural soil reported nationally (Emmett et al., 2010). This is lower than the BD reported for allotments in a case-study in Leicester (Edmondson et al., 2014a); however, our values for Leicester were consistent with this study. Bulk density is typically negatively correlated with SOC and provides a proxy measure for soil compaction with higher bulk density values indicating more compacted soils (Edmondson et al., 2011). Compaction has negative impacts for erosion and flood mitigation, as well as impeding plant growth (Edmondson et al., 2011). We found lower pH on allotments than those reported in the Countryside Survey from arable and horticultural soils (6.5 vs. 7.2; Emmett et al., 2010). For horticultural production, a pH of 6.5 is ideal, allowing optimum earthworm activity and nutrient availability (Royal Horticultural Society, 2020). Total N concentration was higher on allotments than in arable and horticultural soils (3.7 mg g^{-1} vs. 2.5 mg g^{-1}; Emmett et al., 2010), and C:N ratio was also higher (16.0 vs. 11.3; Emmett et al., 2010). The higher C:N ratio is linked to reduced N leaching and maintaining good levels of nutrient cycling, which is also supported by higher WHC (Dominati et al., 2010; Robinson et al., 2013). Overall C:N ratios in this nationwide study were slightly higher than those reported on allotments in Leicester but were consistent with the soils in that urban area (Edmondson et al., 2014a).

Non-urban British soils store an estimated 1582 Tg of OC to 15 cm (Emmett et al., 2010). Our estimates suggest that allotment soils store a further 0.86–2.15 Tg to 20 cm, with the true value likely to be at the

Table 3
Soil quality indicators on allotments analysed using linear mixed effects models, showing transformations applied to the data; the model terms (fixed and random effects) included that created the most parsimonious model for each variable; the results of type III analysis of variance on each of the fixed terms in each model. For N concentration, no analysis was performed as the model was most parsimonious without any fixed effects. Bold text indicates p<0.05.

Variable	Transformation	Fixed effects	Random effects	Results	Annual/perennial	Depth category	Soil type	Crop type:depth	Crop type: soil type	Depth: soil type	Crop type: depth: soil type
Bulk density	None	Crop type, depth, soil type	City	F	$_{1595.8}$ = 0.55	$_{1596.0}$ = 0.93	$_{9601.4}$ = 1.80	$_{1595.78}$ = 0.09	$_{9595.81}$ = 0.55	$_{9595.96}$ = 0.74	$_{9595.82}$ = 0.41
				p	0.81	0.34	0.07	0.76	0.83	0.67	0.93
SOC density	Log	Crop type, depth, soil type	City	F	$_{1560.88}$ = 1.52	$_{1560.95}$ = 0.47	$_{9566.37}$ = 2.11	$_{1560.89}$ = 1.78	$_{9560.89}$ = 0.50	$_{9560.98}$ = 0.54	$_{9560.91}$ = 0.39
				p	0.22	0.49	**0.03**	0.18	0.87	0.85	0.94
SOC concentration	Log	Crop type, depth, soil type	Site	F	$_{1598.91}$ = 0.02	$_{1598.93}$ = 2.13	$_{9604.71}$ = 0.86	$_{1598.9}$ = 0.21	$_{9598.92}$ = 0.43	$_{9598.95}$ = 0.43	$_{9598.91}$ = 0.26
				p	0.90	0.14	0.56	0.65	0.92	0.99	0.98
N concentration	Square-root	None	City & site	F	–	–	–	–	–	–	–
				p	–	–	–	–	–	–	–
C:N	Log	Crop type, depth, soil type	City	F	$_{1598.98}$ = 0.43	$_{1598.98}$ = 0.00	$_{9603.72}$ = 2.03	$_{1598.96}$ = 0.12	$_{9598.97}$ = 0.48	$_{9598.99}$ = 0.16	$_{9598.97}$ = 0.26
				p	0.51	0.99	**0.03**	0.72	0.89	0.99	0.98
pH	Exponential	Crop type, soil type	City & site	F	$_{1293.05}$ = 3.17	–	$_{9,22.50}$ = 0.96	–	$_{9292.49}$ = 2.67	–	–
				p	0.07	–	0.50	–	**0.005**	–	–
Water holding capacity	Log	Crop type, soil type	City	F	$_{1295.46}$ = 0.65	–	$_{9184.82}$ = 5.39	–	$_{7295.64}$ = 0.20	–	–

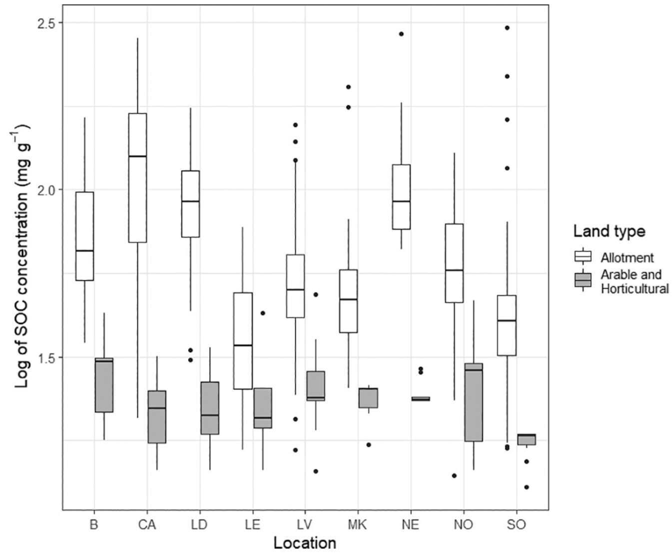

Fig. 5. Graph showing medians, interquartile ranges and outliers for soil organic carbon concentration in topsoil (0–20 cm) in allotments within cities, and arable and horticultural land surrounding each urban area: Bristol (B), Cardiff (CA), Leeds (LD), Leicester (LE), Liverpool (LV), Milton Keynes (MK), Newcastle (NE), Nottingham (NO), and Southampton (SO).

higher end of this estimate, given that most urban greenspaces are higher in SOC concentration than rural arable and horticultural land (Edmondson et al., 2014b). Whilst this suggests that allotments only add another 0.05 to 0.14% to nationwide SOC stock estimates, allotments comprise only 0.0006% land in Great Britain. This suggests that their contribution to SOC stocks is high compared to their areal extent. As only one example form of urban greenspace, this estimation, whilst small, demonstrates the need to accurately assess the total contribution of all forms of urban greenspace to national SOC stocks. It is further evidence that discounting urban greenspace, and specifically urban horticultural land, from estimates in SOC stocks results in underestimation of SOC stocks nationally. As urbanisation is forecast to replace agricultural expansion as the primary driver of land-use change globally, it is increasingly important to accurately estimate urban SOC stocks (Lorenz and Lal, 2015). Further, it is evidence that UH maintains a consistently high level of soil quality, not suffering from the degradation seen in other agricultural land.

Overall, management practices undertaken by allotment gardeners mirror those recommended for the maintenance of soil health and organic matter (Lorenz and Lal, 2009; Lorenz, 2015; Gregory et al., 2016). However, some heterogeneity in influence has also been found, for example an excess of N fertilisation on allotments over five years leading to low C:N in allotments in Pisa, Italy (Bretzel et al., 2018); and the finding that sociodemographic factors affect soil quality in community gardens in California, USA, with more affluent communities better able to manage their soil for long term sustainability and soil health (Egerer et al., 2018). However, our analyses did not reveal any consistent findings regarding the influence of soil management techniques on soil quality. There are a number of possible reasons for this result, which goes against established scientific opinion on the ability of soil management to influence soil properties, including in UH contexts (Bell et al., 2016; Bretzel et al., 2018; Egerer et al., 2018; Tresch et al., 2018). Firstly, our questionnaires with plotholders asked them about whole-plot management; the management of the specific crops sampled may have varied. This means that the management practices detailed in the questionnaire responses may not have directly related to the soils which were sampled. Further to this, long-term management of soils has substantial impacts on their qualities (Lorenz, 2015). Previous tenants on the same plot may have managed their soil differently,

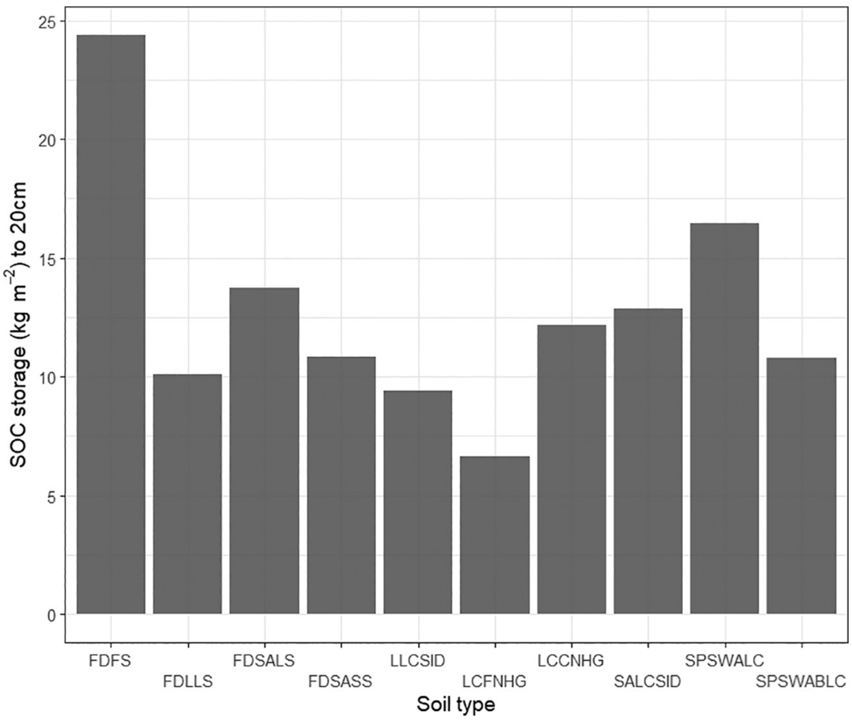

Fig. 6. Soil organic carbon storage (kg m^{-2}) to 20 cm depth by soil types on allotments: freely draining floodplain soils (FDFS), freely draining lime rich loamy soils (FSLLS), freely draining slightly acid loamy soils (FSALS), freely draining slightly acid sandy soils (FDSASS), lime rich loamy and clayey soils with impeded drainage (LLCSID), loamy and clayey floodplain soils with naturally high groundwater (LCFNHG), loamy and clayey soils of coastal flats with naturally high groundwater (LCCNHG), slightly acid loamy and clayey soils with impeded drainage (SALCSID), slowly permeable seasonally wet acid loamy and clayey soils (SPSWALC), and slowly permeable seasonally wet slightly acid but base rich loamy and clayey soils (SPSWABLC).

which would affect those plots where tenancy had only recently been undertaken. Finally, allotment soils were in consistently good health, giving limited scope for variations in management revealed by the questionnaire responses to produce significant variation in the soil quality. This is borne out by the fact that our questionnaire results provided good evidence that UH gardeners manage their soils in ways that are known to be effective in supporting long-term food security and soil health (Tresch et al., 2018; Bretzel et al., 2018), corresponding to good practice guidelines such as those from COST (COST, 2019). Any future expansion of UH should, therefore, follow current practices of food production, utilising knowledge exchange to ensure that when UH land use expands, sustainable soil management practices continue to be employed, and that sociodemographic factors are taken into account so municipal authorities can target education and resource provision to communities more in need of assistance in maintaining good soil quality (Tresch et al., 2018; Bretzel et al., 2018; Egerer et al., 2018).

We found a consistently significant impact of soil type on soil properties, underscoring the need for nationwide approaches to truly understand the properties of urban soils. In future research, biological indicators would provide a further lens through which to examine urban horticultural soil quality, as demonstrated by Zhang et al. (2019); bacterial community composition is an important indicator of ecosystem health. However, the potential dis-services of allotment soils are also in need of further research. This includes issues such as heavy metal contamination and the bio-availability of soil heavy metals; as well as any potential for NPK accumulation (Lorenz, 2018). Adverse health effects of UH through soil contamination have been contested (Leake et al., 2009; Mees and Stone, 2012), but further research is necessary in this area. Indeed, different management practices have been shown to lead to different levels of heavy metal accumulation in UH soils (Bretzel et al., 2018).One paper has however found that risk perception may be a more limiting factor than risk itself in UH, so continued education of its multiplicity of benefits and potential ecosystem service provision is important (Wortman and Lovell, 2013). Opportunities also exist in future research to investigate the potential for the required inputs (e.g. water) for UH to be sourced from within the urban system, utilising waste energy to improve sustainability (Kumar and Hundal, 2016; Mcdougall et al., 2020). In general, further research directions should focus on continuing to improve our understanding of the factors driving the maintenance of high soil quality levels in UH at national and international scales. Other soil-based UH types could be investigated, perhaps building on the work of Loram et al. (2008) to identify the typical crop area cultivated by gardeners who grow food in home gardens, and uncover whether allotment UH soil quality is maintained in domestic gardens, which occupy an even greater areal extent than allotments, and present another important area in which to consider SOC storage. Researchers should also investigate possible areas where trade-offs exist between different ecosystem services, leading to an understanding of the best way to practice UH that delivers the maximum benefits for both human wellbeing and ecosystem health. As an expanding body of research on yields in UH (Edmondson et al., 2020a; Mcdougall et al., 2020) feeds into policies for scaling up urban horticultural production, our findings provide promising empirical evidence to demonstrate that such upscaling would also improve other soil-based ecosystem

Table 4
Estimates of carbon storage on British allotments.

Method	Minimum SOC storage (Tg to 20 cm)	Mid-range SOC storage (Tg to 20 cm)	Maximum SOC storage (Tg to 20 cm)
All allotment permeable areas have the same SOC values	1.35	1.55	2.15
Uncultivated permeable areas have arable land SOC values	0.86	0.99	1.37

services (such as climate change mitigation, flood mitigation, filtration, and biodiversity conservation; Dominati et al., 2010; Edmondson et al., 2012; Rawlins et al., 2013) alongside food provision.

5. Conclusions

This research has demonstrated that urban horticultural soils are of a consistently high quality, for the first time expanding case study locations to a national scale. Our findings add to the evidence base that UH maintains considerably higher levels of SOC than arable and rural horticultural soils, and performs better on other soil quality indicators as well. We have shown that allotments function as a reservoir of SOC, contributing to the national carbon budget and underscoring the need for thorough assessment of urban soils within this. We have also demonstrated that management practices on allotments follow techniques conducive to sustainable crop productivity as well as ecological health. Overall, our findings suggest a potential for valuable ecosystem service provision by UH soils beyond that of just food production. This further contributes to a growing evidence base of the value of UH.

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CRediT authorship contribution statement

Miriam C. Dobson: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Marta Crispo:** Investigation, Formal analysis. **Roscoe S. Blevins:** Investigation. **Philip H. Warren:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision, Funding acquisition. **Jill L. Edmondson:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Funding acquisition.

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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References

Acton, L., 2015. Growing Space: A History of the Allotment Movement. Five Leaves Publications, Nottingham.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67 (1), 1–48. https://doi.org/10.18637/jss.v067.i01.

Batjes, N.H., 2014. Total carbon and nitrogen in the soils of the world. Soil Sci. 65 (1), 10–21. https://doi.org/10.1111/ejss.12114_2.

Bell, S., Fox-Kämper, R., Keshavarz, N., Benson, M., Caputo, S., Noori, S., Voigt, A. (Eds.), 2016. Urban Allotment Gardens in Europe. Routledge, Abingdon, pp. 142–164.

Benis, K., Ferrão, P., 2017. Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – a life cycle assessment approach. J. Clean. Prod. 140 (2), 784–795. https://doi.org/10.1016/j.jclepro.2016.05.176.

Beniston, J., Lal, R., 2012. Improving soil quality for urban agriculture in the north central U.S. Carbon Sequestration in Urban Ecosystems, pp. 279–313 https://doi.org/10.1007/978-94-007-2366-5_15.

Borysiak, J., Mizgajski, A., Speak, A., 2017. Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. Urban Ecosyst. 20 (2), 323–335. https://doi.org/10.1007/s11252-016-0595-4.

Bradley, R., Milne, R., Bell, J., Lilly, A., Jordan, C., Higgins, A., 2005. A soil carbon and land use database for the United Kingdom. Soil Use Manag. 21, 363–369. https://doi.org/10.1079/SUM2005351.

Bretzel, F., Caudai, C., Tassi, E., Rosellini, I., Scatena, M., Pini, R., 2018. Culture and horticulture: protecting soil quality in urban gardening. Sci. Total Environ. 644, 45–51. https://doi.org/10.1016/j.scitotenv.2018.06.289.

Brock, B., Foeken, D., 2006. Urban horticulture for a better environment: a case study of Cotonou, Benin. Habitat Int. 30 (3), 558–578. https://doi.org/10.1016/j.habitatint.2005.02.001.

Campbell, M., Campbell, I., 2013. Allotment Waiting Lists in England 2013. Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2013.pdf.

Church, A., Mitchell, R., Ravenscroft, N., Stapleton, L.M., 2015. 'Growing your own': a multi-level modelling approach to understanding personal food growing trends and motivations in Europe. Ecol. Econ. 110, 71–80. https://doi.org/10.1016/j.ecolecon.2014.12.002.

Climate-Data.org, 2021. Climate data for cities worldwide. https://en.climate-data.org/.

COST, 2019. Urban Allotment Gardens/Action in Detail. European Cooperation in Science and Technology https://www.urbanallotments.eu/action-in-detail.html.

Crouch, D., Ward, C., 1997. The Allotment: Its Landscape and Culture. Five Leaves Publications, Nottingham.

de Brogniez, D., Ballabio, C., Stevens, A., Jones, R.J.A., Montanarella, L., van Wesemael, B., 2014. A map of the topsoil organic carbon content of Europe generated by a generalised additive model. Eur. J. Soil Sci. 66 (1), 121–134. https://doi.org/10.1111/ejss.12193.

Dobson, M.C., Edmondson, J.L., Warren, P.H., 2020. Urban food cultivation in the United Kingdom: quantifying loss of allotment land and identifying potential for restoration. Landsc. Urban Plan. 199 (103803). https://doi.org/10.1016/j.landurbplan.2020.103803.

Dominati, E., Patterson, M., Mackay, A., 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecol. Econ. 69 (9), 1858–1868. https://doi.org/10.1016/j.ecolecon.2010.05.002.

Edmondson, J.L., Davies, Z.G., McCormack, S.A., Gaston, K.J., Leake, J.R., 2011. Are soils in urban ecosystems compacted? A citywide analysis. Biol. Lett. 23, 771–774. https://doi.org/10.1098/rsbl.2011.0260.

Edmondson, J.L., Davies, Z.G., McHugh, N., Gaston, K.J., Leake, J.R., 2012. Organic carbon hidden in urban ecosystems. Sci. Rep. 2, 963. https://doi.org/10.1038/srep00963.

Edmondson, J.L., Davies, Z.G., Gaston, K.J., Leake, J.R., 2014a. Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. J. Appl. Ecol. 51, 880–889. https://doi.org/10.1111/1365-2664.12254.

Edmondson, J.L., Davies, Z.G., McCormack, S.A., Gaston, K.J., Leake, J.R., 2014b. Land-cover effects on soil organic carbon stocks in a European city. Sci. Total Environ. 472, 444–453. https://doi.org/10.1016/j.scitotenv.2013.11.025.

Edmondson, J.L., Cunningham, H., Densley Tingley, D.O., Dobson, M.C., Grafius, D.R., Leake, J.R., McHugh, N., Nickles, J., Pheonix, G.K., Ryan, A.J., Stovin, V., Taylor Buck, N., Warren, P.H., Cameron, D.D., 2020a. The hidden potential of urban horticulture. Nat. Food 1 (3), 155–159. https://doi.org/10.1038/s43016-020-0045-6.

Edmondson, J.L., Childs, D.Z., Dobson, M.C., Gaston, K.J., Warren, P.H., Leake, J.R., 2020b. Feeding a city – Leicester as a case study of the importance of allotments for horticultural production in the UK. Sci. Total Environ. 705. https://doi.org/10.1016/j.scitotenv.2019.135930.

Egerer, M.H., Philpott, S.M., Liere, H., Jha, S., Bichier, P., Lin, B.B., 2018. People or place? Neighborhood opportunity influences community garden soil properties and soil-based ecosystem services. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 14 (1), 32–44. https://doi.org/10.1080/21513732.2017.1412355.

Eigenbrod, C., Gruda, N., 2015. Urban vegetable for food security in cities. A review. Agron. Sustain. Dev. 35 (2), 483–498. https://doi.org/10.1007/s13593-014-0273-y.

Emmett, B.A., Reynolds, B., Chamberlain, P.M., Rowe, E., Spurgeon, D., Brittain, S.A., Frogbrook, Z., Hughes, S., Lawlor, A.J., Poskitt, J., Potter, E., Robinson, D.A., Scott, A., Wood, C., Woods, C., 2010. Countryside Survey: Soils Report From 2007. Technical Report No. 9/07 NERC/Centre for Ecology & Hydrology 192 pp. (CEH Project Number: C03259).

Franzluebbers, A.J., 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil Tillage Res. 66 (2), 95–106. https://doi.org/10.1016/S0167-1987(02)00018-1.

Gardner, W.H., 1986. Water content. Methods of Soil Analysis: Part 1: Physical and Mineralogical Methods. vol. 5, pp. 493–544. https://doi.org/10.2136/sssabookser5.1.2ed.c21.

Goldstein, B., Hauschild, M., Fernández, J., Birkved, M., 2016. Urban versus conventional agriculture, taxonomy of resource profiles: a review. Agron. Sustain. Dev. 36 (1), 1–19. https://doi.org/10.1007/s13593-015-0348-4.

González, M., Gomez, E., Comese, R., Quesada, M., Conti, M., 2010. Influence of organic amendments on soil quality potential indicators in an urban horticultural system. Bioresour. Technol. 101 (22), 8897–8901. https://doi.org/10.1016/j.biortech.2010.06.095.

Grafius, D.R., Edmondson, J.L., Norton, B.A., Clark, R., Mears, M., Leake, J.R., ... Warren, P.H., 2020. Estimating food production in an urban landscape. Sci. Rep. 10 (1). https://doi.org/10.1038/s41598-020-62126-4.

Gregory, M.M., Leslie, T.W., Drinkwater, L.E., 2016. Agroecological and social characteristics of New York city community gardens: contributions to urban food security, ecosystem services, and environmental education. Urban Ecosyst. 19 (2), 763–794. https://doi.org/10.1007/s11252-015-0505-1.

Houba, V.J.G., Temminghoff, G.A.G., van Vark, W., 2000. Soil analysis procedures using 0.01 M calcium chloride as extraction reagent. Commun. Soil Sci. Plant Anal. 31 (9–10), 1299–1396. https://doi.org/10.1080/00103620009370514.

Kumar, K., Hundal, L.S., 2016. Soil in the city: sustainably improving urban soils. J. Environ. Qual. 45 (1), 2–8. https://doi.org/10.2134/jeq2015.11.0589.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. lmerTest package: tests in linear mixed effects models. J. Stat. Softw. 82 (13), 1–25. https://doi.org/10.18637/jss.v082.i13.

Lal, R., 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123 (1–2), 1–22. https://doi.org/10.1016/j.geoderma.2004.01.032.

Lal, R., 2010. Beyond Copenhagen: mitigating climate change and achieving food security through soil carbon sequestration. Food Secur. 2 (2), 169–177. https://doi.org/10.1007/s12571-010-0060-9.

Lal, R., 2018. Urban agriculture in the 21st century. In: Lal, R., Stewart, B.A. (Eds.), Urban Soils. CRC Press, Taylor and Francis, London, pp. 1–13.

Leake, J.R., Adam-Bradford, A., Rigby, J.E., 2009. Health benefits of "grow your own" food in urban areas: implications for contaminated land risk assessment and risk management? Environ. Health 8 (Suppl. 1), S6. https://doi.org/10.1186/1476-069X-8-S1-S6.

Loram, A., Warren, P.H., Gaston, K.J., 2008. Urban domestic gardens (XIV): the characteristics of gardens in five cities. Environ. Manag. 42 (3), 361–376. https://doi.org/10.1007/s00267-008-9097-3.

Lorenz, K., 2015. Organic urban agriculture. Soil Sci. 180, 146–153. https://doi.org/10.1097/SS.0000000000000129.

Lorenz, K., 2018. Managing urban soils for food production. In: Lal, R., Stewart, B.A. (Eds.), Urban Soils. CRC Press, Taylor and Francis, London, pp. 295–312.

Lorenz, K., Lal, R., 2009. Biogeochemical C and N cycles in urban soils. Environ. Int. 35 (1), 1–8. https://doi.org/10.1016/j.envint.2008.05.006.

Lorenz, K., Lal, R., 2015. Managing soil carbon stocks to enhance the resilience of urban ecosystems. Carbon Manag. 6 (1–2), 35–50. https://doi.org/10.1080/17583004.2015.1071182.

Mbow, C.C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., Xu, Y., 2018. Food security. In: Shukla, P.R., Skea, J., Buendia, E. Calvo, Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Pereira, J. Portugal, Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J. (Eds.), Climate Change and Land: An IPCC Special Report on Climate Change, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems (in press).

Mcdougall, R., Rader, R., Kristiansen, P., 2020. Urban agriculture could provide 15% of food supply to Sydney, Australia, under expanded land use scenarios. Land Use Policy 94, 104554. https://doi.org/10.1016/j.landusepol.2020.104554.

Mees, C., Stone, E., 2012. Food, homes and gardens: public community gardens potential for contributing to a more sustainable city. In: Viljoen, A., Wiskerke, J.S.C. (Eds.), Sustainable Food Planning: Evolving Theory and Practice, pp. 431–452 https://doi.org/10.3920/978-90-8686-187-3_35.

Morel, J.L., Chenu, C., Lorenz, K., 2015. Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs). J. Soils Sediments 15 (8), 1659–1666. https://doi.org/10.1007/s11368-014-0926-0.

National Soil Resources Institute, 2001. NATMAPVECTOR: Carbon. Cranfield University, Cranfield, UK.

Ordnance Survey, 2017. OS Open Greenspace. https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-greenspace.html.

Pouyat, R.V., Yesilonis, I.D., Nowak, D.J., 2006. Carbon storage by urban soils in the United States. J. Environ. Qual. 35 (4), 1566–1575. https://doi.org/10.2134/jeq2005.0215.

Powlson, D.S., Gregory, P.J., Whalley, W.R., Quinton, J.N., Hopkins, D.W., Whitmore, A.P., Hirsch, P.R., Goulding, K.W.T., 2011. Soil management in relation to sustainable agriculture and ecosystem services. Food Policy 36 (Supplement 1), S72–S87. https://doi.org/10.1016/j.foodpol.2010.11.025.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria https://www.R-project.org.

Rawlins, B.G., Harris, J., Price, S., Bartlett, M., 2013. A review of climate change impacts on urban soil functions with examples and policy insights from England, UK. Soil Use Manag. 31, S1. https://doi.org/10.1111/sum.12079.

Robinson, D.A., Hockley, N., Cooper, D.M., Emmett, B.A., Keith, A.M., Lebron, I., Reynolds, B., Tipping, E., Tye, A.M., Watts, C.W., Whalley, W.R., Black, H.I.J., Warren, G.P., Robinson, J.S., 2013. Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. Soil Biol. Biochem. 57, 1023–1033. https://doi.org/10.1016/j.soilbio.2012.09.008.

Rowland, C.S., Morton, R.D., Carrasco, L., McShane, G., O'Neil, A.W., Wood, C.M., 2017. Land Cover Map 2015 (Vector, GB). NERC Environmental Information Data Centre https://doi.org/10.5285/6c6c9203-7333-4d96-88ab-78925e7a4e73.

Royal Horticultural Society, 2020. Soil: understanding pH and testing soil. https://www.rhs.org.uk/advice/profile?pid=239. (Accessed 1 July 2020).

Smithers, R., 2020. Interest in allotments soars in England during coronavirus pandemic. The Guardianhttps://www.theguardian.com/lifeandstyle/2020/aug/10/interest-in-allotments-soars-in-england-during-coronavirus-pandemic. (Accessed 25 August 2020) (10 August 2020).

Speak, A.F., Mizgajski, A., Borysiak, J., 2015. Allotment gardens and parks: provision of ecosystem services with an emphasis on biodiversity. Urban For. Urban Green. 14 (4), 772–781. https://doi.org/10.1016/j.ufug.2015.07.007.

Tresch, S., Moretti, M., Le Bayon, R., Mäder, P., Zanetta, A., Frey, D., Fliessback, A., 2018. A gardener's influence on urban soil quality. Front. Environ. Sci. 6. https://doi.org/10.3389/fenvs.2018.00025.

United Nations, 2019. Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision. (ST/ESA/SER.A/420).

Wilson, B.R., Koen, T.B., Barnes, P., Ghosh, S., King, D., 2011. Soil carbon and related soil properties along a soil type and land-use intensity gradient, New South Wales, Australia. Soil Use Manag. 27 (4), 437–447. https://doi.org/10.1111/j.1475-2743.2011.00357.x.

Wiskerke, J.S.C., Viljoen, A., 2012. Chapter 1 Sustainable urban food provisioning: challenges for scientists, policymakers, planners and designers. Sustainable food planning: evolving theory and practice https://doi.org/10.3920/978-90-8686-187-3_1.

Wortman, S.E., Lovell, S.T., 2013. Environmental challenges threatening the growth of urban agriculture in the United States. J. Environ. Qual. 42 (5), 1283–1294. https://doi.org/10.2134/jeq2013.01.0031.

Zhang, P., Zhang, L., Chang, Y., Xu, M., Hao, Y., Liang, S., Wang, C., 2019. Food-energy-water (FEW) nexus for urban sustainability: a comprehensive review. Resour. Conserv. Recycl. 142, 215–224. https://doi.org/10.1016/j.resconrec.2018.11.018.

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Assessing the Direct Resource Requirements of Urban Horticulture in the United Kingdom: A Citizen Science Approach

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Abstract: Interest in urban food production is growing; recent research has highlighted its potential to increase food security and reduce the environmental impact of food production. However, resource demands of urban horticulture are poorly understood. Here, we use allotment gardens in the United Kingdom to investigate resource demands of urban horticultural production across the country. We conducted a nationwide citizen science project using year-long allotment 'diaries' with allotment gardeners (n = 163). We analysed a variety of resources: transportation; time; water use; inputs of compost, manure and topsoil; and inputs of fertilisers, pest control and weed control. We found that, overall, an allotment demands 87 annual visits, travelling 139 km to and from the plot; 7 fertiliser additions; 4 pest control additions; and 2 weed control additions. On average, each kilogram of food produced used 0.4 hours' labour, 16.9 L of water, 0.2 L of topsoil, 2.2 L of manure, and 1.9 L of compost. As interest in urban horticultural production grows, and policy makers build urban horticultural spaces into future sustainable cities, it is of key importance that this is carried out in a way that minimises resource requirements, and we demonstrate here that avenues exist for the diversion of municipal compostable waste and household-level city food waste for this purpose.

Keywords: United Kingdom; allotments; urban agriculture; energy; sustainability; cities

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1. Introduction

The urban population of the world is rising, and is predicted to continue to do so over the next few decades [1]. Increasing urban populations highlight the need to understand and plan for the issues underpinning the sustainability of urban systems. Food is one of these. Cities are dependent on international food supply chains, which are vulnerable to shocks in the global system such as the 2020 coronavirus pandemic and the 2008–2009 food price crisis [2]. In many cities across the world, there is developing interest in the potential of urban horticulture (UH) to build resilience to such shocks. UH is the production of fruit and vegetables taking place in urban areas. It could also improve the environmental footprint of urban food consumption [3] and create opportunities for other social and environmental benefits associated with UH [4]. Research into mechanisms and opportunities for upscaling the amount of food production taking place within city limits has recently found promising results regarding potential food provisioning [5,6]. Some cities already produce a large proportion of their fruit and vegetable needs within the city limits; for example, Shanghai produces 60% of the vegetables consumed by its residents [7]. Many other cities now include some reference to UH within their sustainability planning, and networks of cities interested in scaling up urban food production are increasingly popular. The Milan Urban Food Policy Pact has 210 city signatories [8], and the UK's Sustainable Food Cities network has 52 [9]. There is also a large body of research demonstrating that UH can provide co-benefits alongside food production, such as improved health and wellbeing, educational and nutritional literacy, respect for and awareness of the natural world, and the delivery of ecosystem services [10–15].

An underlying assumption of the above research, and general increase in interest in UH in cities in the global North, is that UH offers a form of fruit and vegetable production that has many benefits not found in conventional horticulture; it may, at the same time also be more sustainable. The nature of much UH activity, which takes place informally, at small scales, and in different settings (unlike conventional horticulture taking place commercially at larger scales), means that the energy and resource flows associated with it have not commonly been integrated into citywide systems thinking [16]. There are many forms of UH with correspondingly varied resource demands [17]. What we do know about resource demand is limited to very few analyses, such as Life Cycle Analysis (LCA) on integrated urban farms, soil-less systems or rooftops [16,18,19]. However, most UH is small-scale, soil-based, activity, and has received little attention from this point of view; a single garden was used as a case study for an LCA in Italy [20], but representative, more geographically ranging multiple case studies have not been undertaken. Two studies which addressed this issue from a systems approach have both identified the need for careful consideration of technologies and policies promoting urban food production, to ensure they do not lead to increased resource demands in the urban system [21,22].

In this paper, we investigate the year-round resource demands of allotment gardening in the UK. Allotments are the most significant form of UH in the UK [23,24], and also form a large proportion of UH land across the European continent [13]. Allotment 'plots', typically 250 m^2 land parcels, are rented by individuals or families from local councils or private landowners, and plots are grouped together on larger sites comprising anything from fewer than ten to over one hundred plots. There are approximately 330,000 allotments plots in the UK [25], and allotment sites as a whole use 82% of their land for plots, with the remaining used for associated infrastructure such as vehicle access [26]. Recent research has demonstrated that allotment gardening has the potential to be a highly important form of UH. One case study analysis found that it could provide fruit and vegetables for 3% of a city's population despite allotments covering less than 1.5% of the city's area [26]. Demand for allotments is rising [27], with an average of 52 people on waiting lists for every 100 plots in the UK [25], and evidence suggests that the COVID-19 pandemic is further increasing demand for growing space [28]. It is therefore timely to develop our understanding of what the associated resource costs of allotment gardening are. We need to assess the sustainability of this form of UH, and identify opportunities for "urban symbiosis" (the potential to use resources otherwise wasted in the urban system, such as rainwater or organic waste) [17], so future developments of UH land can be integrated into cities in a way that enhances the sustainability of resource use.

There are a number of ways in which integration of UH might contribute to enhanced urban sustainability. For example, increasing kitchen waste compost for use in UH and redirecting excess rainfall for growing purposes could not only lead to a reduction in greenhouse gas emissions but also a reduction in costs associated with landfill management, water demand and flood mitigation [29,30]. According to the United States Environmental Protection Agency [31], 28% of household waste sent to landfill is potentially compostable. On average, over 16 kg of vegetables are wasted per year per capita across the world [32]. Producing food locally, and composting waste, has the potential to reduce overall food waste as well as lower the emissions associated with food spoilage occurring during transportation [19,29,32]. The built infrastructure of urban environments also provides considerable potential for rainwater harvesting; it is estimated that Munich could save 26% of its current freshwater supply by harvesting rainwater [33]. If this were integrated into UH, better management of rainwater run-off and a reduction in demand on the water supply could benefit both UH and the overall fabric of an urban area. There is widespread agreement that development and protection of urban green infrastructure, including UH, can contribute to sustainability of urban systems, for example through the mitigation of the urban heat island effect [30,34]. There is also some evidence that greenhouse gas emissions reductions from expanding UH are greater than the sequestration potential of other urban greenspaces, based on LCA results [18].

We know from previous research that allotment gardeners tend to use management practices conducive to the maintenance of highly productive soils: in one study [35], 75% of respondents added manure, 95% composted on their plot, and commercial composts and organic fertilisers were also used. However, the challenge remains to quantify these resources and investigate their origins. There has been no research to date quantifying other resource demands of allotment gardening, such as transportation, time commitments and water use. In light of this, it is clearly important to compile an evidence base of the resource demands of UH.

Here, we use a year-long citizen science project, with allotment gardener participants from England and Wales, to establish the resource use requirements of UH annually. Citizen science is a unique way to collect data in collaboration with members of the public through their active participation in the research process. Here, the volunteer citizen scientists participated by recording their activities on their allotments for every visit over the course of a calendar year. This is an ideal method to answer questions such as those regarding resource use on allotments. Allotments are heterogeneous, small-scale land parcels, and allotment gardening practices are highly dependent on the time, interests, knowledge and proclivities of the individual allotment holders. The wider coverage, and large sample size possible with a citizen science approach lends itself well to establishing the range and variation of such practice. Approaches such as LCA (above) would require much more detailed investigation, and hence a far smaller sample size. The wider citizen science approach here is an important precursor to such, more detailed, approaches. The citizen science approach allowed us to go beyond a small number of case studies (e.g., [18]), and to gather data from across the country, providing good representation of allotment practices overall, as well as demonstrating the variations that exist among gardeners' practices. This has enabled a first understanding of the resource costs associated with allotment gardening, in addition to current levels of resource recycling.

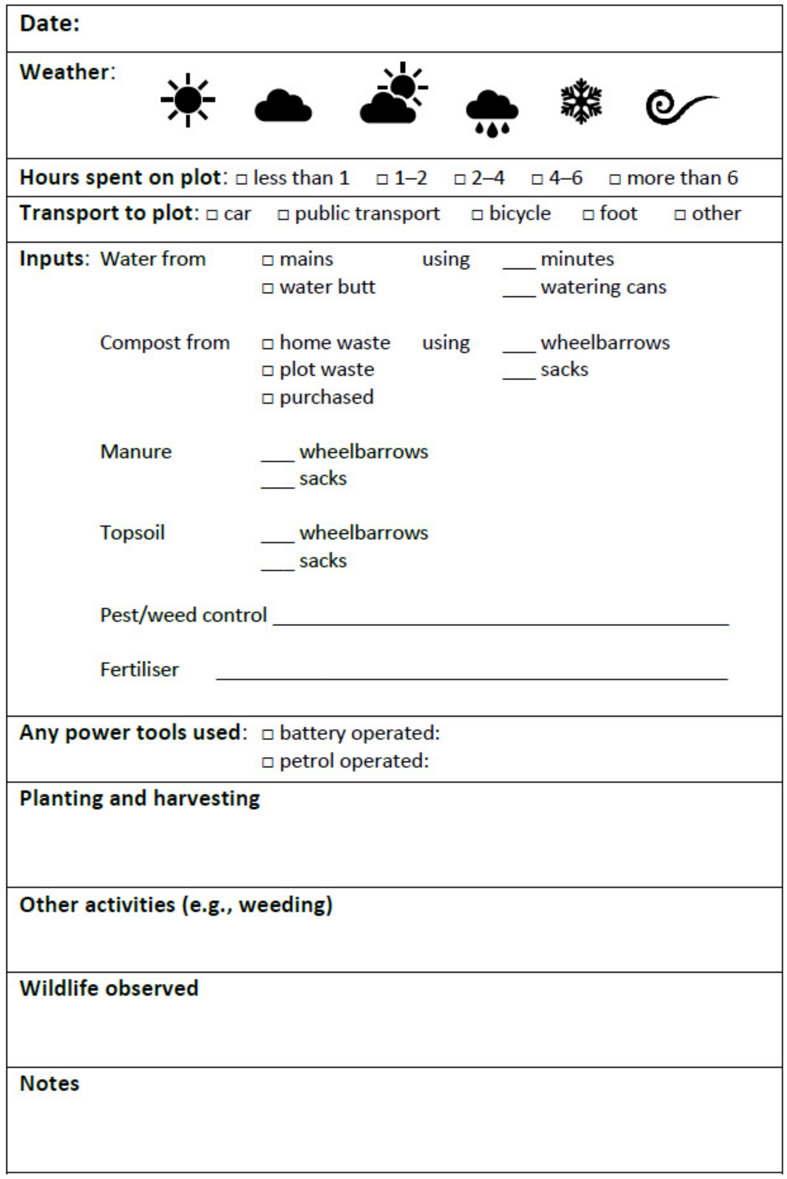
We have also identified the opportunities to further increase the sustainability of allotment gardening through increasing the amount of waste and renewable resources used in this form of UH. This illustrates the potential for integration of UH into whole-system flows of food, energy and water to contribute to the sustainability of urban areas as a whole.

2. Materials and Methods

Citizen science participants, all of whom were allotment gardeners, were recruited through online advertising: Facebook, the MYHarvest website (https://www.myharvest.org.uk, accessed on 1 March 2021), and the National Allotment Society. Recruitment was also carried out in print in the Royal Horticultural Society magazine, and through posters attached to allotment site gates, which were posted to any volunteer who expressed an interest in recruiting other members of their allotment site. In total, 437 participants were recruited with a geographical spread across England, Wales, Scotland and Northern Ireland.

The UK has an average annual minimum and maximum temperature of 5.3 and 12.4 °C, respectively. Average monthly rainfall in the UK is 96 mm, and average monthly sunshine is 114 h [36]. The growing season is, on average, 270 days long [37]. It is worth noting, however, that conditions in urban allotment gardens may vary from the average due to factors such as the urban heat island effect [30,34].

Volunteers were sent an allotment "diary", with a separate page to fill out for each allotment visit (Figure 1). They were asked to fill their diary out each time they visited their allotment, for a full year, with participant recruitment and therefore start date spanning December 2017 to March 2018. Participants were also asked a number of general questions about their allotment, including length of tenancy, whether they grew organically, use of peat free compost, number of people working on the plot, and yearly rent prices (Supplementary Materials). A pilot study was first conducted with volunteer gardeners on an existing citizen science project to refine the diary pages.



Date:

Weather:

Hours spent on plot: □ less than 1 □ 1–2 □ 2–4 □ 4–6 □ more than 6

Transport to plot: □ car □ public transport □ bicycle □ foot □ other

Inputs: Water from □ mains □ water butt using ___ minutes ___ watering cans

Compost from □ home waste □ plot waste □ purchased using ___ wheelbarrows ___ sacks

Manure ___ wheelbarrows ___ sacks

Topsoil ___ wheelbarrows ___ sacks

Pest/weed control ____________________

Fertiliser ____________________

Any power tools used: □ battery operated: □ petrol operated:

Planting and harvesting

Other activities (e.g., weeding)

Wildlife observed

Notes

Figure 1. Recording sheet for participants in the allotment diary project. Copies of the same sheet were filled out every time gardeners visited their allotment over the course of a year.

On each allotment visit, participants recorded the activities they undertook. This included the date; the weather; the method of transport used to get to the allotment; how long they spent on their plot; quantification of water use from the mains or from water butts (rain water containers) in number of watering cans, or minutes of hosepipe time; compost, manure and topsoil additions (in number of wheelbarrows or sacks used); any use of fertilisers, pesticides or weedkillers; planting, harvesting and other activities; wildlife observation; and any other notes they felt they wanted to share. For the purposes of this paper, we focus on the resource inputs recorded by participants. This includes transportation, number of hours spent on the plot, water, compost, topsoil, manure, and other additions.

At the end of the year, participants were sent a stamped addressed envelope to return their diary pages. The returned diary pages were then scanned (so that originals could be returned to those who had requested this) and data were extracted. The mid-point of each option for the number of hours spent on the plot was taken to analyse total and average time spent working on the allotment. Google Maps was used to work out the distance from a participant's house to their plot. Specific parts of data had to be discounted from some participants, for example two of the participants who did not record any water use for an entire year.

One hundred and sixty-three participants (37%) returned their diaries, detailing a total of 14,992 individual allotment visits. Most returns were from England, despite a wider geographical spread of initial participants, which reflects the proportional spread of the initial recruitment (Figure 2). All diaries returned covered a full twelve-month period, apart from one which spanned February to October only, for health reasons, and this was excluded from estimates of year-round inputs but included when analysing on a month-by-month basis. A further two returned diaries were immediately excluded from our analyses due to incompleteness.

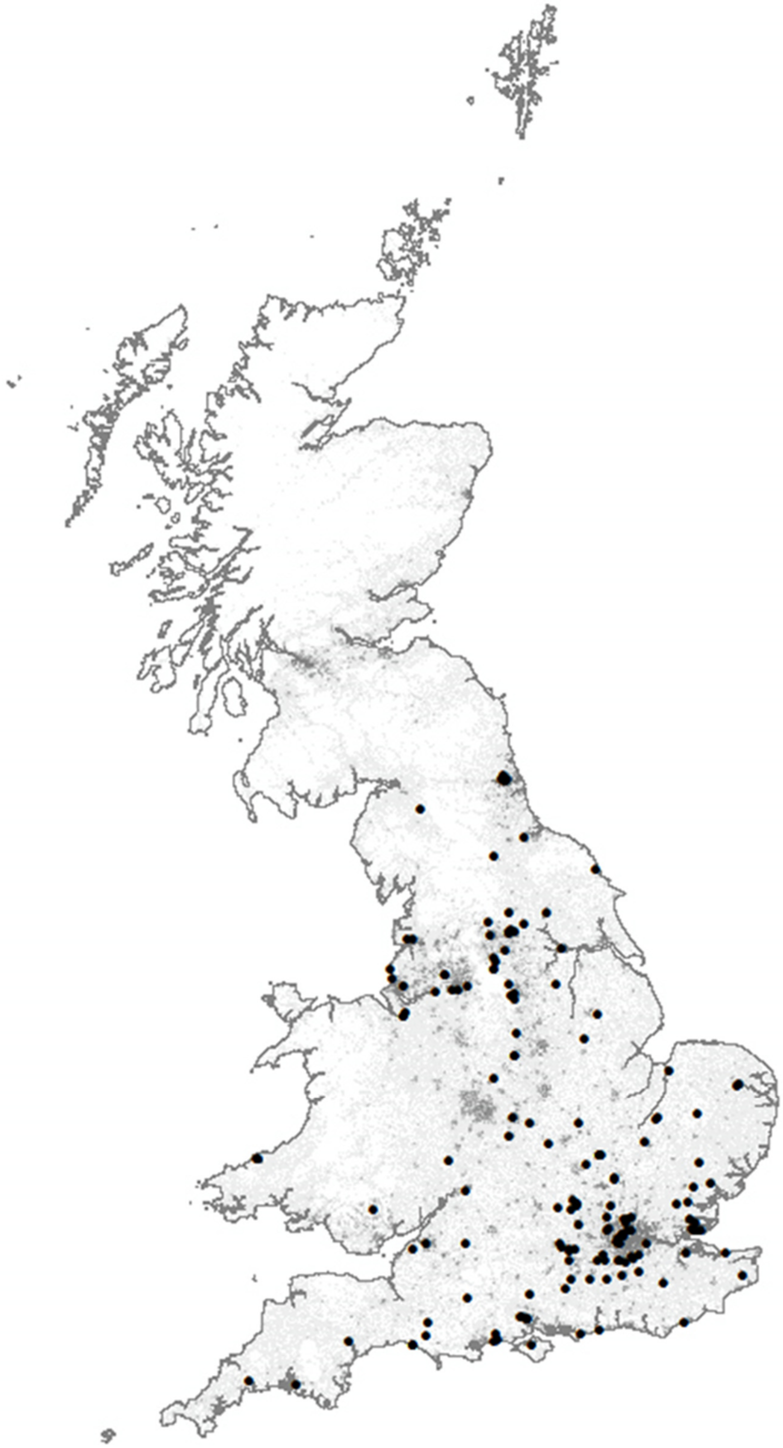


Figure 2. Distribution of allotment diary participants who returned their diary across Great Britain (black dots) and population density (shading) [38].

As is typically the case with citizen science initiatives, we had to compromise between the detail of information people were asked to supply, and the willingness of participants to record information on every visit for an entire year. We therefore adopted a system of quantifying many aspects of resource use in simple, and easily recorded, forms, accepting some sacrifice of precision in individual estimates. We surveyed volunteers from the MYHarvest citizen science project (https://www.myharvest.org.uk, accessed on 1 March 2021) to estimate typical sizes of watering cans. From 207 respondents who told us the size of their watering can, the median (9 L) was used. Average sizes of wheelbarrows and compost sacks (where participants had not quantified this themselves) were estimated by sampling popular items on garden centre websites. Probable hosepipe flow, in litres per minute, was estimated using information from Swanhose [39]. Pesticide, fertiliser and weedkiller use was unquantified beyond whether it had been used on a visit or not. Participants were asked to name the type or brand of each of these inputs when they used them.

We calculated our estimates for the average yearly resource requirements of allotment gardening by using the typical allotment plot size of 250 m^2. Not all of an allotment is cultivated for food production, with a proportion being impermeable surface such as paths and sheds, and a proportion being permeable uncultivated surfaces such as grass areas. The intensity with which each area is managed varies and the food production areas can be assumed to use the majority of resources, but time is also taken to manage the overall allotment and spend time in relaxation. It is unlikely that a gardener would have only food growing area and no other type of land use on their allotment; therefore, we have chosen to treat the plot as a whole rather than divided into individual land use types.

Statistical analysis was conducted in R version 4.0.0 [40]. As data in many cases did not conform to the assumptions of parametric tests, all analyses were carried out using non-parametric techniques: Kendall's tau for bivariate correlations, and Kruskal–Wallis tests to compare groups.

3. Results

3.1. General Characteristics of Allotment Gardeners

Participants' homes were between 0 (an allotment backing on to a residential property) and 9.2 km away from their allotment plots; however, the distribution of distances was skewed and the median distance that people lived from their plot was 1.6 km. Participants had worked their plot a median of 6 years, with a range from zero years (one person who was a new tenant on their plot) to 47 years. Of participants who answered the question of whether they cultivated organically (n = 159), 88 (55%) did, 45 (28%) grew mostly organically, and 26 (16%) did not. Most participants worked their allotment alone, with 97 (61%) being the sole worker on their plot, 61 (38%) sharing the work with one other person, and one respondent having two additional co-workers. The median yearly rent for an allotment was £37, with rent ranging from £0 (two participants) to £280 (a site in London). Overall, only 7% of respondents paid over £100 a year.

3.2. Time Commitment

We included 161 diaries in our analysis of time commitment. The median number of hours spent on the allotment over the course of a year was 150 (with a range from 22 to 647.5 h), with a median of 87 visits. The total number of visits across the year ranged from 30 to 204. The median visit length was 1.5 h. In winter (December, January and February), 30% of time spent on the plot and 26% of visits to the plot took place. In spring (March, April and May), 39% of time and 42% of visits took place. In summer (June, July and August), 21% of time and 21% of visits took place. In autumn (September, October and November), 10% of time and 12% of visits took place. The time spent visiting was greatest in May and June, but the largest number of visits was in July. There was no statistically significant correlation between the total number of visits made over the course of a year and the distance people lived from their allotment (Kendall's tau, tau = −0.01, Z = −0.20, p = 0.84).

3.3. Transportation

Transportation to the allotment was split between bicycle, car, foot, public transport, and "other" (which included one motorcycle journey, and the rest of unknown type). 158 diaries were included in this analysis. In total, 56% of journeys were made by car, 36% by foot, 8% by bicycle, 0.4% by public transport, and 0.05% by "other". The typical distance travelled differed with statistical significance between different forms of transport (Kruskal–Wallis test, H = 32.8, df = 4, $p < 0.0001$). The median car journey length was 1.6 km, and the distribution of car journey lengths was strongly skewed due to people who lived unusually far from their allotment plots (see 3.1.). The median walking journey distance was 1 km, and the median bicycle journey distance was 1.3 km. Ninety-five percent of walking journeys were under 2.1 km (according to Google Maps, this is approximately half an hour of walking time). Walking and cycling was most popular if people lived less than 5 km from their allotment ($n = 141$). Over 5 km, most people were dependent on car travel ($n = 17$), with the maximum walking journey length being 8.0 km and the maximum cycling journey length 4.2 km, but the maximum car journey length 9.2 km (Figure 3).

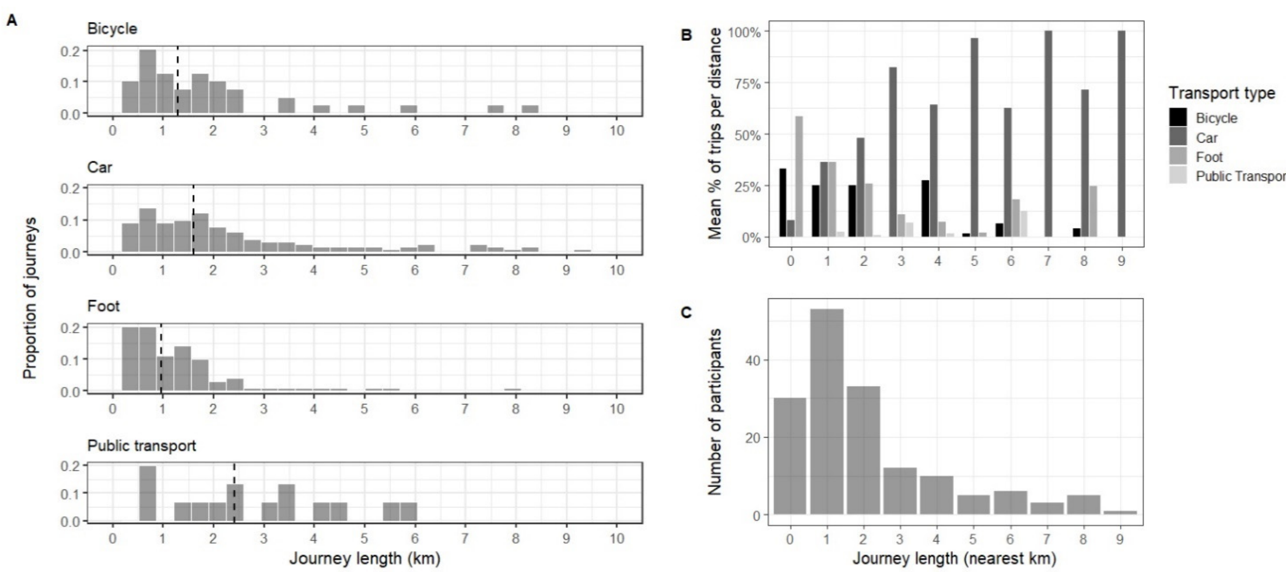


Figure 3. Graphs showing variation in use of different transport models and distances travelled from home to plot by allotment gardeners ($n = 158$). (**A**) Distribution of journey lengths for each transportation type (bicycle, car, foot and public transport); (**B**) distribution of transportation type for each km travelled; (**C**) distribution of distance travelled by participants, not split by transportation type.

3.4. Water Use

Water use was highly variable amongst the 149 participants included in this analysis and ranged from 288 L over the course of the year to 120,013 L. The median annual water use on an allotment was 7595 L, and the data were heavily skewed towards people who used a substantially greater amount of water on their plot. The median annual amount of water used from water butts (which also included other non-mains sources of water, such as river water) was 486 L, and the median amount of water used from the mains was 5993 L (Figure 4).

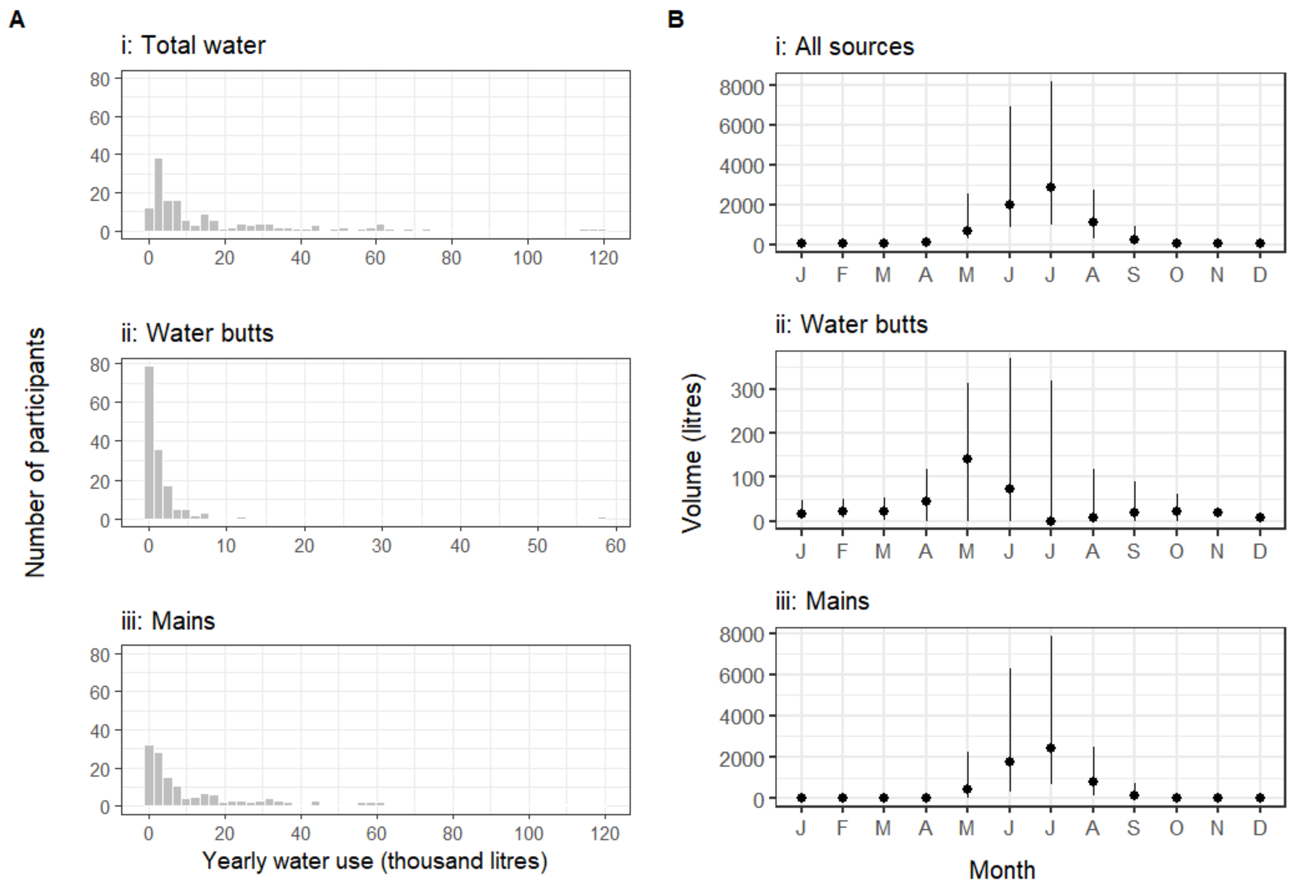


Figure 4. Water use by allotment gardeners (n = 149) over the course of a year. (**A**) Total water use, water from water butts, and water from mains supply. Dashed lines indicate the median water use, for (i) 7595 L; (ii) 486 L; and (iii) 5993 L. (**B**) Monthly median (points) and interquartile ranges (lines) of litres of water used on allotments from water butts, mains water, and all sources.

The types and total amounts of water used varied by month (Figure 4). Overall, 13.2% of water use occurred in spring, 80.8% in summer, 5.7% in autumn and 0.1% in winter. In spring, 11.8% of mains and 26.6% of collected water was used. In summer, 82.4% of mains and 65.5% of collected water was used. In autumn, 5.7% of mains and 7.0% of collected water was used. In winter, 0% of mains and 0.4% of collected water was used. There was a peak in the use of water butt water in May followed by a decline in June and none used in July, and a corresponding increase in the amount of mains water used in June and especially in July as a result. Water butts provide a limited storage for water, and dry conditions meant that they were used up before the peak of the summer (see Discussion below for a discussion of the weather conditions of 2018). The small increase in water butt water usage in the autumn can be interpreted as people going back to using collected water once rain had replenished supplies.

3.5. Compost, Manure and Topsoil

One hundred and thirty-three (86%) participants added compost to their plot; 110 (71%) added manure, and 26 (17%) added topsoil. The median total annual amount of compost, manure and topsoil added to an allotment plot was 1575 L. The median amount of compost per year added by people who used compost was 850 L; the median use of manure by manure users was 992 L; and the median use of topsoil by topsoil users was

85 L (Figure 5). However, when considering all participants (n = 155 for this analysis) rather than just those using each of these inputs, the median amount of compost was 688 L; manure was 275 L and topsoil was 0 L. We asked participants to disclose the origins of the compost they used: council waste comprised 5.3% of the total volume of compost applied by all our participants, home food waste 23.8%, plot waste 54.6%, and purchased compost 16.1%. Therefore, 83.9% of compost used by volume was recycled material, whether from the home, garden or local council. Many respondents used a mixture of sources for their compost, and overall 76 (49%) participants brought home waste to their plot to compost, 92 (59%) purchased compost, and 94 (61%) composted plot waste. Of participants who answered the general question regarding whether they used peat free compost (n = 156), 92 (59%) only used peat-free, 12 (8%) used mostly peat-free and 52 (33%) did not use peat-free compost. Levels of compost, manure and topsoil all varied throughout the year, as demonstrated in Figure 5 showing monthly variation for people using each of these inputs.

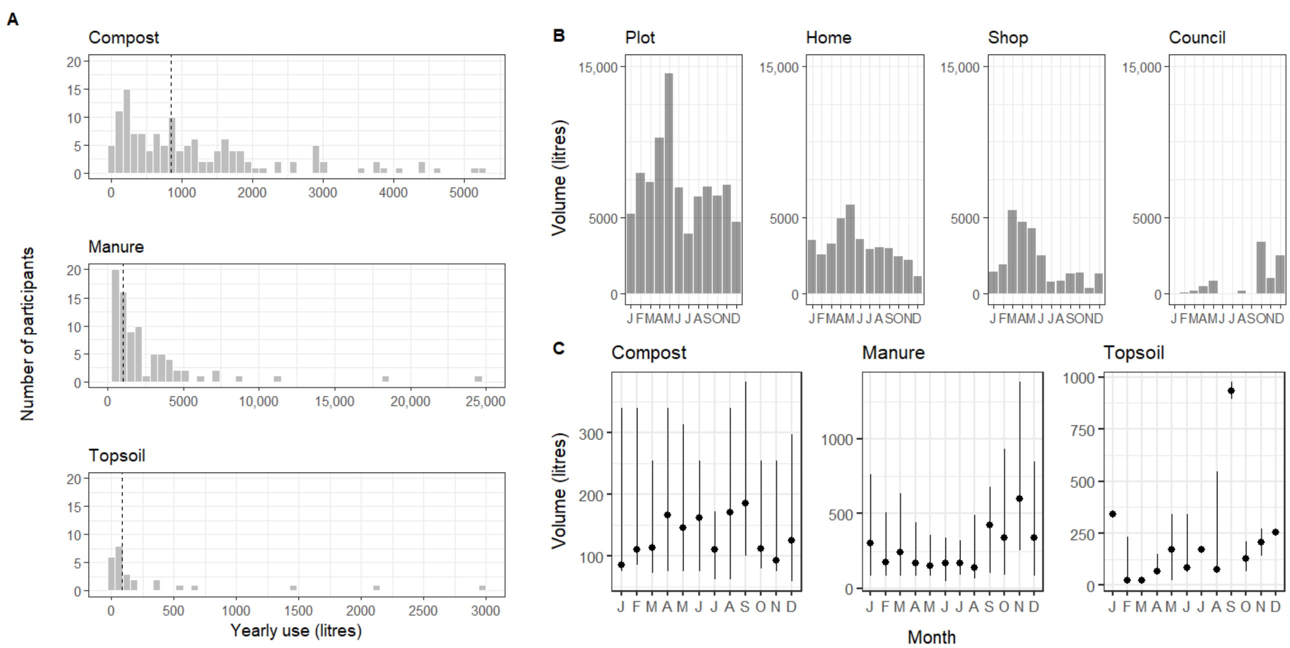


Figure 5. Use of compost, manure and topsoil by allotment gardeners (n = 155). (**A**) Distribution of yearly use (litres) of compost, manure and topsoil with dashed lines indicating the median use of each resource. (**B**) Monthly total use of compost split by source (plot, home, shop or council). (**C**) Monthly median (points) and interquartile ranges (lines) of compost, manure and topsoil additions.

3.6. Fertilisers, Pesticide and Weed Control

Participants recorded a wide variety of fertiliser use (from organic and non-organic sources) as well as pest and weed control inputs. Frequency of inputs varied across the year and peaked in late spring and early summer (Figure 6). Fertiliser was the most commonly added of these inputs, with 131 participants using fertiliser at some point during the year, varying from once to 48 times. The median number of days on which participants applied fertiliser was 7, with the distribution skewed to a small number of participants applying particularly larger than average amounts. Pest control was applied by 120 participants, ranging from once to 31 times. Weed control was used by 66 people, ranging from once to 20 times (this count did not include hand weeding of plots). The median number of days on which pest control was applied was four days in the year, and the median number of days for application of weed control was twice. Similarly to fertiliser use, both pest and weed control were skewed towards a few participants whose gardening techniques involved much greater than average use (Figure 6). Table 1 shows the counts for the total number of days on which general categories of each of these applications was used; see Supplementary Materials for a full list of all the methods by which people fertilised their plots, and used pest and weed control.

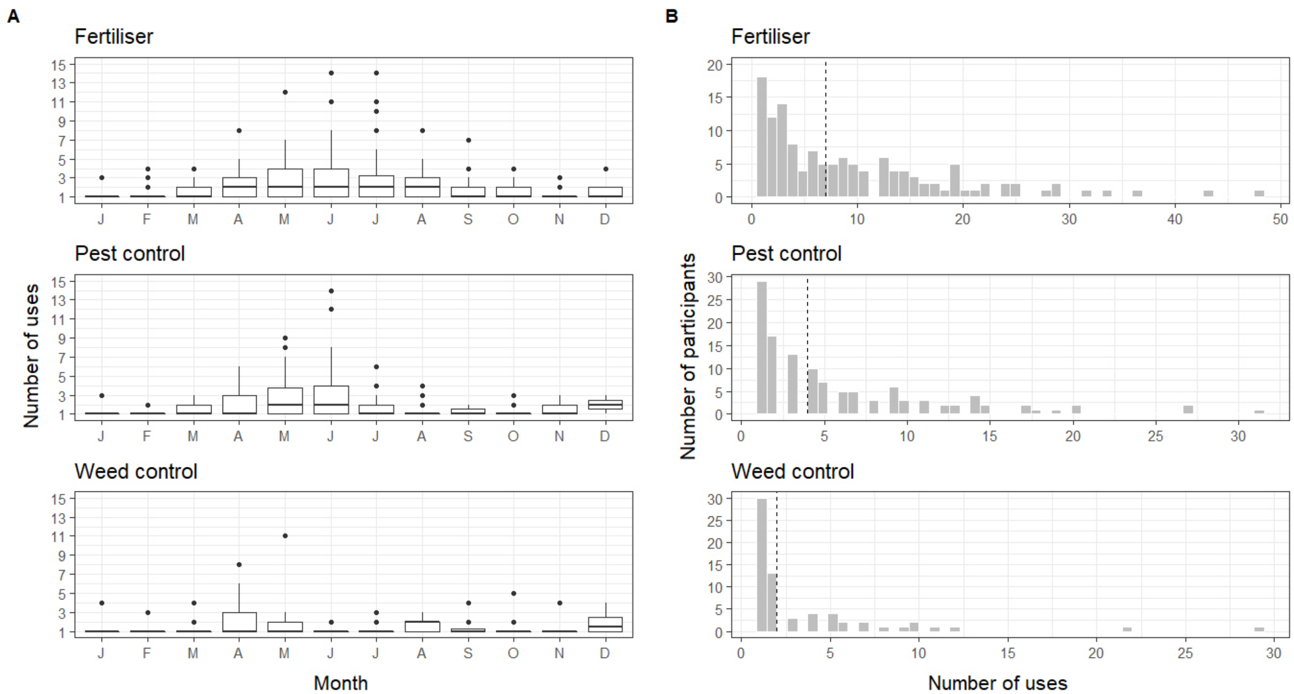


Figure 6. Fertiliser, pest control and weed control use on allotments ($n = 162$). (**A**) Monthly median and interquartile ranges of number of days on which fertilisers, pest control measures and weed control measures were applied (**B**) Distribution of number of days in the year on which fertiliser, pest control and weed control were applied. Dashed lines indicate median number of uses.

Table 1. General categories and number of days on which types of fertiliser, pest control and weed control were used on allotments from a total of 14,992 plot visits by 163 gardeners. Some types which were used once or twice did not fit into these categories and are excluded from the table; see Supplementary Materials for a full list and count of all types.

Fertiliser		Pest Control		Weed Control	
General Type	**Number**	**General Type**	**Number**	**General Type**	**Number**
Branded, e.g., Tomorite	358	Pellets (primarily slug)	530	Chemical weedkiller, e.g., Roundup	129
Seaweed, comfrey and nettles	300	Insecticide and poison	91	Bark, cardboard and woodchip	74
Chicken manure pellets	270	Homemade, e.g., washing up liquid spray	46	Fabric, mesh and carpet	21
Fish, blood and bone	190	Netting, fleece, and wire	42	Plastic	15
General (un-branded/undisclosed brand)	184	Traps, e.g., beer traps for slugs	27		
Lime	38	Nematodes	9		

3.7. Overall Resource Requirements

The above results allow us to estimate the average yearly resource use on allotment gardens per metre squared at the whole plot scale (i.e., including both cultivated areas and other infrastructure, such as paths—see earlier discussion in Section 2).

Overall, the average (median) allotment user would visit their plot 87 times, each visit involving travel of 1.6 km in each direction. This gave a total of 139 km travelled per year (with those journeys most likely to be made by car, or on foot, slightly less likely by bike, and rarely by public transport). They would pay £37 for the rent on their plot. Per square metre of their allotment, they would use 0.6 h of labour and 30.4 L of water over the year. If they used compost, manure or topsoil, their use per square metre would be 3.4 L of compost, 0.3 L of topsoil, and 3.9 L of manure. If they used additional fertilisers, pest control methods and weed control methods on top of hoeing and hand weeding, they would do this seven, four and two times, respectively, over the course of the year (Figure 7).

Using some of the above results, we can also calculate the levels of some resources needed to produce one kilogram of fruit or vegetables. On average it is estimated that allotment gardeners produced an average yield of 1.8 kg m^{-2} over the entire area of an allotment [5]. Therefore, resource requirements per kilo of produce are 16.9 L of water, and, if the following are used, 1.9 L of compost, 0.2 L of topsoil, and 2.2 L of manure.

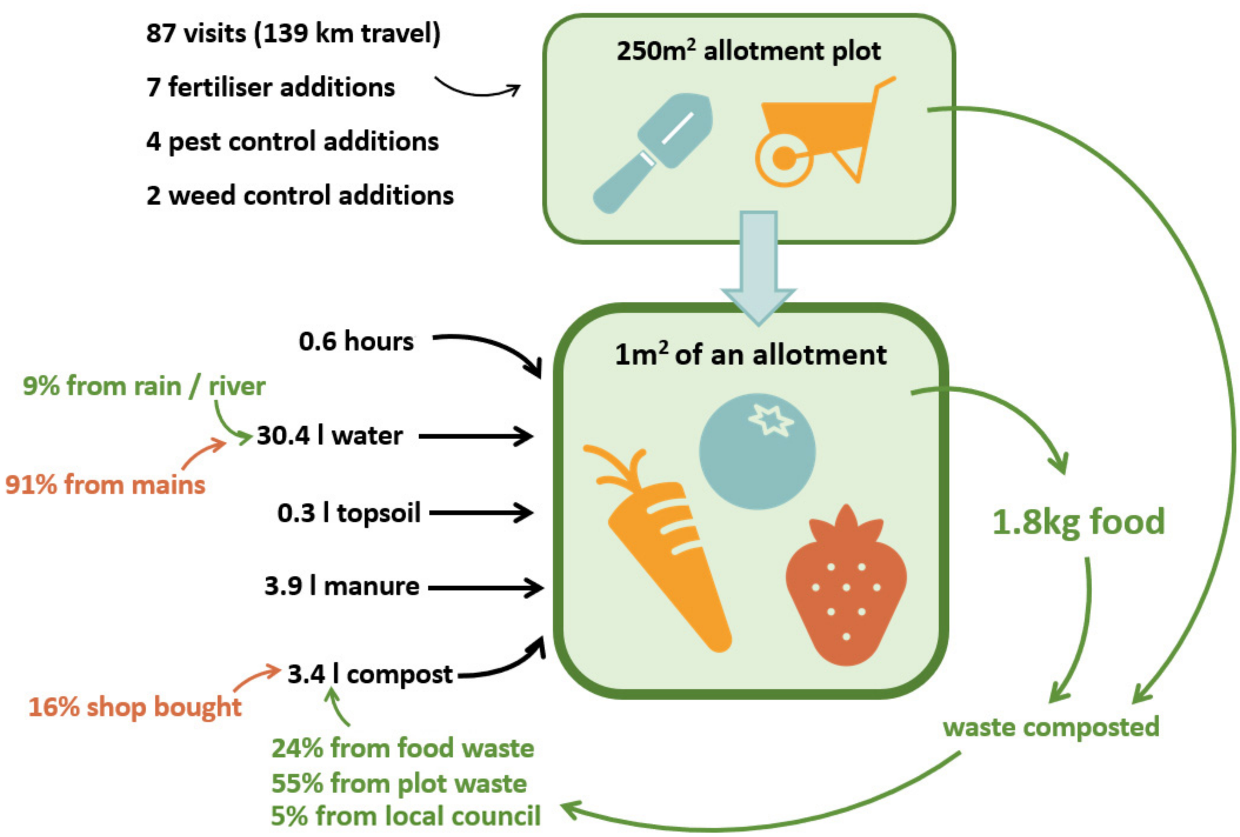


Figure 7. Yearly resource use on allotment plots, and specific requirements to produce 1 kg of fruit and vegetables on an allotment, demonstrating what proportion of recycled or collected and non-recycled resources are used in each input. Data use the median for each resource (n = 163).

4. Discussion

UH, in the form of allotment gardening, uses resources in a variety of forms. These resources are a necessary component of food production taking place in allotment gardens, which provide fresh produce for those involved, alongside other associated benefits and important ecosystem services [11–15]. Global agricultural land currently under-produces fruit and vegetables relative to global needs based on nutritional guidelines [41], and British vegetable production in tonnes has fallen for the past four years in a row [42]. UH presents an opportunity to increase the global supply of fruit and vegetables at a local level for urban residents. Here we present the first year-round investigation into resource requirements for allotment gardening, a key initial step in the assessment of the sustainability of this potentially important form of soil-based food production. Using a citizen science approach, we have derived a country-wide picture of the activities of allotment gardeners, including the seasonal variability in resource use and requirements. Combined with the work of [5], we were then able to determine the resource requirements to produce one kilogram of produce on an allotment. Resources varied in their roles and wider implications for allotment sustainability.

4.1. Fertilisers, Weedkillers, Pesticides and Compost

Previous research has found that allotment gardening maintains high levels of soil quality and its associated ecosystem services [35].Our results, showing relatively low incidences of chemical applications, and high levels of use of manure and compost, are consistent with this, demonstrating that allotment gardeners participate in management practices conducive to the maintenance of soil health. One element of these inputs is food and allotment waste. Whilst we are only just starting to quantify the capacity of UH to absorb urban waste [43], our research demonstrates that allotment gardeners are primarily sourcing their compost from plot or home food waste, diverting compostable waste from landfill or incineration to recycling on the allotment. Use of shop-bought compost was relatively low, and 67% of participants recorded that they used only, or mostly, peat-free compost, removing the greenhouse gas and habitat destruction costs associated with peat, which are orders of magnitude higher than for peat free alternatives [44]. Further to this, 83% of participants grew wholly or mostly organically (as self-reported), a proven method for the maintenance of soil health [45].

Our results detail a wide range of organic and non-organic fertilisers, pest control and weed control used by allotment gardeners, which present a challenge when attempting to understand the consequences of allotment management practices on an overall, national scale. Whilst many of the applications used by our participants were organic (such as seaweed), weedkillers such as glyphosate, and pest control methods such as slug pellets were also used. These may have negative consequences for some wildlife [46,47]. Over-application of non-organic fertilisers also has negative consequences for long-term soil health, water, and potentially human health [48]. However, the median level of applications of all fertilisers, weedkillers and pest control was low. On a national or city-wide scale, problems could present if a particular allotment site had a high density of gardeners using greater-than-average biocides. Other management techniques such as the high levels of compost and manure addition detailed above suggest that allotment gardeners generally maintain good levels of soil health and wildlife-friendly gardening practices. Use of compost and manure mean soil nutrients are restored without an over-reliance on synthetic fertilisers, which helps maintain good soil quality [49]. In comparison to commercial arable farming in the UK, where pesticides and herbicides are applied an average of 34 times per year [50], and 99% of potato crops and 75% of brassica crops (for example) receive synthetic fertiliser applications [51], overall application levels of fertiliser, weedkillers and pesticides were very low on allotments.

4.2. Water Use

High soil quality also means that water use requirements of UH are likely to be lower than in commercial horticulture. In the UK, 34% of commercial horticultural crops are irrigated, and water use has been identified as a target for increasing sustainability and improving environmental impact [52]. Our results found that the average water use per square metre of an allotment was 30.4 L. Per square metre of commercial horticulture, this figure rises to 49 L [52]. This suggests that allotment gardens are more conservative, and, with very low occurrences of the use of irrigation, more sustainable, in their water use that conventional horticultural farms.

However, our results may overestimate the typical water use on allotments over a longer period of time. For the UK, the summer of 2018 was the joint hottest on record [53]. A heatwave from May to August brought drought conditions to much of the country, and in some places broke records for the longest number of consecutive days without rainfall. Diary participants were fully aware of this, with many comments and observations regarding the summer weather (for example, diary entries from one participant: June 24th, 'No-one can remember when it last rained'; July 18th, 'No rain for at least two months'; July 23rd, 'Plants are dying'). In July 2018, the UK experienced 54.3 mm of rainfall. This is much lower than the average of 88.5 mm experienced over the period 2014–2020 when excluding 2018 from the calculation [54]. The IPCC predicts that the UK will have more frequent hot, dry summers in the future due to climate change; models found that the 2018 heatwave was thirty times more likely to have occurred than if climate change had not been a factor [53]. The Met Office also predict that 50% of summers could mirror the 2018 heatwave in the future [55]. Our data on water use requirements are therefore both historically unusual, as more watering was required than in a year of typical rainfall, but also important in the context of future climate change and the resultant changing water use requirements of UH. Our results have clearly demonstrated that with dry conditions beginning in late spring and early summer, winter stocks of rainwater harvested by individual gardeners are insufficient in the majority of cases to meet the water demands of an allotment into the summer months.

4.3. Resource Capture and Recycling

These results suggest opportunities for a wider integration of UH into urban energy and materials flows in order to take advantage of potential opportunities for resource recycling in the urban system. There are a number of forms that this could take, including greywater recycling, demolition and construction waste material recycling for use in infrastructure, and diversion of compostable waste from other sources. Two which arise from this study are increasing the harvesting of rainwater and the capture of compostable waste. Considering the limitations to allotment gardeners' capacity to collect and store water, which was insufficient to meet the demands of the 2018 heatwave, it is important to understand whether this is a limitation of collecting potential, storage, or both. Allotments, by virtue of being collections of plots on sites with few buildings or other hard surfaces, provide limited scope for rainwater harvesting; small sheds or greenhouses are typically the only collecting surfaces available. It may be that this limits the potential for water collecting. However, it is also important to investigate opportunities for greater storage of winter rainfall, potentially at a site-wide or even community level, and the potential for water collected elsewhere (e.g., on buildings) to be diverted for UH use. British winters are becoming wetter (the most recent decade was 12% wetter in winter than 1961–1990 [55]); February 2020 broke rainfall records across the country for the wettest February ever, as part of the wettest ever winter [56]. An opportunity for co-benefits therefore exists here. Expansion of water storage facilities across a city to help mitigate the flood risk from heavy rainfall winters could then be a source of water for UH during drier months. If UH is to be upscaled with its current reliance on mains water, the pressure on the urban water supply would be exacerbated. Therefore, it is key for policy makers to consider water re-use and harvesting when planning future UH sites. Further integration of UH into the sustainability fabric of a city could also utilise wastewater, if safely treated; this is another avenue that warrants further investigation [57,58]. However, the costs associated with collecting and treating water from such alternative sources may limit the viability of any such schemes [57,58].

The capture of compostable waste on a citywide level is the second key opportunity, highlighted by this research, to increase the sustainability of UH and integrate urban resources. Whilst we found that the majority of an allotment gardener's compost comes from home and plot waste, some integration of wider urban compostable waste can also be seen in the 5.3% of compost used that was from local authority green waste sources. Both this municipal green waste, and a wider integration of home food waste from non-gardeners to centralised compost sources that could be used in UH, would further reduce the need for gardeners to purchase compost, and prevent the disposal to landfill or by incineration of compostable material by non-gardeners. This idea is in its infancy in practice but has the potential to reduce the pressure on landfill, save on costs of central waste management in cities, and recycle nutrients currently lost through waste [59]. Overall, with 83.9% of allotment gardeners' compost already coming from recycled sources, the inclination to use sustainable compost sources is high amongst gardeners and suggests they would be favourable to the introduction of other reused sources in the future. Just under half of our participants brought their home waste to compost on the plot, and just over half composted the waste from their plot itself (a lower number than that found by [35], who reported 95% of allotment gardeners composting plot waste on-site and 75% adding household waste). This suggests a great deal of potential to expand the use of compost from personal and potentially municipal waste in the future. However, we do not know how many participants used their compostable home waste for their home gardens. High levels of home composting for gardens would reduce the potential amount available for UH. This also applies to participants who potentially brought 100% of their compostable waste to use on the plot and still needed to make purchases of commercial compost to have the amount they needed. Manure would probably continue to be sourced from animal agriculture in rural areas; however, city farms could also provide a source for this.

4.4. Human Resources: Time, Money, and Travel

One resource unquantified by our study is the amount of money that gardeners spend on their allotments beyond the price of their rent. An investigation into this could provide an important insight into whether there are financial barriers that may prevent those from lower incomes from participating in UH, especially in light of recent research demonstrating that low-income areas have disproportionately suffered from allotment site closures over the past half century [27]. Our results demonstrate a huge variation in rent costs across the country, with the highest rates standing at £280 per year, compared to a lowest cost of £0. Gardening has been shown to be an important opportunity for more deprived communities to actively participate in creating their own food security nets as well as creating thriving neighbourhoods through the associated wellbeing and physical health benefits of participating in UH [60–62]. Therefore, an important policy consideration is the need to distribute food growing areas across a city in a way that ensures equitability of local access to these areas. Given the evident time commitments required for allotment gardening, it is understandable that using a car for transportation to the plot may be a preferred form of transport for people who are time-poor. With 95% of walking trips under 2 km in length, our results suggest that if somebody lived further than this from their allotment, walking became too time consuming to be an effective mode of transportation. However, there was no significant relationship between the distance from their plot that somebody lived and the number of times they visited their plot. This therefore appears to necessitate access to a vehicle to successfully participate in UH if the cultivation space is more than 2 km from a person's residence. Ensuring that sites of urban food production are within walking distance for participants would enable non-car owners to participate in UH, as well as limiting the use of cars and their associated emissions and congestion impacts.

5. Conclusions

Understanding the resources required for food production, as seen in Figure 7, furthers our scientific understanding of the sustainability and resource costs of UH. It also has the potential to be used as an educational and informational tool for prospective urban gardeners. They can use this information to estimate their resource demands over a year depending on the size of their growing space; assess whether they possess the requisite spare time to participate in UH; and help in planning for the resources they need throughout the year. We can assume that gardening management practices (bar travel) are broadly similar to other soil-based UH types, such as home gardening or community garden [17], meaning that our results are valuable for participants in a number of forms of UH beyond allotments.

Understanding the lifecycle demands of UH is of particular importance as interest in upscaling the amount of food production in cities grows. In order to understand the lifecycle demands of UH in this form, in the future, researchers should use the data presented here to ensure their chosen allotment gardens for study are representative of the national average resource use levels. Understanding can then be drawn down to the crop level, looking at variation in resource use across the most common crops grown by allotment gardeners [5], and research can answer the arising questions on whether selection of particular crops to grow would increase resource use efficiency and sustainability at the plot level. This would also enable more direct comparisons with resource use in conventional agricultural systems, on a crop-by-crop basis. However, recent research has noted the tendency of LCA analysis to under-represent the sustainability and resilience benefits, as well as ecosystem service provision potential, of conventional agriculture [63], so investigations of this nature must be conducted with a methodology that takes such benefits into account.

Further investigation into the resource requirements of different forms of UH could be combined with approaches such as that of combining citizen science, field mapping and GIS [26] or coupling own-grown yields with areal surveys [64], investigating the potential for upscaling a multiplicity of UH types across a city. Allotment gardening and equivalent soil-based UH in home gardens is the dominant form of UH in the UK. However, as interest in UH grows, especially as a commercial venture, it will become necessary to compile similar data regarding the resource demands of the full multiplicity of UH types, including hydroponic systems, rooftop gardens and so on. Most current UH in the UK is non-commercial, which has the benefit of making it less reliant on producing consistent levels of food year-round. As a result, the associated negative environmental impacts of food production (such as heating of greenhouses) may be reduced, giving more weight to positive environmental impacts [43]. A suite of data available to practitioners and policy makers that takes into account the resource needs of different forms of UH, including commercial ventures that may need more costly environmental inputs, would be an invaluable tool to help site the most appropriate UH type in each available food growing space within a city. Previous research has demonstrated that allotment gardeners often share surplus produce with friends and family [65]; future research analysing the end location of harvests could bring an assessment of food miles into the picture of resource use sustainability.

UH has hitherto been an under-researched component of urban sustainability, and its place within the material flows of cities is poorly understood. As interest in upscaling UH to contribute to sustainable food production in cities grows, it is equally important to understand its resource demands. Our results suggest that there is the potential for high levels of sustainability: recycling rainwater, low pesticide use, recycling of household food waste and garden green waste, active travel, and the known health and wellbeing benefits of UH. Typical allotment management practices are conducive to the maintenance of soil health and ecosystem services, with an emphasis on the use of compost and manure. However, it is also clear that this potential is not always realised as fully as it could be. Opportunities exist to further integrate UH into citywide resource use, for example by increasing the harvesting of rainwater to reduce the demands of UH on mains water supplies, or by spatial planning of UH sites to minimise car travel. These results help to develop a more holistic picture of UH, and provide guidance for policy makers and practitioners seeking to integrate UH into the development of more sustainable cities.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/13/5/2628/s1, Figure S1: General questions asked about allotments; Table S1: Fertilisers, pest control and weed control methods used by allotment gardeners, with frequency of applications (count of all days applied for all participants).

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References

1. United Nations. *World Urbanization Prospects: The 2018 Revision*; United Nations Publications: New York, NY, USA, 2019.
2. Food and Agriculture Organization of the United Nations. *COVID-19 and the Risk to Food Supply Chains: How to Respond?*; FAO: Rome, Italy, 2020.
3. Goldstein, B.P.; Birkved, M.; Fernandez, J.E.; Hauschild, M. Surveying the environmental footprint of urban food consumption. *J. Ind. Ecol.* **2017**, *21*, 151–165, doi:10.1111/jiec.12384.
4. Benis, K.; Ferrão, P. Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA)—A life cycle assessment approach. *J. Clean. Prod.* **2017**, *140*, 784–795, doi:10.1016/j.jclepro.2016.05.176.
5. Edmondson, J.L.; Cunningham, H.; Tingley, D.O.D.; Dobson, M.C.; Grafius, D.R.; Leake, J.R.; McHugh, N.; Nickles, J.; Phoenix, G.K.; Ryan, A.J.; et al. The hidden potential of urban horticulture. *Nat. Food* **2020**, *1*, 155–159, doi:10.1038/s43016-020-0045-6.
6. Mcdougall, R.; Rader, R.; Kristiansen, P. Urban agriculture could provide 15% of food supply to Sydney, Australia, under expanded land use scenarios. *Land Use Policy* **2020**, *94*, 104554, doi:10.1016/j.landusepol.2020.104554.
7. Lovell, S.T. Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability* **2010**, *2*, 2499–2522, doi:10.3390/su2082499.
8. Milan Urban Food Policy Pact. Signatory Cities. 2020. Available online: http://www.milanurbanfoodpolicypact.org/signatory-cities/ (accessed on 24 August 2020).
9. Sustainable Food Places. Members. 2020. Available online: https://www.sustainablefoodplaces.org/members/ (accessed on 24 August 2020).
10. McClintock, N. Why farm the city? Theorizing urban agriculture through a lens of metabolic rift. *Camb. J. Reg. Econ. Soc.* **2010**, *3*, 191–207, doi:10.1093/cjres/rsq005.

11. McClintock, N.; Cooper, J.; Khandeshi, S. Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landsc. Urban Plan.* **2013**, *111*, 46–58, doi:10.1016/j.landurbplan.2012.12.009.
12. Lin, B.B.; Philpott, S.M.; Jha, S. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic Appl. Ecol.* **2015**, *16*, 189–201, doi:10.1016/j.baae.2015.01.005.
13. Speak, A.; Mizgajski, A.; Borysiak, J. Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. *Urban For. Urban Green.* **2015**, *14*, 772–781, doi:10.1016/j.ufug.2015.07.007.
14. Webber, J.; Hinds, J.; Camic, P.M. The well-being of allotment gardeners: A Mixed methodological study. *Ecopsychology* **2015**, *7*, 20–28, doi:10.1089/eco.2014.0058.
15. Borysiak, J.; Mizgajski, A.; Speak, A. Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. *Urban Ecosyst.* **2017**, *20*, 323–335, doi:10.1007/s11252-016-0595-4.
16. Maye, D. 'Smart food city': Conceptual relations between smart city planning, urban food systems and innovation theory. *City Cult. Soc.* **2019**, *16*, 18–24, doi:10.1016/j.ccs.2017.12.001.
17. Goldstein, B.; Hauschild, M.; Fernández, J.; Birkved, M. Urban versus conventional agriculture, taxonomy of resource profiles: A review. *Agron. Sustain. Dev.* **2016**, *36*, 1–19, doi:10.1007/s13593-015-0348-4.
18. Kulak, M.; Graves, A.; Chatterton, J. Reducing greenhouse gas emissions with urban agriculture: A life cycle assessment perspective. *Landsc. Urban Plan.* **2013**, *111*, 68–78, doi:10.1016/j.landurbplan.2012.11.007.
19. Sanyé-Mengual, E.; Oliver-Solà, J.; Montero, J.I.; Rieradevall, J. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. *Int. J. Life Cycle Assess.* **2015**, *20*, 350–366, doi:10.1007/s11367-014-0836-9.
20. Sanyé-Mengual, E.; Gasperi, D.; Michelon, N.; Orsini, F.; Ponchia, G.; Gianquinto, G. Eco-efficiency assessment and food security potential of home gardening: A case study in Padua, Italy. *Sustainability* **2018**, *10*, 2124, doi:10.3390/su10072124.
21. Goldstein, B.P.; Hauschild, M.Z.; Fernández, J.E.; Birkved, M. Contributions of local farming to urban sustainability in the northeast united states. *Environ. Sci. Technol.* **2017**, *51*, 7340–7349, doi:10.1021/acs.est.7b01011.
22. Mohareb, E.; Heller, M.; Novak, P.; Goldstein, B.; Fonoll, X.; Raskin, L. Considerations for reducing food system energy demand while scaling up urban agriculture. *Environ. Res. Lett.* **2017**, *12*, 125004, doi:10.1088/1748-9326/aa889b.
23. Crouch, D.; Ward, C. *The Allotment: Its Landscape and Culture*; Five Leaves Publications: Nottingham, UK, 1997.
24. Acton, L. *Growing Space: A History of the Allotment Movement*; Five Leaves Publications: Nottingham, UK, 2015.
25. Campbell, M.; Campbell, I. Allotment waiting lists in England 2013. Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, United Kingdom. Available online: http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2013.pdf (accessed on 28 August 2020).
26. Edmondson, J.L.; Childs, D.Z.; Dobson, M.C.; Gaston, K.J.; Warren, P.H.; Leake, J.R. Feeding a city—Leicester as a case study of the importance of allotments for horticultural production in the UK. *Sci. Total. Environ.* **2020**, *705*, 135930, doi:10.1016/j.scitotenv.2019.135930.
27. Dobson, M.C.; Edmondson, J.L.; Warren, P.H. Urban food cultivation in the United Kingdom: Quantifying loss of allotment land and identifying potential for restoration. *Landsc. Urban Plan.* **2020**, *199*, 103803, doi:10.1016/j.landurbplan.2020.103803.
28. Niala, J. Dig for vitality: UK urban allotments as a health-promoting response to COVID-19. *Cities Health* **2020**, 1–5, doi:10.1080/23748834.2020.1794369.
29. Grewal, S.S.; Grewal, P.S. Can cities become self-reliant in food? *Cities* **2012**, *29*, 1–11, doi:10.1016/j.cities.2011.06.003.
30. Petit-Boix, A.; Llorach-Massana, P.; Sanjuan-Delmás, D.; Sierra-Pérez, J.; Vinyes, E.; Gabarrell, X.; Rieradevall, J.; Sanyé-Mengual, E. Application of life cycle thinking towards sustainable cities: A review. *J. Clean. Prod.* **2017**, *166*, 939–951, doi:10.1016/j.jclepro.2017.08.030.
31. Environmental Protection Agency. Composting at home. 2020. Available online: https://www.epa.gov/recycle/composting-home (accessed on 30 March 2020).
32. Chen, C.; Chaudhary, A.; Mathys, A. Nutritional and environmental losses embedded in global food waste. *Resour. Conserv. Recycl.* **2020**, *160*, 104912, doi:10.1016/j.resconrec.2020.104912.
33. Gondhalekar, D.; Ramsauer, T. Nexus city: Operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany. *Urban Clim.* **2017**, *19*, 28–40, doi:10.1016/j.uclim.2016.11.004.
34. Pataki, D.E.; Carreiro, M.M.; Cherrier, J.; Grulke, N.E.; Jennings, V.; Pincetl, S.; Pouyat, R.V.; Whitlow, T.H.; Zipperer, W.C. Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Front. Ecol. Environ.* **2011**, *9*, 27–36, doi:10.1890/090220.
35. Edmondson, J.L.; Davies, Z.G.; Gaston, K.J.; Leake, J.R. Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. *J. Appl. Ecol.* **2014**, *51*, 880–889, doi:10.1111/1365-2664.12254.
36. Met Office. UK Climate Averages. 2021. Available online: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages (accessed on 10 February 2021).
37. Carbon Brief. England's Growing Season Now Almost a Month Longer, Says Met Office. 2021. Available online: https://www.carbonbrief.org/englands-growing-season-now-almost-a-month-longer-says-met-office (accessed on 10 February 2021).
38. Reis, S.; Liska, T.; Steinle, S.; Carnell, E.; Leave, D.; Roberts, E.; Veino, M.; Beck, R.; Dragosits, U. *UK Gridded Population 2011 Based on Census 2011 and Land Cover Map 2015*; UK Centre for Ecology & Hydrology: Midlothian, UK, 2017. Available online: https://doi.org/10.5285/0995e94d-6d42-40c1-8ed4-5090d82471e1 (accessed on 01 March 2021).

39. Swan Products. The Flow Rate of a Garden Hose. 2020. Available online: https://www.swanhose.com/garden-hose-flow-rates/1952.htm (accessed on 8 July 2020).
40. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2018. Available online: https://www.R-project.org (accessed on 1 March 2021)
41. Kc, K.B.; Dias, G.M.; Veeramani, A.; Swanton, C.J.; Fraser, D.; Steinke, D.; Lee, E.; Wittman, H.; Farber, J.M.; Dunfield, K.; et al. When too much isn't enough: Does current food production meet global nutritional needs? *PLoS ONE* **2018**, *13*, e0205683, doi:10.1371/journal.pone.0205683.
42. Department for Environment Food and Rural Affairs. Horticulture Statistics 2019. 2020. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/901689/hort-report-17jul20.pdf (accessed on 6 November 2020).
43. Goldstein, B.P.; Hauschild, M.Z.; Fernández, J.; Birkved, M. Testing the environmental performance of urban agriculture as a food supply in northern climates. *J. Clean. Prod.* **2016**, *135*, 984–994, doi:10.1016/j.jclepro.2016.07.004.
44. Boldrin, A.; Andersen, J.K.; Møller, J.; Christensen, T.H.; Favoino, E. Composting and compost utilization: Accounting of greenhouse gases and global warming contributions. *Waste Manag. Res.* **2009**, *27*, 800–812, doi:10.1177/0734242x09345275.
45. Lorenz, K. Organic urban agriculture. *Soil Sci.* **2015**, *180*, 146–153, doi:10.1097/ss.0000000000000129.
46. Purvis, G.; Bannon, J.W. Non-target effects of repeated methiocarb slug pellet application on carabid beetle (Coleoptera: *Carabidae*) activity in winter-sown cereals. *Ann. Appl. Biol.* **1992**, *121*, 401–422, doi:10.1111/j.1744-7348.1992.tb03453.x.
47. Relyea, R.A. The lethal impact of roundup on aquatic and terrestrial amphibians. *Ecol. Appl.* **2005**, *15*, 1118–1124, doi:10.1890/04-1291.
48. Altieri, M.A.; Companioni, N.; Cañizares, K.; Murphy, C.; Rosset, P.; Bourque, M.; Nicholls, C.I. The greening of the "barrios": Urban agriculture for food security in Cuba. *Agric. Hum. Values* **1999**, *16*, 131–140, doi:10.1023/a:1007545304561.
49. Beniston, J.; Lal, R. Improving soil quality for urban agriculture in the North Central, U.S. In *Carbon Sequestration in Urban Ecosystems*; Augustin, B., Lal, R., Eds.; Springer International Publishing: Geneva, Switzerland, 2011; pp. 279–313.
50. Garthwaite, D.; Ridley, L.; Mace, A.; Parrish, G.; Barker, I.; Rainford, J.; MacArthur, R. Pesticide Usage Survey Report 284: Arable Crops in the United Kingdom 2018. Available online: https://secure.fera.defra.gov.uk/pusstats/surveys/documents/arable2018.pdf (accessed on 6 August 2020).
51. Department for Environment, Food and Rural Affairs. *The British Survey of Fertiliser Practice: Fertiliser Use on Farm Crops for Crop Year 2019*; Department for Environment, Food and Rural Affairs: London, UK, 2019. Available online: https://www.gov.uk/government/statistics/british-survey-of-fertiliser-practice-2019 (accessed on 6 August 2020).
52. Knox, J.; Rodriguez-Diaz, J.; Weatherhead, E.K.; Kay, M. Development of a water-use strategy for horticulture in England and Wales—A case study. *J. Hortic. Sci. Biotechnol.* **2010**, *85*, 89–93, doi:10.1080/14620316.2010.11512636.
53. Met Office. Chance of Summer Heatwaves Now Thirty Times More Likely. 2018. Available online: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave (accessed on 8 July 2020).
54. Statista. Total Monthly Rainfall in the United Kingdom (UK) from 2014 to 2020. 2021. Available online: https://www.statista.com/statistics/584914/monthly-rainfall-in-uk/ (accessed on 10 February 2021).
55. Met Office. UK Climate Projections: Headline Findings. 2019. Available online: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf (accessed on 30 March 2020).
56. Met Office. Record Breaking Rainfall. 2020. Available online: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2020/2020-winter-february-stats (accessed on 30 March 2020).
57. Buechler, S.; Mekala, G.D.; Keraita, B. Wastewater use for urban and peri-urban agriculture. In *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities*; van Veenhuizen, E., Ed.; FUAF Foundation: Hague, The Netherlands, 2006.
58. Miller-Robbie, L.; Ramaswami, A.; Amerasinghe, P. Wastewater treatment and reuse in urban agriculture: Exploring the food, energy, water, and health nexus in Hyderabad, India. *Environ. Res. Lett.* **2017**, *12*, 075005, doi:10.1088/1748-9326/aa6bfe.
59. De Zeeuw, H.; Van Veenhuizen, R.; Dubbeling, M. The role of urban agriculture in building resilient cities in developing countries. *J. Agric. Sci.* **2011**, *149*, 153–163, doi:10.1017/s0021859610001279.
60. Travaline, K.; Hunold, C. Urban agriculture and ecological citizenship in Philadelphia. *Local Environ.* **2010**, *15*, 581–590, doi:10.1080/13549839.2010.487529.
61. Milbourne, P. Everyday (in)justices and ordinary environmentalisms: Community gardening in disadvantaged urban neighbourhoods. *Local Environ.* **2012**, *17*, 943–957, doi:10.1080/13549839.2011.607158.
62. Poulsen, M.N.; Hulland, K.R.S.; Gulas, C.A.; Pham, H.; Dalglish, S.L.; Wilkinson, R.K.; Winch, P.J. Growing an urban oasis: A qualitative study of the perceived benefits of community gardening in Baltimore, Maryland. *Cult. Agric. Food Environ.* **2014**, *36*, 69–82, doi:10.1111/cuag.12035.
63. Van Der Werf, H.M.G.; Knudsen, M.T.; Cederberg, C. Towards better representation of organic agriculture in life cycle assessment. *Nat. Sustain.* **2020**, *3*, 419–425, doi:10.1038/s41893-020-0489-6.
64. Grafius, D.R.; Edmondson, J.L.; Norton, B.A.; Clark, R.; Mears, M.; Leake, J.R.; Corstanje, R.; Harris, J.A.; Warren, P.H. Estimating food production in an urban landscape. *Sci. Rep.* **2020**, *10*, 1–9, doi:10.1038/s41598-020-62126-4.
65. Dobson, M.C.; Reynolds, C.; Warren, P.H.; Edmondson, J.L. "My little piece of the planet": The multiplicity of well-being benefits from allotment gardening. *Br. Food J.* **2020**, *123*, 1012–1023, doi:10.1108/bfj-07-2020-0593.

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"My little piece of the planet": the multiplicity of well-being benefits from allotment gardening

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Abstract

Purpose – Participation in urban horticulture (UH) is increasing in popularity, and evidence is emerging about the wide range of social and environmental benefits "grow your own" can also provide. UH can increase mental and physical well-being, as well as improve nature connectedness, social capital and community cohesion.

Design/methodology/approach – This study focusses on allotments, which is one of the dominant forms of UH that takes place in the United Kingdom. 163 volunteers in England and Wales participated in keeping a year-long allotment diary as part of a citizen science project investigating activities on allotment gardens. This study examines the unprompted comments that 96 of these gardeners offered as observations when visiting their allotment plots.

Findings – Participants recorded high levels of social and community activities including the sharing of surplus food produce, knowledge exchange, awareness and interaction with wildlife, emotional connection to their allotment, appreciation of time spent outside and aesthetic delight in the natural world around them.

Originality/value – At a time when waiting lists for allotment plots in the United Kingdom are on the rise, and allotment land is subject to multiple pressures from other forms of development, this study demonstrates that these spaces are important sites not only for food production but also health, social capital and environmental engagement.

Keywords Urban horticulture, Well-being, Allotments, Citizen science

Paper type Research paper

1. Introduction

Urban horticulture (UH) is an area of research becoming increasingly relevant to policy; it has been highlighted by the Intergovernmental Panel on Climate Change as a potential way to ensure food security in an increasingly globalised world (Mbow *et al.*, 2019). Indeed, recent research has demonstrated that there is a promising level of yields potential from expanding UH land in cities (Edmondson *et al.*, 2020; Mcdougall *et al.*, 2020). However, food provision is not the only benefit of UH. Participation in UH also has the potential to increase well-being in a number of ways.

Two prominent British gardening organisations, Sustain (https://sustainweb.org) and Garden Organic (https://gardenorganic.org.uk) have publicised this with the message that UH can provide multiple benefits for both physical and mental health (e.g. increasing fruit and vegetable consumption, increasing overall activity levels, increasing social interactions and reducing stress levels; Schmutz *et al.*, 2014). A systematic review of occupational health literature (Genter *et al.*, 2015) found that allotment gardening, a key form of UH in the United

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Kingdom, provided similar well-being benefits to more formal therapy gardening groups, and a meta-analysis by Soga *et al.* (2017a) found across-the-board positive benefits of gardening on health. Gardeners' own opinions support these findings, with recreation and mental health coming top of a list of reasons that 144 gardeners in Philadelphia participated in food growing (Blair *et al.*, 1991). In Tokyo, a survey of 332 people found that those who participated in allotment gardening reported better physical and mental health than those who did not (Soga *et al.*, 2017b). Results from the European Quality of Life Survey also support these findings, where people who grew their own food reported feeling happier than those who did not (Church *et al.*, 2015). These well-being benefits of UH have been found to occur even after a single gardening session (Wood *et al.*, 2016), and for a number of different groups of people, such as refugees (Harris *et al.*, 2014); prisoners (Richards and Kafami, 2008) and school groups (Ohly *et al.*, 2016). However, the review of research specifically on allotment gardening (Genter *et al.*, 2015) found that there was a paucity of studies of individual allotment gardeners in comparison to those participating in group gardening sessions, and recommended that further investigation is needed in the research to explore the impact of everyday allotment gardening for individuals.

More broadly, there is an established evidence base of the benefits of spending time outdoors, and developing nature connectedness, on physical and mental well-being (Martin *et al.*, 2016). Doctors' surgeries in Scotland have piloted "prescribing" outdoor activities to treat mental and physical health complaints (Fleischer, 2018). The idea of a "nature deficit disorder" (Louv, 2005) has become a popular lens through which to discuss the lack of nature connection amongst children and adults in the 21st century. This is particularly an issue in urban areas, which present an obvious challenge for people to connect with wildlife and greenspace when contrasted to the lives of people living in rural areas; indeed, rural dwellers experience less life stress in childhood as a result of their nearby access to greenspace (Wells and Evans, 2003). The British population is forecast to be 90% urban by 2050 (United Nations, 2019), meaning that barriers to nature connectedness specifically faced by city dwellers are relevant topics for most of the population. It is as important for people to experience wildlife in their "own backyards" as in a holiday or tourism setting (Curtin, 2009), suggesting that spaces within urban areas where people can encounter wild animals and birds are particularly precious. The psychological benefits of spending time in green spaces in urban areas also increases as biodiversity (or perceived biodiversity) increases (Fuller *et al.*, 2007).

The well-being benefits of nature connectedness become even more important when placed in the context of the state of mental health in the UK. The Organisation for Economic Co-operation and Development (OECD) estimated in 2018 that mental health problems cost the UK over 1bn Euros per year, or 4% of GDP (OECD/European Union, 2018). Against this general background, there can additionally be marked increases in demand on mental health services generated by specific national or global pressures, as demonstrated by the current coronavirus crisis, which is expected to directly cause at least half a million more people in the UK to experience mental ill health (NHS Providers, 2020). Mental health in the UK worsened by an average of 8.1% during the first two months of lockdown and social distancing (Banks and Xu, 2020), and with the impacts of lockdown particularly acute in urban areas, long-term mental health impacts for city dwellers may be severe.

In the above context, and with the additional recognition of its potential role in increasing food security, particularly in urban areas (Edmondson *et al.*, 2020; Mcdougall *et al.*, 2020), it is timely to investigate the potential opportunities to ameliorate poor mental health, and engage in physical activity and connection to nature, that are presented by participation in UH. Allotments are a key form of UH in the UK (Crouch and Ward, 1997; Acton, 2015), with around 330,000 allotment plots nationwide (Campbell and Campbell, 2013). They cover a land area of 135 km^2 across the country. Plot holders rent their allotment plot for a yearly fee, and most plots consist of a patch of land (approximately 250 m^2) adjacent to other plots, forming allotment sites, which can vary in their size depending on the number of plots. Allotments are predominately owned by local authorities, with, in many cases, individual allotment societies renting the land and letting plots out to tenants, although some privately run sites also exist. Allotments were originally conceived as a means to widen access to food production for urban dwellers (Crouch and Ward, 1997), and plot holders are legally obligated to maintain minimum cultivation levels of fruit and vegetables on their plot. However, many allotment gardeners also grow ornamental plants and have space on their plot for relaxation, such as garden chairs and tea making facilities.

Although widely recognised as an important opportunity for people to benefit from growing their own food, particularly in urban areas, there has been relatively little systemic research into the practices, resource use and personal benefits derived from allotment gardening. Here we report some of the results from a UK-wide citizen science project, which involved gardeners keeping year-long allotment diaries, recording a range of things such as time spent on different activities and water and fertilizer use, but also including an opportunity for recording unprompted notes. These notes are the focus on this analysis, and overall they provide a positive picture of the impact of allotment gardening on mental and physical well-being. Our findings add to the growing evidence base suggesting a strong link between allotment gardening and a spectrum of benefits for the individual, such as community cohesion, mental health and nature connectedness, and specifically address the research gap identified by Genter *et al.* (2015) concerning a lack of data on individual, as opposed to community group, allotments.

2. Methods

Allotment gardeners across the UK were recruited through online and in-print advertising (primarily Facebook, the MYHarvest website at https://myharvest.org.uk, and the Royal Horticultural Society magazine). In total 437 people, all of whom were individual allotment gardeners, signed up to complete a year-long (2018) allotment diary from all four constituent nations of the United Kingdom. Research was conducted in line with the University of Sheffield ethical standards and guidelines. Ethical approval was given by the University of Sheffield (Application 01284) for the project, and participants consented to the use of their data in this research project, and agreed that they could drop out of the project at any time if they so wished. They were asked to detail the amount of time they spent on their plot, resources used such as water or compost, and planting and harvesting activities. At the end of the year, participants were sent a stamped addressed envelope to return their diary pages, which were then scanned (so that originals could be returned to those who had requested this) and data extracted manually. One hundred and sixty three participants returned their diaries, forming a geographical distribution across England and Wales. Unfortunately, no diaries were returned from Scotland or Northern Ireland.

To the best of our knowledge, none of the allotment gardeners responding to this study were engaged in more formal horticultural therapy, but all practiced allotment gardening for the primary purpose of the production of fruit and vegetables, as is typical (and indeed, legally obligated) in the United Kingdom. Participants were not directly asked about well-being, but on each diary page (corresponding to a visit to the allotment) there was a space specifically for "Notes" which participants could use for any thoughts or observations they wanted to make. Ninety-seven of the 163 participants chose to write spontaneous observations and thoughts in this section for at least some of their allotment visits, giving 342 entries in all. We extracted the text of the Notes section for these entries. Participant start dates spanned late 2017 to early 2018, and as a result the full year was slightly varied in actual dates for each participant. The extracted Notes span a date range of 27 December 2017–25 February 2019. Two entries were undated notes written at the end of the participants' diaries.

These notes described wildlife encounters, non-plot-related activities such as participating in communal building projects, social interactions on the plot, use of surplus harvests and so on. As it was a free space to write in, the comments we received were very wide ranging. Therefore, we then analysed these notes to extract the different broad themes of the texts, coding comments into 11 dominant thematic strands. These categories were deduced *a posteriori*, after grouping comments together and seeing where dominant themes emerged (a "cutting and sorting" technique, as described in Ryan and Bernard, 2003; Popping, 2015; Vaughn and Turner, 2016). After comments had been assigned a dominant theme, any comment related less strongly to another theme as well as its main one was also given a sub-category so it could be included when analysing the comments theme by theme. Each comment was also coded to be positively, or negatively, related to its dominant theme, where this was applicable (such as negative or positive attitudes towards the weather). For example, "Educating children of visiting family re allotment culture" (09/08; hereon this denotes the date of example comments; see Supplementary Info for full list of comments, dates and anonymised participant ID) was categorised primarily as "Social" and secondarily as "Knowledge", with no positive/negative coding as there was no obvious emotion communicated by the participant in this comment. However, "So very very dry – no rain still, not a lot of pollinators in sight, no bees probably little nectar in such dry weather" (10/07) was coded primarily as "Weather", secondarily as "Wildlife", and with a negative associated emotion. Coding was carried out by hand in Microsoft Excel and statistical analysis to produce figures was undertaken using R 4.0.0 (R Core Team, 2020).

3. Results

3.1 Overall thematic observations

Some participants had included more notes entries over the year than others, which led to a slight bias in the thematic interpretation of the data. However, as shown in Figure 1, which demonstrates the number of comments per participant per emotion, the bias effect was minimal, with the vast majority of participants noting only one, two or three comments of either emotion (positive/negative) over the course of the year (Figure 1).

Overall, comments related to social activities or expressing emotions were the most common across the aggregation of primary and secondary thematic types (Table 1). Comments related to social activities were the most commonly expressed in positive terms,

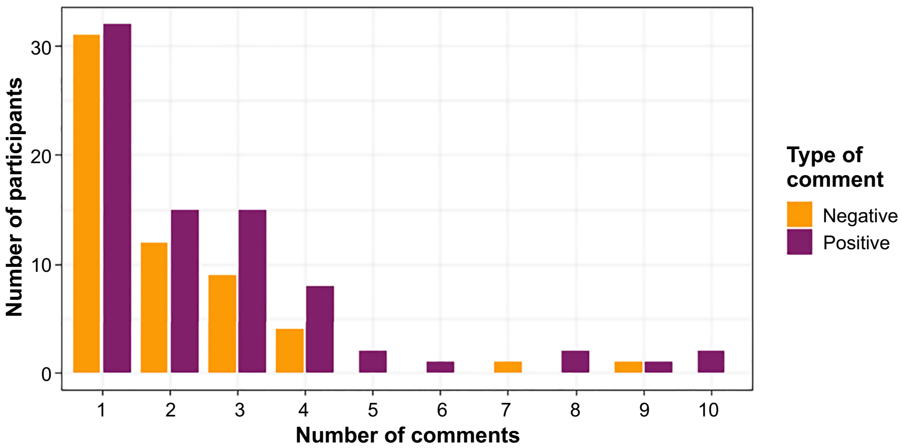

Figure 1.
Graph showing the number of comments received per participant of a negative or positive nature in allotment diaries over the course of the year

Theme	Number of entries, primary theme	Number of entries, secondary theme	Total number of entries associated with theme
Emotional	44	22	66
Health	10	3	13
Knowledge	4	5	9
Organisation	19	11	30
Pride	12	3	15
Relaxation	4	1	5
Sharing	18	10	28
Social	86	11	97
Surplus	6	9	15
Weather	83	11	93
Wildlife	56	9	65

Table 1. Thematic analysis of notes written in allotment diaries over the course of a year

Theme	Positive comments	Negative comments
Emotional	25	19
Health	4	6
Knowledge	0	0
Organisation	2	9
Pride	11	0
Relaxation	1	0
Sharing	18	0
Social	71	3
Surplus	6	0
Weather	23	60
Wildlife	39	17

Table 2. Analysis of positive or negative emotions associated with different primary themes of notes written in allotment diaries over the course of a year

and comments related to the weather were the most commonly expressed in negative terms (Table 2). On average, there were a median of 6 negative and 13 positive comments made each month. Positive entries started earlier in the year and ended later than negative responses; June and July were the only months with more negative than positive responses, and these months were dominated by the theme of weather in the negative comments (Figure 2). See Supplementary Information for a full list of comments with their associated themes.

3.2 Specific themes and examples

Comments related primarily to the emotional theme comprised 13.1% of responses. They generally captured a spontaneous observation of a participant's emotional response to their presence on the plot, for example, "A lovely morning: just right to be down on the allotments!" (18/11). Positive comments such as this were 57% of the emotional theme; the other 43% were negative. The negative responses were often related to outside influences, such as "Dictatorial council inspected the allotments!!" (31/03), or "Today was a sad day. I helped [a fellow plot holder] to bury his pet dog at the bottom of his allotment" (16/06).

Primarily health-related responses made up 3% of responses. These were often related to physical health, both pertaining to events occurring in the course of allotment gardening, such as "Hurt my back :(" (25/03), or general health consequences of gardening, such as "Who needs the gym!! I'm 70 next year!!" (16/06). Mental health was also discussed, always in positive language, such as "The plot is my safe place. It is my mental health balancer" (31/12).

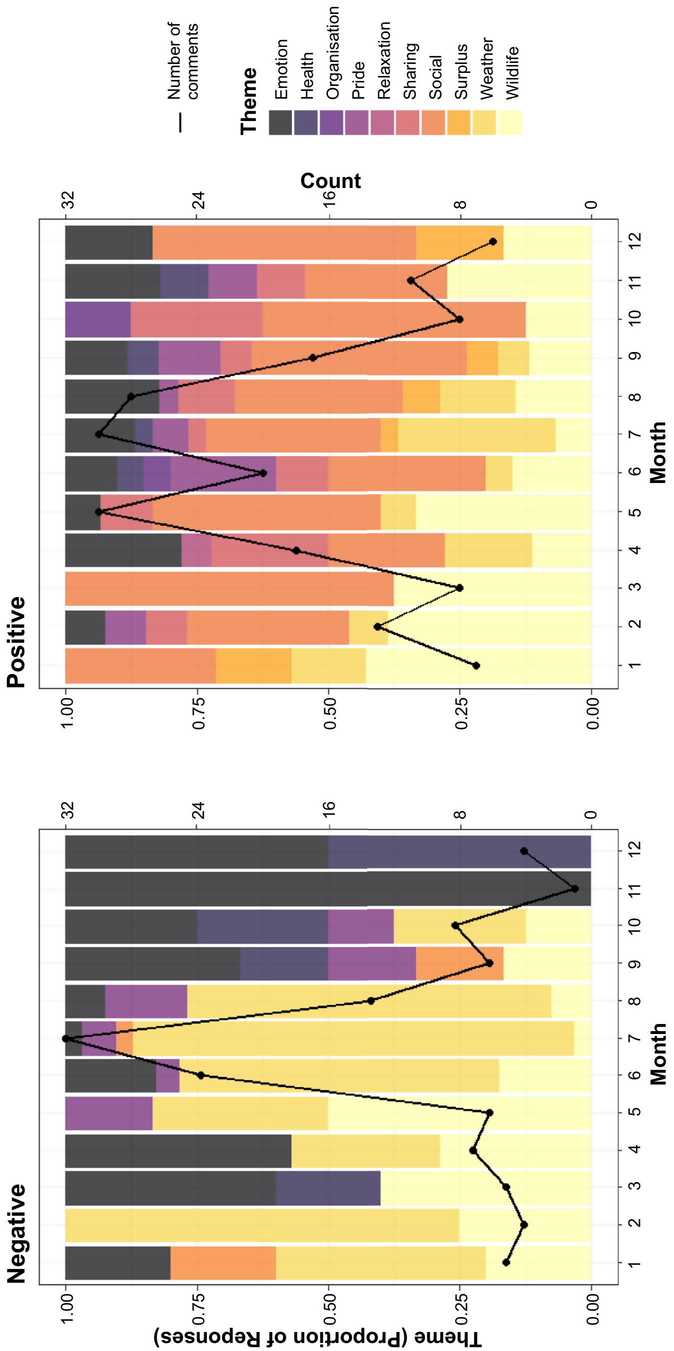

Figure 2.
Graphs showing the count, and distribution of themes, within negative and positive notes made in allotment diaries for each month of the year

Negative health-related comments were all to do with accidents while gardening, such as the above participant who hurt their back, and positive comments were more general and related to the overall benefit of having an allotment for physical and mental health.

The theme of knowledge made up 1% of responses, either through advice such as "Hoe when you cannot see a weed and you will never see a weed" (08/05) or uncertainty such as "Still not sure about funny courgettes, if they're squashes or not. Only time will tell" (11/08). All these comments were neutral emotionally, not positive or negative.

Organisation-related responses were 6% of the total. These were defined as comments primarily relating to the organisation of allotments at a site-wide level, such as participation in community events or the management of a site and involvement in committee activities. Committee activities ranged from annoyance such as "As a member of the committee – covered a vacant plot with tarpaulin to prevent weeds spreading. Also tidied up a bit of rubbish. It's amazing what some plot holders dump!" (20/05) to positive engagement such as "Allotment Association Working Party with 5 helpers" (14/01) and "Helped sort out seed potatoes in the shop = main reason for visit. Put up notices re volunteers for working party, shop opening & shop rota" (13/03). Of these comments, 81% were negative and related to having to deal with outside influences on the plot, such as the local council or new rules, suggesting that people have a strong sense of plot ownership and personal space that they do not like to be interfered with.

Comments on the theme of pride were another 3% of responses. These were intrinsic observations or external validation from competition results, and all were positive comments. For example, "Autumn show 4 bunches herbs - 3rd, carrot - 2nd, sweetcorn - 1st place, melon - 1st place, sugar snap peas - 3rd. Proud day :)" (08/09) and the more general "Allotment looking good" (02/11).

Another 1% of comments were on the theme of relaxation. For example, visiting just to spend time on the plot – "Just looked around" (30/06) – or satisfaction after hard work – "Pooped now. Time for a beer!" (20/04).

The theme of sharing occurred in 5% of comments. These were always related to having surplus produce, or social connections: "Left all my dahlia tubers in a box near the allotment gates with a note saying 'For anyone who wants them'" (22/05), "The 'April' cabbage seed I planted are ready to move on. I will have far more than I need so will share!" (19/09), and "Brought tray of green broccoli plants from home to plot greenhouse. Gave some away to plot neighbours" (21/04). Along with the social and surplus categories, sharing related comments demonstrate the networks of free exchange and mutual help that exist as part of having an allotment. All sharing comments were positive.

Social observations were the most dominant form of response, with primary-type social comprising 25% of observations. Mostly this was related to chatting and socialising with fellow plot holders, such as "Cut a cucumber for a friend on another plot. Drank a bottle of sparkling apple juice and had a laugh with two fellow allotmenteers!" (08/07) and "Spent too much time talking and not enough gardening! Must try harder tomorrow" (12/11). There were also incidents of bringing non-plot holders onto site such as "Took a walk around the allotment site to show a friend the place and just to enjoy it in its spring glory!" (05/05) and contributing to the wider community such as "Spent the morning 11 am-1300 at my old allotment site encouraging them to vote" (28/10). Of these comments, 96% were positive.

The theme of surplus related to having surplus produce and made up 2% of responses, such as "Didn't pick veg because too much waiting in the kitchen to be eaten already!" (28/08). This was also connected to sharing of such produce, including in the wider community, such as "Spinach and loads of courgettes which we put outside the house 'Help Yourself!'" (06/07). All such comments were positive.

Weather was the second most dominant category for the primary response type, with 24% of entries discussing the weather. The allotment survey was conducted in 2018, where record-breaking heatwaves and drought hit the United Kingdom during the summer, which may explain a heightened and more emotional focus on the weather than would otherwise be expected. For example, "No-one can remember when it last rained", "No rain for at least two months" (24/06 and 18/07, from the same participant), and "RAINED AT LAST!!" (30/07). Weather was most often talked about in negative terms due to both the effect of the drought on crop productivity but also structural damage to plot items such as greenhouses in autumn and winter storms. Negative comments about the weather made up 72% of occurrences.

Wildlife was the dominant theme in 16% of responses. These were of varying emotions, such as "B****** squirrel. It had all my cobnuts & 80% of my apples" (14/10). When wildlife was not interfering with the plot holders' gardening, observations were mostly made of animal behaviour, such as "Two seagulls fighting over scrap of food. A crow joined in like a boxing referee. The gulls fought so much they dropped the food and the crow nipped in and stole it! You had to be there" (04/05) and "Fox sitting at gate – resident on site" (14/01). 70% of comments about wildlife were positive.

4. Discussion

Here, we have uncovered the different ways that allotment gardeners interact with their growing space through unprompted thoughts and observations related to several key themes. These themes demonstrate that whilst the overarching purpose of allotment gardening is one of food production, co-benefits for participants' nature connectedness, social capital and mental well-being also arise as strong themes. Previous research, demonstrating that participation in UH can improve quality of life, is therefore supported by our findings here; and there is no evidence that the benefits uncovered in this paper do not occur more widely in other UH contexts. Further to this, we have also found that the benefits of allotment gardening have the potential to extend beyond the gardeners themselves, with participants talking about friends and family visiting and helping on their plots, as well as the potential to share surplus produce amongst the wider community. Overall, our results confirm the findings of Genter *et al.* (2015) that "Allotment gardening provides stress-relieving refuge, contributes to healthier lifestyle, creates social opportunities, provides valued contact with nature, and enables self-development". This study has demonstrated that these findings of Genter *et al.* (2015) on allotment gardening groups also apply to individual allotment gardeners.

The observations offered by participants in this project fell broadly into two categories: interactions with other humans and interactions with the natural world.

Interactions with other humans were generally spoken of in positive terms, except for negative interactions with outside authorities such as the council, or when plot holders were dealing with vandalism or break-ins at the plot. Most interactions, however, demonstrate that allotment gardeners have strong social links with other members on their sites, participating in knowledge exchange regarding plot management practices, free sharing of tools, surplus produce and seeds, and participation in activities related to the organisation of the site. Many plot holders spoke of bringing friends, children or grandchildren onto their plot to help them with food growing activities, and a large amount of the time spent on allotments is shown by this study to be involvement in social activities such as chatting and sharing cups of tea.

Participants also demonstrated a high level of engagement with the natural world and wildlife, from comments about the beauty of flowers and being outside, to specific observations about wildlife. When observing wildlife, participants mentioned the same animal (for example, a particular fox or frog) on multiple occasions, which shows that repeated visits to a specific place, such as an allotment, create human–nature bonds that are revisited throughout the year. As may be expected, participants also demonstrated a high level of engagement with the weather and changing seasons. Most comments about the weather were negative, and whilst this may corroborate British stereotypes, it also demonstrates an awareness and connection to the changing weather systems that show allotment gardeners have a depth of knowledge of the effect of weather patterns on their plot productivity, and ability to successfully cultivate their land.

The overall benefit of a year spent visiting an allotment, which requires an average of 55 visits, and 190 h (Edmondson *et al.*, 2020), was mentioned in positive terms in regard to mental health and time spent outdoors observing and directly participating in activities related to nature and growing. A sense of pride and ownership of successful gardening was a strong theme, showing that food growing can help people feel fulfilled and productive. Overall negative comments about organisation-related activities such as local council involvement with allotments, combined with the positive comments regarding prizewinning at allotment shows, demonstrate that a strong sense of personal ownership is prevalent amongst allotment gardeners.

Allotment gardens clearly provide a multiplicity of benefits for their tenants. However, the number of allotments in the UK has declined by almost two-thirds since the 1950s, with the most deprived urban areas experiencing eight times the level of closures as the least deprived (Dobson *et al.*, 2020). Research has demonstrated that gardening can be an important way for deprived communities to improve mental and physical health as well as create stronger, more resilient community networks (Travaline and Hunnold, 2010; Milbourne, 2012; Poulsen *et al.*, 2014). Our findings add to these by demonstrating that nature connectedness can also be added to the list of benefits for these communities; lower levels of green space access are associated with loneliness (Maas *et al.*, 2009), and more deprived communities in the UK have less access to greenspace (Jones *et al.*, 2009). Improving access to land for UH, not only in the form of allotments but also the broader swathe of soil-based UH such as community gardening projects, could therefore be one avenue to improve the standards of living in deprived urban areas. Further research would be needed to elucidate whether allotment gardening is addressing specific mental or physical health problems, or more generally contributing to overall well-being; this would allow policymakers to target horticultural therapy interventions to deal with specific issues. In general, this study should provide valuable evidence to policymakers of the benefits to be gained for communities from maintaining, preserving and increasing access to allotment gardening: it demonstrates a broad spectrum of issues (such as individual mental health, nature connection and social capital) that are benefitted by allotment gardens. As cities expand their urban horticultural activities, this study demonstrates that focussing on co-benefits beyond food production means that UH can be addressed from a number of policy perspectives, such as physical health, nutrition, mental health and community cohesion.

Our findings also present a number of possible future avenues for research. Firstly, the definition of the term "horticulture"; here, we have focussed on allotments cultivated for fruit and vegetables, but gardeners often also cultivate ornamental flowers. Horticultural therapy literature often covers both the cultivation of fruit and vegetables, and the cultivation of ornamental plants; in future research, investigating whether well-being benefits differ between those who do and do not also cultivate flowers could present some interesting findings. Secondly, this project discussed only allotments cultivated privately by individuals or families; a targeted study comparing the well-being benefits of allotments for gardeners such as our participants, and other allotment-based projects such as allotments for schoolchildren or refugee communities, could elucidate the specific nature of gardens where well-being is maximised, to provide clear evidence to produce policy guidelines to maximise well-being on a plot. Using unprompted comments, such as we have done here, has resulted in a non-standardised data set; this is both a limitation and a unique aspect of this study. Further research mirroring our approach assessing gardeners year-round should involve targeted questions about well-being at different points in the year; but also preserve the space for unprompted comments, as many unique observations from participants arose in this way.

One way to do this would be to conduct longer semi-structured interviews with gardeners at regular intervals throughout the year; more detailed insight from gardeners rather than the brief entries we have analysed here could provide some interesting results.

In conclusion, the findings of this project echo the statement, "'Local food projects' in urban areas are not really about food, and are best described as community projects with food as the pretext and a vector for social agency and the development of community capacity" (Maye, 2019). This was captured by one participant's end of year reflection: "Read back the year's diary. Sat + reflected upon the year. The plot is my safe place. It's my mental health balancer. Peaceful, but sociable, accepting, a place to connect, to disconnect. A place to grow, to write, to accept that things die and turn to compost. To be me without being judged. To eat and share food, drink + friendship. Not tidy or regimented, it changes + develops. It flowers and envelopes blossoms and blooms or freezes and browns. The bird song at all times, the outside industrial noises of the docks, roads, next door's motorbike, generator, chainsaw, rotavator, strimmer, friends, but mostly... it's mine. It's my little piece of Earth, the planet. I aim for no chemicals, using rainwater, last year's seeds, cuttings, pots donated, second hand stuff made into plant containers. A calm place to listen, to cry, to eat, to welcome friends, to walk around + know deep in my heart here, I feel connected, balanced (despite the wobbly deckchair) and recharged. I'm drawn here in the winter to the stark bareness of it all. Stripped back to the structure, paths + beds defined, perennials on show, spring bulbs daring to peek out... It's time for soup. Thank you for this diary. It helps me to write so some days you've helped my mental health" (31/12).

As the quote demonstrates, there is a spectrum of benefits aside from food production that allotment gardening can provide: peace, health, social interaction, nature connectedness, commensality, recycling and a feeling of autonomy, pride and ownership of one's allotment plot. In an increasingly disconnected, socially isolated society where the idea of "nature deficit disorder" in cities is connected to increasing mental health problems (Louv, 2005), this study has shown that the activity of allotment gardening, and by implication other forms of UH, can play a role in helping people to deal with many aspects of the issues facing communities in urban areas. Waiting lists for allotments are often long (Campbell and Campbell, 2013), suggesting that increased allotment provision could bring these benefits to many more people than presently provided for.

References

Acton, L. (2015), *Growing Space: A History of the Allotment Movement*, Five Leaves Publications, Nottingham.

Banks, J. and Xu, X. (2020), "The mental health effects of the first two months of lockdown and social distancing during the Covid-19 pandemic in the UK", IFS Working Paper W20/16, available at: https://www.ifs.org.uk/uploads/WP202016-Covid-and-mental-health.pdf (accessed 12 June 2020).

Blair, D., Giesecke, C.C. and Sherman, S. (1991), "A dietary, social and economic evaluation of the Philadelphia urban gardening project", *Journal of Nutrition Education*, Vol. 23 No. 4, pp. 161-167.

Campbell, M. and Campbell, I. (2013), *Allotment Waiting Lists in England 2013*, Transition Town West Kirby, National Society of Allotment and Leisure Gardeners, available at: http://www.transitiontownwestkirby.org.uk/files/ttwk_nsalg_survey_2013.pdf (accessed 20 March 2020).

Church, A., Mitchell, R., Ravenscroft, N. and Stapleton, L.M. (2015), "'Growing your own': a multi-level modelling approach to understanding personal food growing trends and motivations in Europe", *Ecological Economics*, Vol. 110, pp. 71-80.

Crouch, D. and Ward, C. (1997), *The Allotment: Its Landscape and Culture*, Five Leaves Publications, Nottingham.

Curtin, S. (2009), "Wildlife tourism: the intangible, psychological benefits of human–wildlife encounters", *Current Issues in Tourism*, Vol. 12 Nos 5-6, pp. 451-474.

Dobson, M.C., Edmondson, J.L. and Warren, P.H. (2020), "Urban food cultivation in the United Kingdom: quantifying loss of allotment land and identifying potential for restoration", *Landscape and Urban Planning*, Vol. 199 No. 103803, doi: 10.1016/j.landurbplan.2020.103803.

Edmondson, J.L., Cunningham, H., Densley Tingley, D.O., Dobson, M.C., Grafius, D.R., Leake, J.R., McHugh, N., Nickles, J., Pheonix, G.K., Ryan, A.J., Stovin, V., Taylor Buck, N., Warren, P.H. and Cameron, D.D. (2020), "The hidden potential of urban horticulture", *Nature Food*, Vol. 1 No. 3, pp. 155-159, doi: 10.1038/s43016-020-0045-6.

Fleischer, E. (2018), *Doctors in Scotland Can Now Prescribe Nature*, World Economic Forum Agenda, available at: https://www.weforum.org/agenda/2018/10/doctors-in-scotland-can-now-prescribe-nature (accessed 29 January 2020).

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H. and Gaston, K.J. (2007), "Psychological benefits of greenspace increase with biodiversity", *Biology Letters*, Vol. 3 No. 4, pp. 390-394.

Genter, C., Roberts, A., Richardson, J. and Sheaff, M. (2015), "The contribution of allotment gardening to health and wellbeing: a systematic review of the literature", *British Journal of Occupational Therapy*, Vol. 78 No. 10, pp. 593-605.

Harris, N., Minniss, F.R. and Somerset, S. (2014), "Refugees connecting with a new country through community food gardening", *International Journal of Environmental Research and Public Health*, Vol. 11 No. 9, pp. 9202-9216, doi: 10.3390/ijerph110909202.

Jones, A.P., Brainard, J., Bateman, I.J. and Lovett, A.A. (2009), "Equity of access to public parks in Birmingham, England", *Environmental Research Journal*, Vol. 3 Nos 2-3, pp. 237-256.

Louv, R. (2005), *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder*, Algonquin Books of Chapel Hill, Chapel Hill, NC.

Martin, G., Clift, R. and Christie, I. (2016), "Urban cultivation and its contributions to sustainability: nibbles of food but oodles of social capital", *Sustainability*, Vol. 8 No. 5, pp. 409-427.

Mass, J., van Dillen, S.M.E., Verheij, R.A. and Groenewegen, P.P. (2009), "Social contacts as a possible mechanism behind the relation between green space and health", *Health and Place*, Vol. 15 No. 2, pp. 586-595, doi: 10.1016/j.healthplace.2008.09.006.

Maye, D. (2019), "'Smart food city': conceptual relations between smart city planning, urban food systems and innovation theory", *City, Culture and Society*, Vol. 16, pp. 18-24.

Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N. and Xu, Y. (2019), "Food security", in Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M. and Malley, J. (Eds), *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, In press.

Mcdougall, R., Rader, R. and Kristiansen, P. (2020), "Urban agriculture could provide 15% of food supply to Sydney, Australia, under expanded land use scenarios", *Land Use Policy*, Vol. 94, p. 104554, doi: 10.1016/j.landusepol.2020.104554.

Milbourne, P. (2012), "Everyday (in) justices and ordinary environmentalisms: community gardening in disadvantaged urban neighbourhoods", *The International Journal of Justice and Sustainability*, Vol. 17 No. 9, pp. 943-957, doi: 10.1080/13549839.2011.607158.

NHS Providers (2020), "Coronavirus briefing: the impact of COVID-19 on mental health trusts in the NHS", available at: https://nhsproviders.org/media/689590/spotlight-on-mental-health.pdf (accessed 12 June 2020).

OECD/European Union (2018), *Health at a Glance: Europe 2018: State of Health in the EU Cycle*, OECD Publishing/European Union, Paris and Brussels. doi: 10.1787/health_glance_eur-2018-en.

Ohly, H., Gentry, S., Wigglesworth, R., Bethel, A., Lovell, R. and Garside, R. (2016), "A systematic review of the health and well-being impacts of school gardening: synthesis of quantitative and qualitative evidence", *BMC Public Health*, Vol. 16, p. 286, doi: 10.1186/s12889-016-2941-0.

Popping, R. (2015), "Analyzing open-ended questions by means of text analysis procedures", *Bulletin de Méthodologie Sociologique*, Vol. 128, pp. 23-39.

Poulsen, M.N., Hulland, K.R.S., Gulas, C.A., Pham, H., Dalglish, S.L., Wilkinson, R.K. and Winch, P.J. (2014), "Growing an urban oasis: a qualitative study of the perceived benefits of community gardening in Baltimore, Maryland", *Culture, Agriculture, Food and Environment*, Vol. 36 No. 2, pp. 69-82, doi: 10.1111/cuag.12035.

R Core Team (2020), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, available at: https://www.R-project.org.

Richards, H.J. and Kafami, D.M. (2008), "Impact of horticultural therapy on vulnerability and resistance to substance abuse among incarcerated offenders", *Journal of Offender Rehabilitation*, Vol. 29 Nos 3-4, pp. 183-193, doi: 10.1300/J076v29n03_11.

Ryan, G.W. and Bernard, H.R. (2003), "Techniques to identify themes", *Field Methods*, Vol. 15 No. 1, pp. 85-109.

Schmutz, U., Lennartsson, M., Williams, S., Devereaux, M. and Davies, G. (2014), "The benefits of gardening and food growing for health and wellbeing", *Garden Organic and Sustain*, available at: https://www.sustainweb.org/secure/GrowingHealth_BenefitsReport.pdf (accessed 28 January 2020).

Soga, M., Gaston, K.J. and Yamaura, Y. (2017a), "Gardening is beneficial for health: a meta-analysis", *Preventive Medicine Reports*, Vol. 5, pp. 92-99.

Soga, M., Cox, D.T., Yamaura, Y., Gaston, K.J., Kurisu, K. and Hanaki, K. (2017b), "Health benefits of urban allotment gardening: improved physical and psychological well-being and social integration", *International Journal of Environmental Research and Public Health*, Vol. 14 No. 1, pp. 71-84.

Travaline, K. and Hunold, C. (2010), "Urban agricultural and ecological citizenship in Philadelphia", *The International Journal of Justice and Sustainability*, Vol. 15 No. 6, doi: 10.1080/13549839.2010.487529.

United Nations (2019), "Department of economic and social affairs, population division", *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*, New York, p. 39.

Vaughn, P. and Turner, C. (2016), "Decoding via coding: analyzing qualitative text data through thematic coding and survey methodologies", *Journal of Library Administration*, Vol. 56 No. 1, pp. 41-51.

Wells, N.M. and Evans, G.W. (2003), "Nearby nature: a buffer of life stress among rural children", *Environment and Behaviour*, Vol. 35 No. 3, pp. 311-330.

Wood, C.J., Pretty, J. and Griffin, M. (2016), "A case–control study of the health and well-being benefits of allotment gardening", *Journal of Public Health*, Vol. 38 No. 3, pp. e336-e344.

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