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Feeding a city – Leicester as a case study of the importance of allotments for horticultural production in the UK

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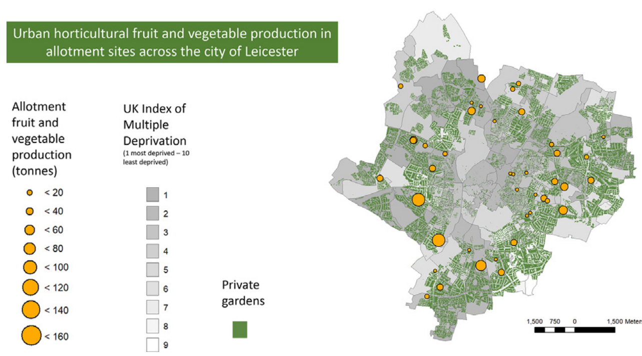
HIGHLIGHTS

- Urban agriculture provides important ecosystem services to people living in cities.
- Allotment gardening in 1.5% land within a city provides fresh produce for 3% of population.
- Crop yields achieved by own-growers were similar to commercial crop yields.
- Availability of land for own-growing has significantly declined since the 1950s.
- Urban food security could be increased by providing more allotment land.

GRAPHICAL ABSTRACT



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ABSTRACT

The process of urbanization has detached a large proportion of the global population from involvement with food production. However, there has been a resurgence in interest in urban agriculture and there is widespread recognition by policy-makers of its potential contribution to food security. Despite this, there is little data on urban agricultural production by non-commercial small-scale growers. We combine citizen science data for self-provisioning crop yields with field-mapping and GIS-based analysis of allotments in Leicester, UK, to provide an estimate of allotment fruit and vegetable production at a city-scale. In addition, we examine city-scale changes in allotment land provision on potential crop production over the past century. The average area of individual allotment plots used to grow crops was 52%. Per unit area yields for the majority of crops grown in allotments were similar to those of UK commercial horticulture. We estimate city-wide allotment production of >1200 t of fruit and vegetables and 200 t of potatoes per annum, equivalent to feeding >8500 people. If the 13% of plots that are completely uncultivated were used this could increase production to >1400 t per annum, feeding ~10,000 people, however this production may not be located in areas where there is greatest need for increased access to fresh fruits and vegetables. The citywide contribution of allotment cultivation peaked in the 1950s when 475 ha of land was allotments, compared to 97 ha currently. This suggests a decline from >45,000 to <10,000 of people fed per annum. We demonstrate that urban allotments make a small but important contribution to the fruit and vegetable diet of a UK city. However, further urban population expansion will exert increasing

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development pressure on allotment land. Policy-makers should both protect allotments within cities, and embed urban agricultural land within future developments to improve local food security.

1. Introduction

The global population is increasingly urbanized, with the number of people living in cities and towns rising from 29% of 2.56 billion people in 1950 (Goldewijk et al., 2011) to >55% of 7.63 billion by 2018, with a further projected rise to 68% of 9.8 billion by 2050 (UN, 2018). In developed countries such as the UK >80% of people are now urban dwellers (ONS, 2013). The process of urbanization has detached a large proportion of people from food production and made them dependent on food imported from increasingly distant regions (Howe and Wheeler, 1999; Martin et al., 2016). This has potential consequences for food security, greenhouse gas emissions, environmental sustainability, and social justice (de Ruiter et al., 2016).

It is estimated that 25–30% of urban dwellers practice some form of urban agriculture globally (Orsini et al., 2013). In many low-income countries, particularly in the Global South, self-provisioning urban agriculture is necessary for subsistence (Orsini et al., 2013). However, there has also been a resurgence of interest by urban populations in growing their own fruit and vegetables including individuals, households and community groups in the Global North. In the US the National Gardening Association (2014) 'Garden to Table Report' indicated that 35% of Americans now grow some of their own food, the highest participation rate for more than a decade, and that the most rapid increase in own-growing has taken place amongst urban populations and those aged 18–34 years old. At the same time, there has been a rise in use of 'vacant lots' for community gardens in the USA (Grewel and Grewel, 2012). Michelle Obama's (2012) book 'American Grown: The Story of the White House Kitchen Garden and Gardens Across America' came at a time of regaining interest in kitchen and community gardening in the US, and may have helped further popularize this as a family activity. In the UK demand for land rented from local authorities for food growing in the form of allotment plots has risen in recent years (Campbell and Campbell, 2011), similarly, in Germany, there are over 1 million allotment gardens, mostly in cities, often with long waiting lists (Cabral, 2014). Across the Global North there is growing recognition of the multiple health and social benefits from the activity of urban agriculture, and in particular the practice of fruit and vegetable gardening (Leake et al., 2009; Andreatta, 2015; Opitz et al 2016; Genter et al., 2015; Speak et al., 2015; Martin et al., 2016; White and Bunn, 2017). In addition, research has demonstrated that greenspaces used for urban agriculture can provide a habitat for biodiversity (Speak et al., 2015; Baldock et al., 2019) and support other key ecosystem services including urban heat island mitigation (Lin et al., 2015), soil carbon storage (Edmondson et al., 2014) and storm water regulation (Lin et al., 2015; Goldstein et al., 2016). By contrast, there remains a relatively poor understanding of the amount of food grown in urban agricultural sites, such as allotments, despite an increasing recognition amongst policy-makers from local to international levels of government of the importance of urban agriculture for food security, particularly in the Global North (Edmondson et al., 2019).

Urban agriculture in the Global North is predominantly focussed on the production of fruit and vegetable crops (Mok et al., 2014; Orsini et al., 2013), and is practiced in a variety of ways. These include community gardens, rooftop growing, controlled environment horticulture, urban farms, domestic gardens and allotments (Opitz et al., 2016). The location of urban agriculture in cities is likely to vary in relation to urban form. In Europe where urban areas are often very densely built, over 40% of the population live in flats or apartments, (Eurostat 2018) most of which lack private garden space. In many UK cities like Leicester the densest built residential parts of the city have terraced houses with no front gardens and small yards or gardens at the rear. As a consequence, one of the main areas, in terms of areal extent, of urban agriculture in European cities and towns are allotments (Crouch and Ward, 1997; Speak et al., 2015), which are also known as Kleingärten or Schrebergärten in Germany (Cabral 2014). In many European countries, including the UK, local authorities have been required in law for >100 years to provide these allotments (Crouch and Ward, 1997). In contrast, in North American cities which are characterised by greater sprawl, over 30 million households participate in food gardening with 70% of this activity taking place in suburban gardens (National Garden Association, 2014). This is likely to be facilitated by the more generous garden plot sizes than is typical in Europe, and the lack of statutory provision of land for allotments.

During the Second World War the 'Dig for Victory' and 'Victory Garden' campaigns promoted the use of greenspaces for food production in the UK and USA respectively (Defra, 2017; Andreatta, 2015; Opitz et al., 2016; Keep, 2009; Crouch and Ward, 1997). It has been estimated that in the UK *c.*18% of fruit and vegetables consumed (by value) were grown in allotments and gardens as a result of the Dig for Victory campaign, using <1% of the area of arable cultivation (Crouch and Ward, 1997; Keep, 2009; Defra, 2017). However, at that time the UK population was 46 million people, approximately 20 million fewer than at present (ONS, 2015), the land area available for self-provisioning was much larger, and diets were much less varied than today and more strongly based on UK-grown seasonal crops. Allotment plot provision in the UK declined in the post-war era from approximately 1.5 million plots to 300,000 in the late 1990s (Crouch and Ward, 1997), but the actual impact of this decline on the potential for self-provisioning and food security at a city-scale is poorly understood.

Addressing the critical knowledge-gap that exists in understanding of the fruit and vegetable production potential of urban greenspaces is particularly timely as at present the commercial horticultural sector faces a number of environmental, economic and social challenges that potentially threaten its sustainability and associated food security, especially in the UK. First, as part of the global agricultural system, intensive field-based horticulture which is prevalent on lowland peatlands is responsible for widespread, often irreversible, soil degradation (Natural England, 2010; Evans et al., 2016). A second challenge is the availability of seasonal labour for crop harvests, particularly in a post-Brexit UK where 99% of the 60,000 seasonal labourers employed originate from other EU countries (ONS, 2018). Indeed, labour shortages in 2017 meant that some UK growers were unable to complete their harvests (Lang and McKee, 2018). Coupled to challenges to the horticultural sector, there is a global problem of insufficient consumption and access to fresh fruits and vegetables, which is one of the leading causes of reduced life expectancy and preventable health cost burdens (Global Panel on Agriculture and Food Systems for Nutrition, 2016). Even in the Global North there are substantial numbers of people in extreme poverty and food insecure. In the UK 1.58 million emergency food parcels were distributed in 2018–19 from food banks run by the Trussell Trust (Sosenko et al., 2019) however, whilst these provide staple foods, they often provide little in the way of fresh fruit and vegetables.

In terms of area, urban greenspaces provide a considerable resource potentially suitable for production of fruit and vegetables, particularly when compared to the relatively small footprint of commercial horticultural production. In the UK urban areas cover 16,000 km^2 (UK NEA, 2011) of which greenspace accounts for approximately 50% (e.g. Edmondson et al., 2012; Caselegno et al., 2017; Dennis et al., 2018), which is 4.7 times larger than the area used for commercial production of fruit and vegetables (Defra, 2018). By comparison, in the USA urban areas cover >270,000 km^2 (US Census Bureau, 2010) of which 30% is greenspace (Wen et al., 2013) and this is approximately double the area of land used for commercial horticultural production of fruit and vegetables (USDA-NASS, 2014).

Despite a growing interest in the potential for urban agriculture to contribute to local food security amongst policy-makers and scientists (Edmondson et al., 2019), there is still a critical knowledge-gap in understanding of the productive capacity of cities at present and how this has changed over time. The overarching aim of this research is to quantify how much food is grown in allotments at a city-scale in the UK and how the land area available has changed over time. This will be achieved by addressing the following questions:

1) What are the yields achieved by fruit and vegetable gardeners in the UK?
2) What proportion of allotment plots are used for the cultivation of fruit and vegetable crops in a typical UK city?
3) What fruit and vegetables crops are grown in allotment plots and how much land is used for each individual crop type at a plot level?
4) How much land is currently used for allotment sites in a typical UK city and what are the current levels of individual allotment plot occupancy across the city?
5) How has provision of allotment land changed over the past century?

2. Methods

2.1. Rationale for methods

To address the hierarchy of research questions we used a novel combination of citizen science data collection, field mapping and spatial analyses in a geographic information system (GIS). In brief, we combined crop yields collected from individual fruit and vegetable growers using citizen science methodology (question 1) with allotment plot level information about cultivation practices (questions 2 and 3) and city-scale spatial information using a GIS to understand the current and historical distribution of allotment sites (questions 4 and 5) (Fig. 1). This enabled us to provide a first estimate of fruit and vegetable production in allotments at a city-scale in the UK, and how provision of allotment land has changed this potential production over time (Fig. 1).

2.2. Study area

Our study city, Leicester (52°38′N, 1°08′W), is a mid-sized UK city of approximately 73 km^2 (defined by the unitary authority boundary), situated in the East Midlands of England (Fig. 2). It has a human population of 330,000 (Leicester City Council, 2012), with a population density of 45 people ha^{-1} similar to that of many English cities (e.g. 39–44 people ha^{-1} for Outer London, Nottingham, Liverpool, Birmingham, and Manchester: ONS, 2013). As is typical for local authorities responsible for urban areas in England (including those listed above), according to the Index of Multiple Deprivation, inhabitants of Leicester are generally more deprived than those from the surrounding rural areas (ONS, 2009). However, at a local level within the city (Lower Level Super Output Area (LLSOA) – average population 1500) there is variation in deprivation according to the Index of Multiple Deprivation. Nearly a quarter of all LLSOAs were in the first most deprived decile in England and with each increasing decile the proportion of the LLSOAs in the city within declined – <2% of the LLSOAs were in the 9th decile and there were none in the 10th (Fig. 2). The city experiences a temperate climate, with average annual minimum and maximum daily temperature of 6.1 and 13.9 °C respectively and 620 mm of precipitation annually (Met Office, 2010). Allotments are provided at 46 sites across the city, 45 of which are owned by Leicester City Council and these 45 comprise 3200 individual plots (Leicester City Council, 2012). The allotment sites cover 97 ha, which is 2% of the city's greenspace and 1.3% of the whole city.

2.3. Citizen science collection of individual crop yields

Crop yield data were collected over the 2012 and 2013 growing seasons, using a citizen science methodology, from people growing their own fruit or vegetable crops in allotments, gardens or other growing spaces in Leicester, and other UK cities (see Supplementary Material

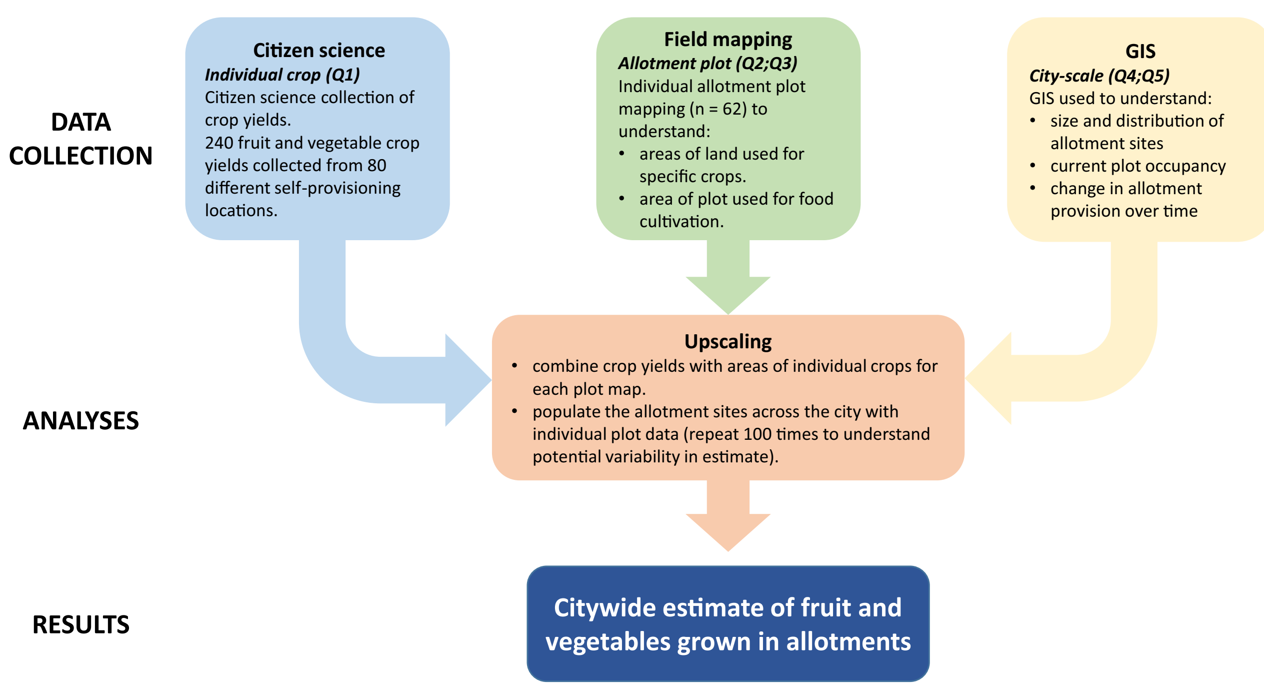

Fig. 1. A schematic diagram of the methodological approach used to produce an estimate of city-wide fruit and vegetable production in allotments (text in parentheses indicates the individual research question being addressed).

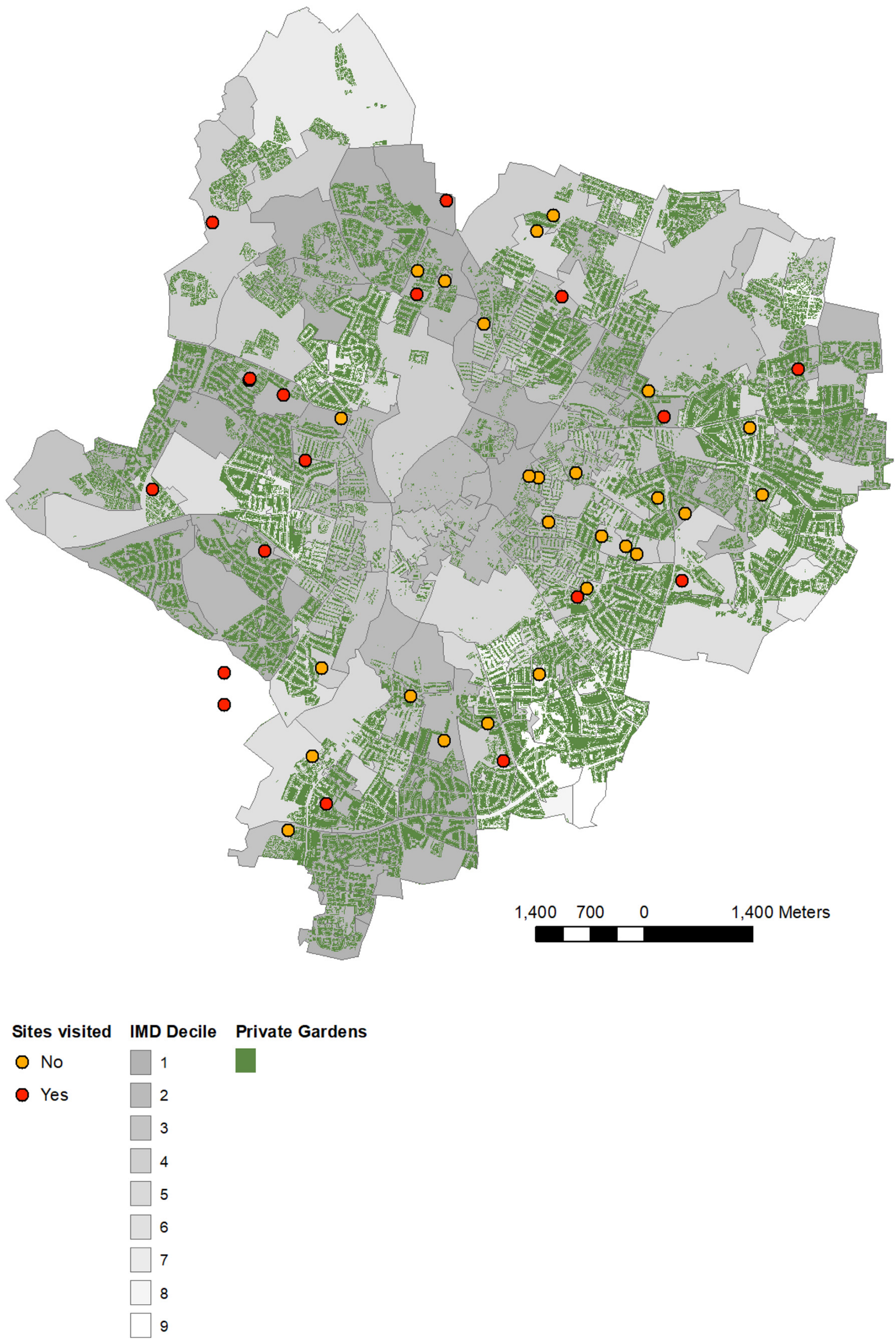

Fig. 2. Distribution of allotment sites across Leicester overlaying the Index of Multiple Deprivation (IMD) in the city at the Lower Level Super Output Area level.

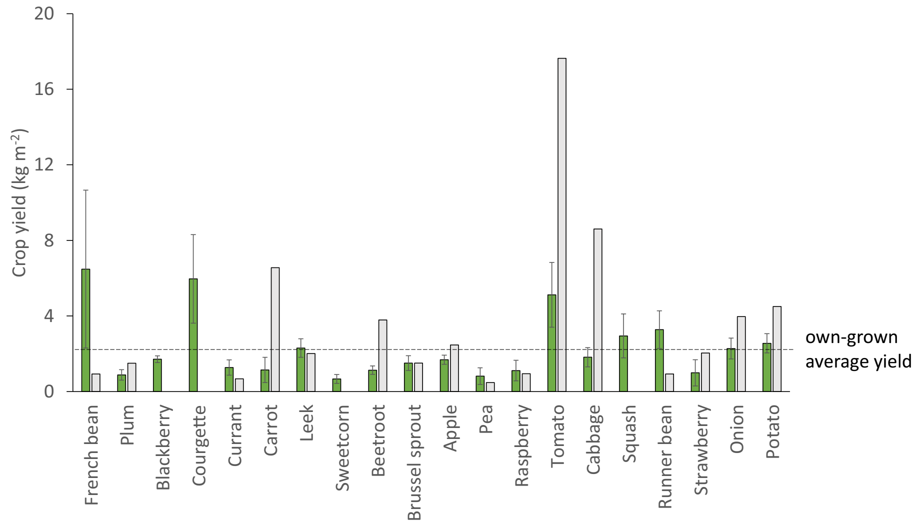

Fig. 3. Average fruit and vegetable yields achieved by citizen science participants (green bars) and equivalent commercial horticultural yields (grey bars - Defra, 2018). Error bars represent ±1 standard error. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

S1 for recording guidelines and participation sheet). Participants were recruited via outreach events associated with allotment societies (Leicester City Council, Liverpool Allotment Association, St Helens Allotment Regeneration Initiative, National Federation of City Farms and Community Gardens, The North East Allotments Officers Forum, Grow Sheffield, and through an article in the National Allotment Society Magazine) and fruit tree harvests were collected by volunteers with Abundance Sheffield. The data were returned by post or email using a reporting form in which the area of land used to grow a specific crop and the weight of that crop when harvested were reported. This enabled yield per unit area (kg m^{-2}) to be determined for each crop, and mean values to be calculated for the same crop types grown on different plots and by different growers. In total 240 individual crop yields were recorded in 80 different self-provisioning locations. Self-provisioning crop yields were compared to UK commercial horticultural crop yields provided by Defra (2018) (for a full list of crops with Latin names please see Supplementary Material S2).

Table 1
Management characteristics of surveyed allotment plots (n = 64).

	Mean	Standard error	Median	Minimum	Maximum
Length of time plot held (years)	11	2	7	1	40
Plot size (m^2)	264.3	14.5	235.8	85	720
Uncultivated area					
Hard surface (m^2)	18.2	2.9	10.9	0	96.2
Hard surface (%)	7.1	1.1	5.4	0	33.3
Shed area (m^2)	5.6	0.5	4.3	0	20.3
Greenhouse area (m^2)	3.8	0.6	2.7	0	18.6
Growing area					
Fruit and vegetable cultivation (m^2)	128.5	8.7	112.0	26.5	338.5
Fruit and vegetable cultivation (%)	51.5	2.0	50.0	15.1	87.0
Fruit tree area (m^2)	8.5	2.0	0	0	97.3
Grass (m^2)	10.6	3.7	0	0	350.6
Non-food cultivation (m^2)	7.5	1.3	1.1	0	39.8
Other plot features					
Compost heap	2.1	0.3	1.8	0	11.8
	Proportion of plots (%)			Minimum	Maximum
Dalek compost bin		37%		0	7
Water storage		66%		0	12
Pond		6%			

2.4. Field mapping of allotment plots

Sixteen allotment sites were selected to provide a good geographical spread across the city (Fig. 2: one site fell outside the administrative boundary but was still owned and managed by Leicester City Council). Within each site permission was sought from plot holders, and in total 62 allotment plots were surveyed. Allotment plot size for each individual plot was recorded and a detailed map was produced for each of these plots, including area assigned to individual crops and bare soil ready for planting.

2.5. City-scale analyses of current and historical allotment land provision

2.5.1. Current allotment site distribution, size and plot occupancy

All council managed allotment sites in Leicester were identified in Google Earth. Where image quality was sufficient (i.e. not obscured by shading) the sites were surveyed for total area, area of land assigned to on site infrastructure (i.e. roads, communal paths, site huts and other buildings), number of allotment plots that were completely uncultivated and the area of land they covered.

2.5.2. Historical allotment survey

Historical Ordnance Survey Maps for Leicester were available for six different periods (1910–1920s, 1940s, 1950s, 1960s, 1970s and 1980s) and this enabled change in allotment provision over time to be determined in ArcGIS. The area of allotment provision was quantified for each of the historical map periods by digitising individual allotment sites within the current administrative boundary of the city. OS MasterMap was used for current allotment provision in combination with the Leicester City Council allotment map. Absolute change in area over time was converted to change in per capita provision using census data for the city in the nearest decade to each mapping period.

2.6. Upscaling total food production

A resampling methodology was used to estimate city-wide food production by combining the citizen science crop yield, field mapping data, and the citywide GIS data. An estimate was first created for each allotment site in Leicester as follows. For each site, the 62 allotment survey plots were resampled with replacement until their cumulative cultivated area reached that of the allotment site. The total area of each crop present in the sample was then calculated and these were combined with the crop yield data to estimate the total site-specific crop yield. Where no yield data were available for a specific crop type a mean value was applied based on all the crop data submitted to the project. City-scale food production was estimated by summing over the estimated production of every allotment site in Leicester. This resampling scheme was repeated 100 times to derive a mean and standard deviation of the crop-specific and total food production at the city-scale. Two different scenarios were considered. In the first, uncultivated plots were excluded to estimate production under current usage patterns. A second estimate that included these plots was then derived to estimate potential production. Finally, estimates of total city-scale crop production were converted to the potential number of people fed on a '5-a-day' diet using the World Health Organisation recommendation of consumption of 400 g of fruit or vegetables per day (WHO, 2003). The potato harvest was separated as potatoes are not included as part of the 400 g fruit and vegetable consumption target outlined by the WHO. In the UK, people typically buy 35.1 kg of potatoes (either fresh or prepared) annually (Defra, 2017), using this value we calculated the number of people within the city that potatoes grown by allotment gardeners could support.

3. Results

3.1. Citizen science collection of individual crop yields

The average crop yield recorded in the citizen science project was 2.3 ± 0.2 kg m^{-2}. When compared to commercial horticultural yields for the UK, the citizen science crop yield was greater for French beans, runner beans, currants, leeks and raspberries, and vice versa for tomatoes, carrots and cabbages (Fig. 3). Defra do not provide commercial horticultural yields for blackberries, courgettes, sweetcorn and squashes.

3.2. Allotment plot cultivation area and crops grown

The 64 allotment plots across the city that were field surveyed had a mean area of 264 ± 15 m^2 and ranged from 85 to 720 m^2, the smallest plot being on a site where 'half' plots were let. Median hard surface cover in allotment plots was 10.9 m^2 or 5.4% of the total plot

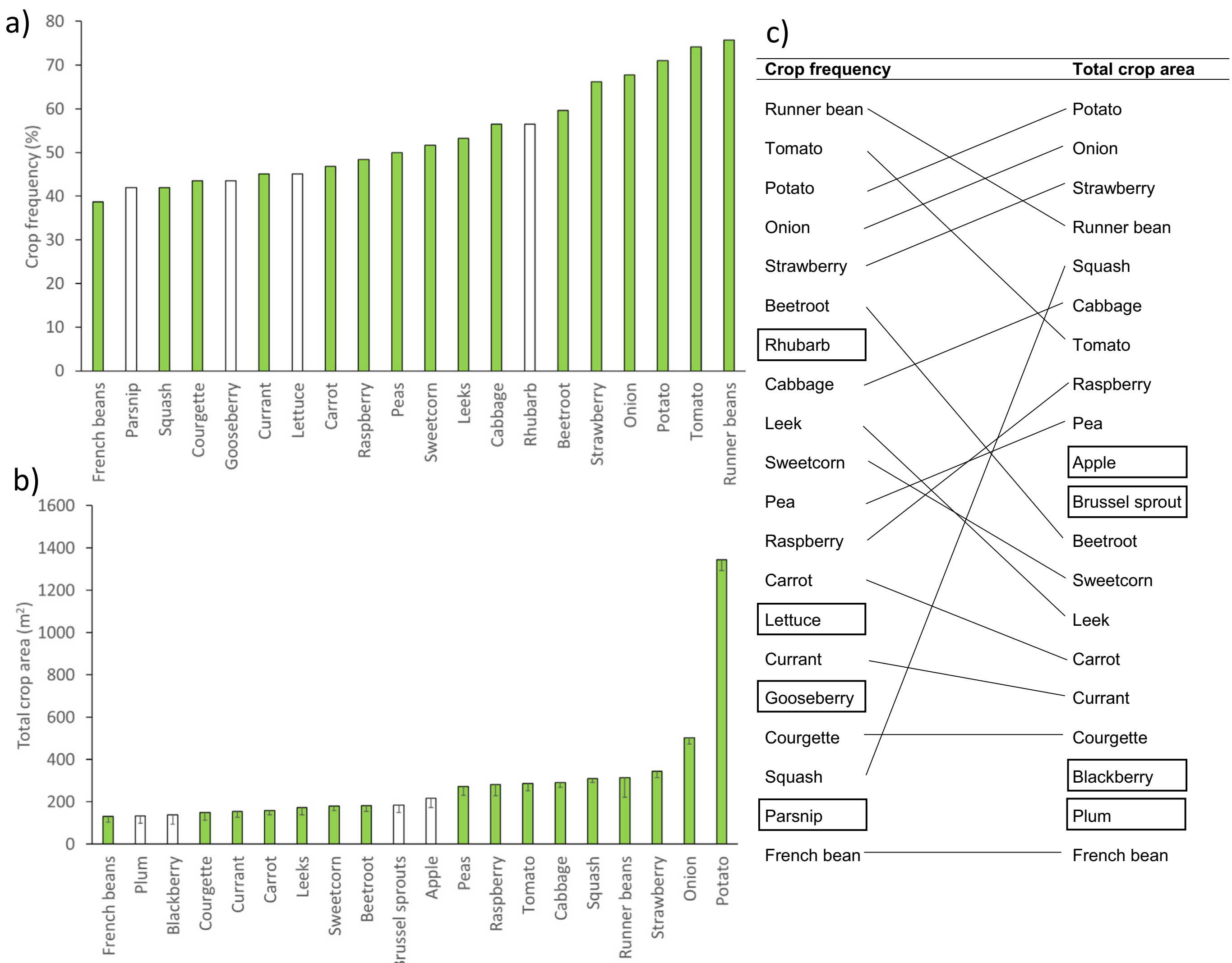

Fig. 4. Allotment fruit and vegetable cultivation patterns from the 64 plots field surveyed. a) The top 20 most frequently recorded fruit and vegetable crops in individual allotment plots, b) the top 20 fruit and vegetable crops in terms of overall areal extent, and c) a comparison of the shift between the most commonly grown crops and most important crops in terms of areal extent (negative error bars indicate the largest area covered by each crop in a single plot). Green bars indicate crops that occur in both a) or b) and white bars indicate crops that occur in only a) or b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Table 1). Greenhouses, sheds, water storage and composting were common on the allotment plots (Table 1). Across the 64 allotment plots surveyed, the average proportion of the area that was used to grow food crops was 51.5 ± 2%, and ranged from 15% to 87% (Table 1). There were 78 different crop types recorded, 33 of which had three or more yield values reported in the citizen science project, whereas 15 crop types had only a single record.

The most frequently recorded crops were runner beans, with tomatoes, potatoes, onions and strawberries occurring at a similarly high frequency (Fig. 4). Across the total cultivated area of the 64 plots, potatoes were the most extensive crop covering 16% of the area, more than twice the area of onions, the second most extensive crop (Fig. 4b). Of the top 20 most frequently recorded crops, rhubarb, lettuces, gooseberries and parsnips were not in the top twenty crops in terms of area used. In contrast, apple trees, Brussels sprouts, blackberries, and plums were in the top 20 in terms of plot coverage but not frequency (Fig. 4a and b). Squashes (including pumpkins) were the 17th most frequently occurring but 5th in overall areal extent reflecting their large growth form (Fig. 4c). The mapping period in Leicester spanned July – September and so bare cultivated soil, where a crop had recently been harvested, was also frequent (58% of plots) and covered nearly 10% of the total cultivated area of the plots, so it is likely that production of some early maturing crops such as spring onions, lettuces and early potatoes, together with some over-wintering crops like purple sprouting broccoli and winter cabbage may have been underestimated as a result.

3.3. Allotment site characteristics at a city-scale

Allotment sites in Leicester cover 97 ha of the city (<1.5% of the areal extent). The survey revealed that 82% of the allotment site area (80 ha) comprised allotment plots, the remaining 18% was used for onsite infrastructure, including roads, paths, and communal buildings (e.g. allotment society sheds). However, at a citywide scale, 13% of the allotment plots were completely uncultivated so the total area of plots actively being used was 69 ha.

3.4. Current citywide production of fruit and vegetables in allotments

Total fruit and vegetable production on allotment plots in Leicester was estimated at >1200 t of fruit and vegetables and 200 t of potatoes. This was approximately 1.6 kg produce m^{-2} of total allotment land area, i.e. including unused plots and uncultivated areas within plots (Fig. 5a). This could be increased to >1400 t of fruit and vegetables and >300 t of potatoes if the currently unused plots were cultivated to the average of 51.5% of their area seen in the 64 sampled plots. This would increase the productivity of the citywide allotment area to 1.8 kg m^{-2} (Fig. 5a). The current production would feed >8500 people on a '5-a-day' diet and >7500 on potatoes per annum (Fig. 5b). This increases to nearly 10,000 and 9000 people with fruit and vegetables and potatoes respectively, if all the plots in the city were cultivated to the extent recorded in the 64 surveyed plots (Fig. 5b).

3.5. Historical provision of allotments in Leicester and their per capita food production

The total area of allotments in Leicester peaked during the 1950s, and at this time covered 475 ha (6.5% of the city) but this provision has subsequently declined by 84% to leave only 97 ha or 1.5% of the current area of the city (Fig. 6). Allotment provision in Leicester is now at its lowest for over a century, and of the 396 ha lost since the 1950s the majority has been developed for schools and housing (Fig. 6, Fig. 7a). However, >20 ha of former allotment land remain as greenspace, potentially able to be returned to allotments, in seven cases directly abutting remaining allotments, and 3 ha of new allotment land has been created since the 1950s. Per capita provision of allotment land in the city has fallen from >16 m^2 in the 1950s to <3 m^2 at present (Fig. 7b). Based on our yield and cropping data, we estimate that this has resulted in a decline in the potential number of people fed on a '5-a-day' diet from >45,000 in the 1950s to the current figure of <10,000, which is a decline from over 16% to <3% of the city's respective population sizes at those times (Fig. 7c & d).

4. Discussion

4.1. Citizen science fruit and vegetable yields

Our research achieves an important advance in providing the first assessment of the actual yields and total contribution of allotments to local food production for a typical UK city, based on the mean yields achieved by growing for self-provisioning, and the areas used for the main crops they grow. The yields of fruit and vegetable crops achieved by allotment gardeners in the UK were often as good or exceeded those of commercial horticulture, contrasting with the expectation that greater professionalism and technologies used in commercial production would result in poorer yields from gardeners (Opitz et al., 2016). However, commercially produced carrots and cabbages, which are grown on very high quality soils, and tomatoes, which are grown in highly controlled heated greenhouses with liquid feeding (Defra, 2018), all showed poorer yields by participants in the citizen science project. Courgette yields recorded by participants in the citizen science project were high but this crop is not widely grown commercially in the UK so there are no Defra statistics on its yields. Knapp and Osborne (2017) report 1.9 kg m^{-2} yields for commercially grown courgettes. This is ~4 kg m^{-2} lower than the average yield reported in our study. This improved understanding of how fruit and vegetable crops grown

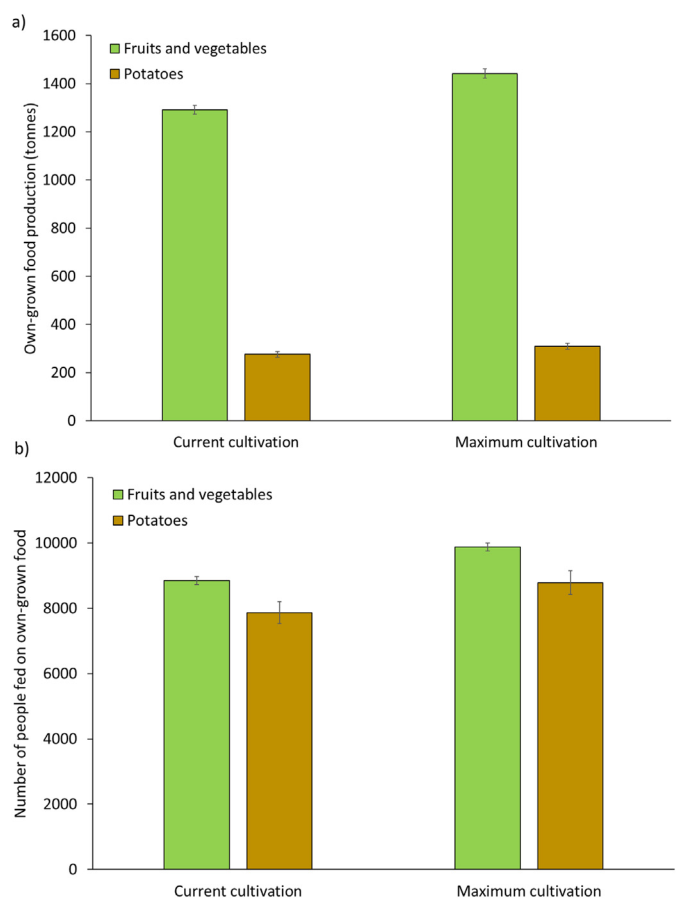

Fig. 5. Citywide estimate of a) the amount of allotment fruit and vegetable and potato production and b) the number of people fed per annum on allotment fruit and vegetables and potatoes at current levels of allotment plot cultivation and at maximum allotment plot cultivation. Error bars represent ±1 standard error.

by urban agricultural practitioners compares to commercial horticultural yields has enabled the robust estimation of production potential of urban agriculture and may inform crop choices in the relatively small space available to individual growers in allotments, gardens, and community gardens.

4.2. Citywide fruit and vegetable production by allotment holders

Our estimate that Leicester's allotments would provide 2.6% of the city's population with a '5-a-day' fruit and vegetable diet contrast with the conclusions of Martin et al. (2016). They reported that urban agriculture is only able to provide 'nibbles of food' amounting to 0.002–0.06% of the food requirements of the immediate populations at three urban agricultural sites - a community farm in London, a community garden in New York and an agricultural park in San Francisco. The Leicester allotments are providing 1–3 orders of magnitude more food per capita for a whole city population than the estimates of Martin et al. (2016) that were based on specific sites, suggesting that focusing on only a few urban agricultural sites within different cities may not be representative of the potential production at a city-scale. The community growing space described by Martin et al. (2016) had less than a third of its area allocated to food production, whereas we found that more than half of the area of allotments in Leicester is currently used for food production. Furthermore, our assessment of food production by allotment gardeners is conservative with respect to non-commercial urban production as it does not include contributions of private gardens and other growing spaces outside of allotments, does not account for any sequential cropping off the same land in the same year, and was calculated for optimal fruit and vegetable consumption targets. In practice the UK average daily purchase of fruit and vegetables is actually only 3.9 portions per person per day (Defra, 2017), and at this consumption rate current allotment produce in Leicester would hypothetically feed approximately 3.3% of the population, increasing to 3.8% if all the available plots were cultivated.

The substantially higher historical estimates of 18% of the nation's fruits and vegetables by value being produced during the Dig for Victory campaign in World War Two (Defra, 2017) included all non-commercial production not just that taking place in allotments. This figure is similar to our estimate that during peak provision in the 1950s in Leicester, allotments alone could have produced enough fruit and vegetables to feed 16% of the city's population, assuming the crops grown and areas cultivated were similar to those found today. If a higher proportion of high-yielding staples such as potatoes were grown in the 1950s, then the contribution of the allotments to diets could have been even greater. Although during the latter half of the 20th Century demand for allotment land dwindled, the recent resurgence in interest in self-provisioning of fruit and vegetable crops means that allotment availability in the UK is insufficient to meet demand - there are 75,000 people nationally on waiting lists (Campbell and Campbell, 2011).

The UK is not unique in the increasing interest in urban agriculture and self-provisioning food production which is also occurring in some continental European cities and in the USA, and this rising demand may not be fully met by existing greenspace allocations to allotments and community growing space. For example, in urban areas in Germany demand often exceeds supply for allotment plots (BBSR, 2018). Access to land is one of the major limiting factors for food production within a city (Brunori and Di Iacovo, 2014; Opitz et al., 2016), but this does not mean that all available land is being used effectively. In Leicester 13% of allotment plots in the city were completely uncultivated, however, this rate of underuse is considerably better than at nine allotment sites in Manchester, where 30% of plots were uncultivated (Speak et al., 2015). In Leicester, about 5% of the land that was previously used for allotments (approximately 20 ha) remains as urban greenspace that could be converted back to urban agriculture – this could represent a 25% increase in currently available allotment land in

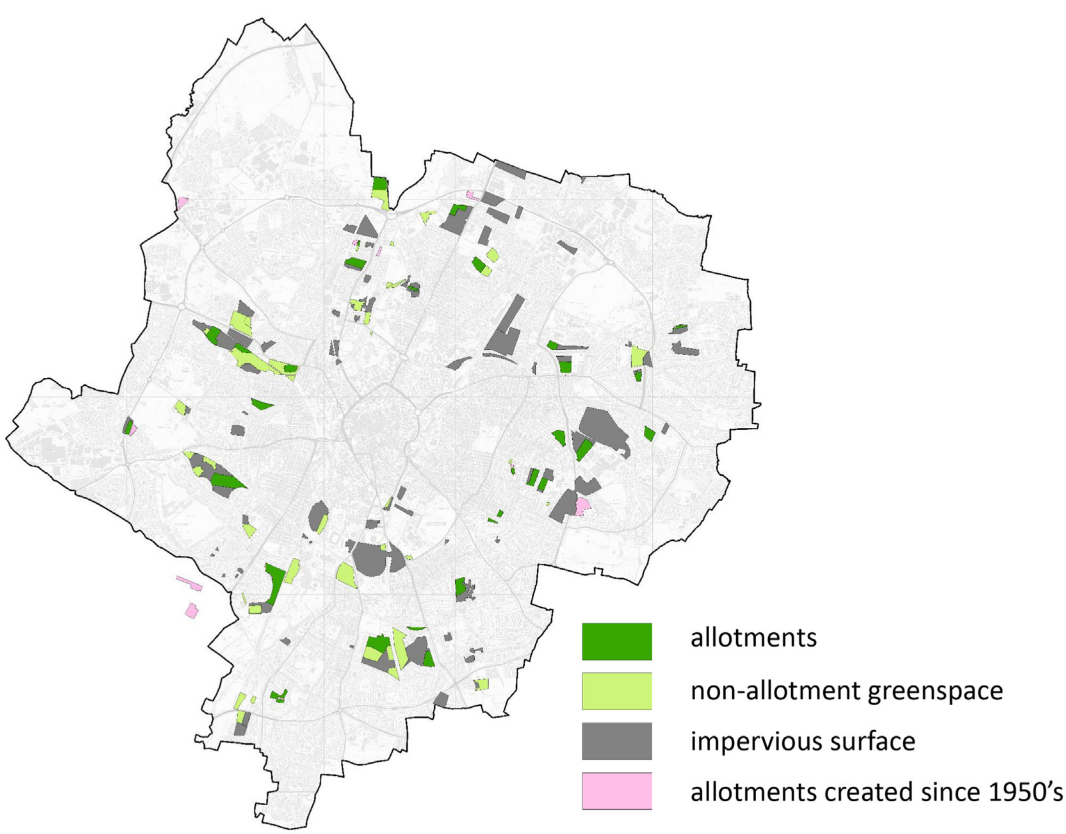

Fig. 6. Changes in allotment land-use from peak provision in the 1950's to the present day.

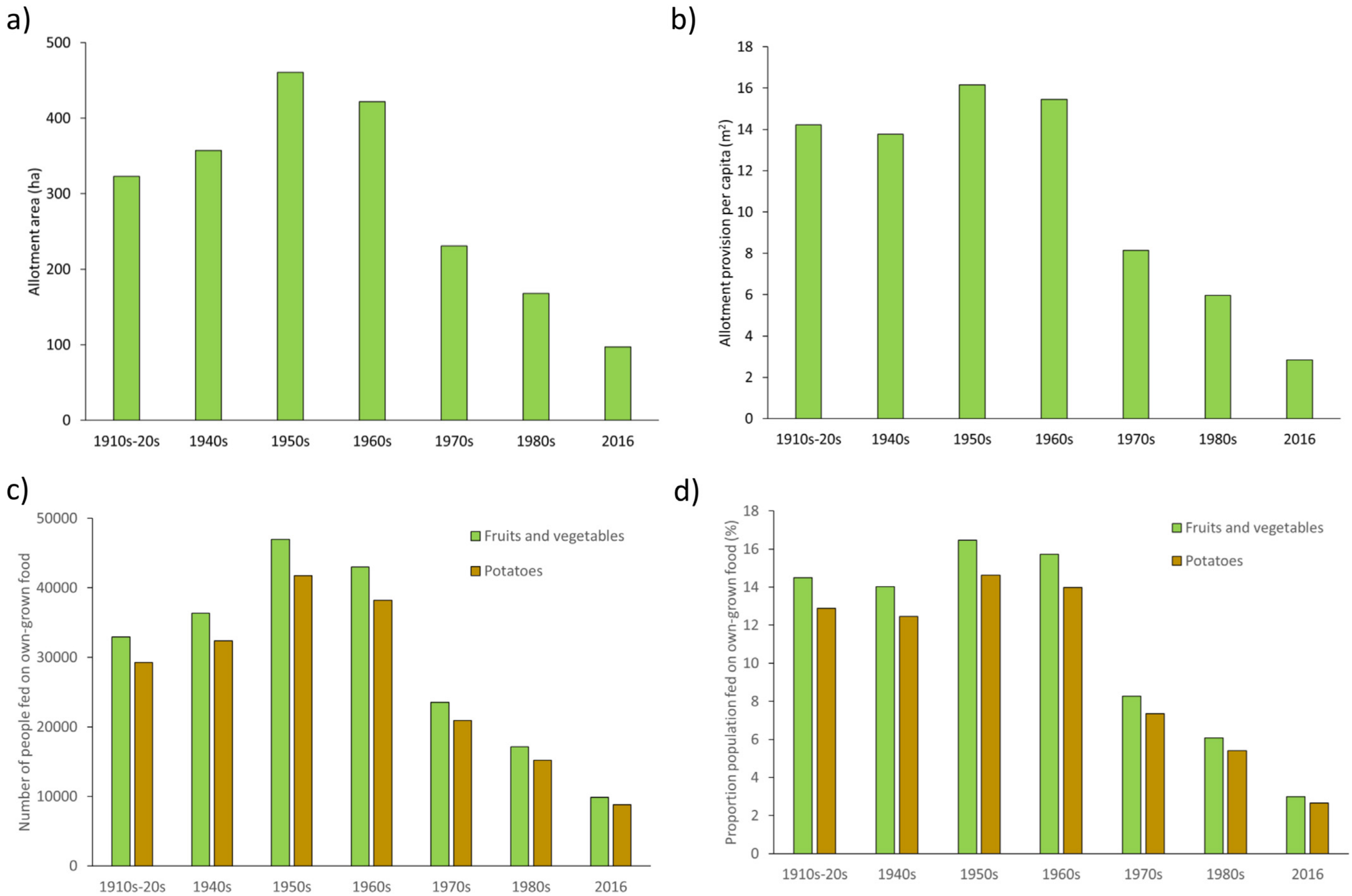

Fig. 7. Temporal change in a) allotment area; b) allotment provision per capita; c) number of people fed; and d) proportion of contemporary population fed from 1910 to the present day.

the city and could potentially feed a further 2500 people on a '5-a-day' fruit and vegetable diet. A previous study in Leicester found that 580 ha of the city's greenspace would be suitable for short rotation coppice biofuel production (McHugh et al., 2015). This is larger than the historical maximum area for allotments in the 1950s, and if used for allotments would provide 19,000 standard sized plots (250 m^2), with associated infrastructure, and could provide an additional 18% of the city's population with '5-a-day' fruit and vegetables. In addition to allotment land, domestic gardens typically cover about a quarter of the urban area (Loram et al., 2008), and in our study city these comprise 56% of the greenspace resource (Davies et al., 2011). However, at present relatively little is known about the contribution self-provisioning in gardens makes to local or national food security (Taylor and Lovell, 2014; Kirkpatrick and Davison, 2018), although initial analyses suggest considerable potential (CoDyre et al., 2015). A survey of gardens ($n = 267$) in five UK cities found that 20% contained a vegetable plot (Loram et al., 2008).

In the absence of legally-available land, in many cities "guerrilla gardeners" are planting food crops on land that does not belong to them and often without permission (Adams et al., 2015). In the USA 'vacant lots' are increasingly being used for community gardens (Grewel and Grewel, 2012; Andreatta, 2015). In Cleveland, Ohio, between 1.3 and 1.7% of total expenditure on fresh produce was on food grown in vacant lots in the city used for community gardens totalling about 20 ha (Grewel and Grewel, 2012). These estimates were based on using fruit and vegetable yields from commercial horticulture or from a very small dataset provided by four households >20 years earlier. At this rate of production, had the cultivated area been the same as the area of allotments in Leicester (97 ha), Cleveland would be able to grow between 6.5 and 8.5% of the city's fresh produce by expenditure on the vacant lots. However, these estimates based on expenditure need to be viewed in relation to food consumption in Ohio. In this state, in 2009, only 29% of adults consumed two or more portions of fruit per day, and only 25% consumed three or more portions of vegetables (Centre for Disease Control and Prevention, 2010). The expenditure on fruit and vegetables in Cleveland is therefore, at best, just over half what is required by the population to provide a 5-a-day diet, so the actual contribution of vacant-lot growing to food security in Cleveland is much less than half that achieved from allotment growing in Leicester. However, as in Leicester, there is scope for increasing this contribution to local food production and food security, if 80% of all vacant lots in Cleveland were used to grow food they could provide between 22 and 48% of the city's fresh produce by value, depending on production practices ranging from conventional fruit and vegetable growing to intensive gardening and hydroponics (Grewel and Grewel, 2012; Andreatta, 2015).

4.3. Allotment fruit and vegetable production and food security

Although allotment food production currently makes a relatively modest contribution to overall food supply in our exemplar study city, it is important to recognize its importance for food security of the most disadvantaged, and vulnerable people in extreme food poverty such as asylum seekers (Bishop and Purcell, 2013). Asylum seeker allotment projects have been set up by charities in many UK cities including Bristol, Birmingham, Manchester, Lancaster and Morecambe, Newcastle and Gateshead, Tees Valley, Milton-Keynes, Bradford, Liverpool, and Sheffield. Asylum-seekers are currently excluded from employment and state benefits, and dependent on food-banks, so giving access to land to grow fruit and vegetables improves their food security and allows them to benefit from "therapeutic horticulture" and social networking (Bishop and Purcell, 2013). With the rapid recent increases in the UK population that are dependent on food banks for emergency food supplies (Sosenko et al., 2019), and continuing under-consumption of fresh fruit and vegetables, there is a real opportunity for urban self-provisioning to play a larger role in food security and improving public health. However, in order for allotment food production to actually benefit the food insecure in urban areas allotments need to be co-located in areas where there may be limited access to safe nutritious food and access potentially provided to the most food insecure. For example, in Leicester, there is a large area of the city centre that has no provision of allotment sites, despite the fact that the population in these areas are in the lowest deciles of the Index for Multiple Deprivation (Fig. 2). In addition, at present, with the exception of asylum-seeker projects, and some projects run for disabled people and mental health therapeutic horticulture projects, there is no priority given to allocation of plots to the food insecure and, indeed, there is no data available on the socio-demographics of plot holders at present across the UK. In general, in the UK the majority of allotment sites are owned by councils and they either directly let individual allotment plots or sites are self-managed by allotment societies but they are still in the ownership of the council. Many sites across the UK now have waiting lists for a plot (Campbell and Campbell, 2011) on a 'first come first served basis', but, people who access the benefit system are eligible for discounted rent (House of Parliament, 1996). Indeed, in Germany there is evidence that on some allotment sites Germans from immigrant families are being discriminated against as they are being refused allotment plots, despite being at the front of the waiting list (Anderson, 2016).

Assuming our study city is typical for the UK, based on the numbers of allotments nationally there are potentially 1.7 million people being fed on a 5-a-day diet by allotment gardeners, and that could increase to 9.9 million people if UK cities had similar greenspace land available for allotment style fruit and vegetable production as identified by McHugh et al. (2015) in Leicester. Similarly, extrapolating the production of allotment grown potatoes in Leicester to a national scale, over 1.5 million people could be provided with their annual consumption of this important part of the UK diet that supplies starchy carbohydrate, vitamin C and nutrients such as potassium (Weichselbaum, 2010).

It is estimated that land equivalent to 1/3 of the global urban area could supply the vegetable demands of the world's urban population (Martellozzo et al., 2014). The relatively small footprint of horticulture and the areal extent of urban areas, demonstrates the potential of urban agriculture to contribute to national food security and the urban diet. Indeed, it has been recognised that urban agriculture has unused potential and could meet a large share of the vegetable demand in developed countries (Mok et al., 2014; Martellozzo et al., 2014; Opitz et al., 2016). In 2008 the area of land abroad used to supply fruit and vegetables to the UK population was 6080 km^2, whilst the area of land within the UK used to grow these crops was less than a third of this and declining (de Ruiter et al., 2016; Defra, 2018). The increasing reliance in the UK on the import of fruit and vegetables from abroad has displaced the environmental footprint to other countries (de Ruiter et al., 2016) and has consequences for national food security if supply is disrupted.

Urban areas are projected to triple in size between 2000 and 2030, increasing by 1.2 million km^2 globally (Seto et al., 2012), but whilst they are expanding out into the surrounding land, they are also densifying, particularly in European cities (Kabisch et al., 2016). With increasing urbanization and densification comes a threat of loss of greenspaces and the ecosystem services that they provide to urban inhabitants (Kabisch et al., 2016), including the land used for urban agriculture. Our research provides insight into the hidden contribution of urban agriculture in the Global North to achieving the aims set out in United Nations (2015) Sustainable Development Goals 2 (Zero Hunger) and 11 (Sustainable Cities and Communities) to '*end hunger, achieve food security and improved nutrition and promote sustainable agriculture*' and to '*reduce the per capita environmental impact of cities*'. However, whilst it is likely that growing food within a city does contribute to a reduction in the environmental impact of a city, there are still unanswered questions about the sustainability of self-provisioning and more generally urban agriculture (Mok et al. 2014; Goldstein et al., 2016). It is now critical to develop research to understand whether our study city is typical by scaling up this work to a national level; understanding current levels of production, how this could be increased in the existing greenspace resource and understanding how cropping patterns and self-provisioning crop yields vary with climate, soil type and management practices.

5. Conclusions

Here, we demonstrate that the use of urban land for allotments can contribute over 2% of the fruit and vegetable diets of urban inhabitants in a typical UK city. However, more research is needed to investigate the pathways that are needed by policy-makers to ensure this source of healthy and nutritious food, or the land and skills in which to grow it, are accessible to the food insecure within urban areas. In addition, further urban population expansion will exert increasing development pressure on ecosystem service delivery by urban greenspaces. Policy-makers and planners should both protect the current urban allotment land resource within urban areas, and also embed urban agricultural spaces within future urban developments to increase the production potential within urban areas.

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Author contributions

J.L.E, K.J.G., J.R.L. designed the research. J.L.E. conducted the fieldwork. M.C.D., J.L.E. and P.H.W. designed the historical GIS analyses and M.C.D. carried out the GIS analyses. J.L.E., D.Z.C. analysed the data the field-mapped and citizen science crop data. J.L.E. and J.R.L. led the writing of the manuscript. *All authors contributed critically to the drafts and gave final approval for publication.*

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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