Article:

Mears, M. orcid.org/0000-0002-9947-0349, Brindley, P. orcid.org/0000-0001-9989-9789, Maheswaran, R. orcid.org/0000-0002-3899-4421 et al. (1 more author) (2019)
Understanding the socioeconomic equity of publicly accessible greenspace distribution: The example of Sheffield, UK. Geoforum, 103. pp. 126-137. ISSN 0016-7185

https://doi.org/10.1016/j.geoforum.2019.04.016

Geoforum 103 (2019) 126–137

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Understanding the socioeconomic equity of publicly accessible greenspace distribution: The example of Sheffield, UK

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ARTICLE INFO

Keywords:
Urban greenspace
Environmental justice
Equity mapping
Inequality

ABSTRACT

Urban greenspace can improve the health of local residents by facilitating physical activity, psychological restoration, and social contacts, as well as through amelioration of the physical environment and immune system modulation. In some cases, greenspace exposure has been reported to reduce health inequalities associated with deprivation. However, studies investigating the socioeconomic equity of greenspace distribution find conflicting results. We investigate how greenspace distribution varies with socioeconomic deprivation in Sheffield, UK, for three aspects of greenspace distribution (access; provision, or accessible greenspace area; and population pressure, or potential for crowding), and for three types of greenspace (any publicly accessible greenspace; greenspaces meeting criteria that increase the likelihood of providing health benefits; and greenspaces with specific provision for children and young people). We find that the accessibility of greenspace favours people living in more deprived areas, although the total area provided is not proportionally greater, and greenspaces have a greater potential for crowding. When looking only at high quality greenspaces, the relationship with deprivation is far weaker, although the potential for crowding remains greater in more deprived areas. When looking only at greenspaces with provision for children and young people, accessibility once again favours people in more deprived areas, but the total area provided is less and the potential for congestion is greater. Our results are influenced by the historic choice of locations for urban parks in Sheffield, i.e. within walking distance of working class neighbourhoods. Both methodological details and local historic context are key drivers of whether greenspace distribution is equitable within cities, and increasing the complexity of questions being asked also increases the complexity of results. Researchers should carefully consider which aspects of equity are of interest when designing studies. We recommend that planners and policy makers ensure that greenspaces are designed and maintained to a high standard that meets the cultural, recreational and accessibility needs of urban residents, including those belonging to minorities, in order to provide maximal public health benefits.

1. Introduction

The public body responsible for the natural environment in England has stated that "everyone should have access to good quality natural greenspace near to where they live" (Natural England, 2010, p. 5). This reflects the substantial body of evidence for the role that urban greenspace plays in supporting the physical, psychological, cognitive and social wellbeing of the population, as well as its importance to biodiversity (James et al., 2015; Keniger et al., 2013; Natural England, 2010; Sugiyama et al., 2018; World Health Organization, 2016). Living in a greener environment is linked to improved health outcomes including mortality, cardiovascular disease, birth weight and physical activity levels (James et al., 2015). Benefits are thought to derive from mechanisms including facilitation of stress reduction and psychological restoration, facilitation of physical activity, amelioration of the physical environment (e.g. temperature, noise, air pollution), modulation of the immune system, and promotion of social cohesion (James et al., 2015; Keniger et al., 2013; World Health Organization, 2016).

Greenspace near to people's homes has the potential to mitigate health inequalities associated with socioeconomic deprivation (Brown et al., 2018, 2016; Maas et al., 2009; Mitchell and Popham, 2008). Reductions in inequalities may result from the fact that socioeconomically deprived groups have fewer opportunities to travel away from their neighbourhood of residence, and so are more dependent on local resources (Maas et al., 2009; Mitchell and Popham, 2008; Talen, 2003). The spatial distribution of urban greenspace is, therefore, an important environmental justice issue (Boone et al., 2009; Wolch et al., 2005).

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https://doi.org/10.1016/j.geoforum.2019.04.016
Received 24 January 2019; Received in revised form 28 March 2019; Accepted 18 April 2019
Available online 26 April 2019

1.1. Greenspace distribution equity

There are at least three ways of conceptualising equity of distribution: in terms of *accessibility*, usually operationalised as distance to greenspace or proportion of the population within a given distance; *provision*, usually operationalised as greenspace cover within a given area; and *population pressure*, or the potential crowding of a greenspace, for example if everyone were to visit a nearby greenspace simultaneously (Kimpton, 2017). Studies of the UK population have found relationships between greater local greenspace provision and lower socioeconomic deprivation, lower mortality, and better self-reported general health (Mitchell and Popham, 2008; Wheeler et al., 2015). The present study focuses on the UK city of Sheffield, where previous work has found greater greenspace accessibility amongst more deprived groups (Barbosa et al., 2007), who generally suffer worse health outcomes (Lakshman et al., 2011).

These seemingly contradictory results are typical of the conflicting findings in greenspace distribution research. Many studies find that areas of greater deprivation have worse greenspace provision, accessibility or population pressure (Apparicio et al., 2016; Astell-Burt et al., 2014; Boone et al., 2009; Dai, 2011; Heckert, 2013; Jones et al., 2009; Kimpton, 2017; Mavoa et al., 2015; Shen et al., 2017; Talen, 1997; Wolch et al., 2005; Wüstemann et al., 2017). In contrast, others find no relationship (Heckert, 2013; Kimpton, 2017; Wüstemann et al., 2017), or even greater deprivation in areas of more favourable greenspace distribution (Barbosa et al., 2007; Boone et al., 2009; Heckert, 2013; Hoffimann et al., 2017; Jones et al., 2009; Kessel et al., 2009; Kimpton, 2017; Mavoa et al., 2015; Talen, 1997; Wolch et al., 2005). A potential complicating factor is that greenspaces in deprived areas may be (or be perceived as) unsafe or of lower quality (James et al., 2015; Sugiyama et al., 2018). Consequently, it is challenging to make generalisations about the socioeconomic equity of greenspace distribution.

1.2. Study aims

In this paper, we address the socioeconomic equity of greenspace distribution in Sheffield, with an interest in identifying reasons for conflicts both within our results, and with other studies. We quantify aspects of provision, accessibility and population pressure at small spatial scales, using network analysis (computational traversal of the transport network) to calculate distances. We undertake analysis at the finest possible spatial scales, as spatial aggregations average out potentially interesting variation. Compared to straight-line distance, network distance more accurately reflects local areas as experienced by pedestrians and reduces skew caused by large or inaccessible greenspaces (Oliver et al., 2007).

Further, we look at how the relationship between greenspace distribution and socioeconomic deprivation varies by greenspace quality, by identifying greenspaces that are likely to have the features necessary to provide health benefits for the general population, and for children and young people specifically. The specific characteristics of greenspaces that maximise their health-giving potential are not well-defined (Lee et al., 2015; McCormack et al., 2010; Sugiyama et al., 2018). Nevertheless, the UK government's natural environment advisory body provides guidelines to assist greenspace planners and managers (Natural England, 2010). Key amongst these are the accessibility standards (Accessible Natural Greenspace Standard, or 'ANGSt'), of which the first is that everyone should live within 300 m of an accessible, natural greenspace of at least 2 ha in size. We use this to define high quality (referred to as 'good') sites for the general population.[1]

The 300 m distance, equivalent to five minutes' walk, is based on how far people are prepared to walk to natural spaces (Natural England, 2010). The distance is derived from a study that found that urban woodlands should be within five minutes' walk of households in order to achieve high social value, with more than 70% of visits taking no more than five minutes' travel time (Coles and Bussey, 2000). More recently, Rojas et al. (2016) found this to be similar to the mean walking distance to urban green spaces in two Chilean cities, although they note that this varies with demographic factors, most notably with age. Similarly, Grahn and Stigsdotter (2003) found that people living 101–300 m from their nearest greenspace visit greenspaces 2.7 times as frequently as those living 301–1000 m (those living < 100 m visited even more frequently), and Schipperijn et al. (2010) and Nielsen and Hansen (2007) also found a substantially higher greenspace visit frequency amongst urban residents living < 300 m from their nearest greenspace. This distance has also been used in recent studies of greenspace accessibility (Cheesbrough et al., 2019; de Sousa Silva et al., 2018; Martins and Nazaré Pereira, 2018; Moseley et al., 2013), and is the distance recommended for a greenspace accessibility indicator for public health based on a literature review and case studies (Van Den Bosch et al., 2016). The 2 ha minimum size is also based on a study indicating that there was little interest amongst urban residents in visiting greenspaces of less than this size (Coles and Bussey, 2000).

To identify 'natural' greenspaces where field surveys are not possible, Natural England recommend using an evidence-based proxy based on the naturalness of different categories of greenspace. However, these criteria do not take quality into consideration; this is important as most research finds that quality is at least as important as quantity (Brindley et al., 2018; Sugiyama et al., 2018; van Dillen et al., 2012). To ensure that we only include high quality greenspaces, we use a survey-based rating of their quality.

Research indicates that children and young people have different requirements from greenspaces compared with adults, with a particular need for facilities intended specifically for their age group, including for games and play (Day and Wager, 2010; Jansson et al., 2016). In a separate analysis, we therefore consider access to greenspaces with specific provision for children and young people, such as playgrounds, games areas, and BMX or skateboard facilities.

2. Methods

2.1. Study area

The city of Sheffield, UK (53°23′N, 1°28′W) is an inland city covering an area of 368 km^2, with a population in 2011 of 552,000 (Office for National Statistics, 2016). Sheffield lies over a wide altitudinal range of nearly 600 m, and includes a large expanse of moorland in the west. The population is concentrated within the eastern half of Sheffield's boundaries. The eastern part of the urbanised area was a centre of industry until the mid-twentieth century, and there remains a strong west-east gradient in deprivation, with ex-industrial areas suffering income and health deprivation relative to the historically wealthier and cleaner west (Department for Communities and Local Government, 2011). A map of the geography of deprivation, and the location of Sheffield within England is shown in the Supplementary Material.

2.2. Data

Data required for the analysis were: location of greenspaces and access points, and greenspace attributes; location and deprivation of households; and a map of the transport network.

2.2.1. Greenspaces

We used greenspace data supplied by Sheffield City Council, representing 945 sites identified as part of the Council's 2008 PPG17 (Planning Policy Guidance 17: Planning for open space, sport and recreation[2]) assessment of "accessible open spaces, sports and recreation

[1] Three other standards relate to larger, more distant sites; these standards are less relevant in the case of Sheffield due to its close proximity to the large Peak District National Park.

Table 1
Criteria used to select greenspace sites for inclusion in analyses.

Descriptor	Selection criterion	Rationale
Accessible	Included in PPG17 assessment, access points identified	PPG17 assessment was undertaken specifically to identify publicly accessible provision
Large	Area > = 2 ha (from PPG17 spatial data)	ANGSt recommendation is for everyone to live within 300 m of an accessible greenspace of at least 2 ha in size (Natural England, 2010)
Natural-feeling	PPG17 assessed typology is one of: natural and semi-natural greenspace; woodland; green corridor; active or visual amenity; local or large park; formal gardens	ANGSt defines a natural space as "where human control and activities are not so intensive that a feeling of naturalness is allowed to predominate", and describes a proxy measure of naturalness based on land use classification; the classification has been adapted to align with the PPG17 typology (Natural England, 2010)
High quality	'Good' or better overall quality in PPG17 assessment	PPG17 recommendation is for all sites to be of 'good' or better standard (Strategic Leisure Limited, 2008). Quality criteria are based on national standards and are designed to determine whether the site is fit for purpose.
Provision for children and young people	PPG17 assessment includes a non-zero 'play value' rating	Play value is only assessed for sites including "areas designed primarily for play and social interaction involving children and young people" (Strategic Leisure Limited, 2008)

provision", although we excluded six hard-surfaced civic spaces (Strategic Leisure Limited, 2008). The data comprised GIS polygons accompanied by attributes including the type, size, selected amenities and assessed quality of each greenspace. The quality assessment criteria were based on the national Green Flag Award standard for parks and open spaces; on the Royal Society for the Prevention of Accidents play value criteria for play areas; and on Sport England's 'Towards a Level Playing Field' methodology for sports provision. Each greenspace was scored against a range of criteria focusing on visitors' experience, including accessibility, safety, maintenance, vegetation design, aesthetics, and amenities (e.g. benches, bins, gates, information and paths), as appropriate for the type of site.

Our analysis thus relates to the state of greenspaces at a point in time in 2008; no more recent assessment was available. We used the GIS and attribute data to identify 'good' greenspaces (large, natural-feeling, high quality) and greenspaces with provision for children and young people. The selection criteria are detailed in Table 1. Ninety-five sites did not have a quality assessment. In all except two cases this was due to lack of access, or sports pitches that had recently been assessed separately; these would not have been included as 'good' greenspaces because accessibility is a component of the quality rating, and sports pitches are not considered natural-feeling. The other two cases were woodlands of adequate size to be considered 'large', so it is possible these should have been included as 'good' or as having provision for children and young people if data were available.

2.2.2. Households

Household locations (n = 252564) were identified using residential address points from Ordnance Survey (OS) AddressBase Plus data relating to 2017; older data were not available. 541 address points were found to be inside greenspace polygons. The majority of these were due to sites having been partially or fully developed as housing since the greenspace assessment, with the remainder being due to minor digitisation inaccuracies or the presence of a club house, chapel or similar building associated with a residential address. Given that the majority of affected addresses did not exist at the time of the greenspace assessment, we excluded from analysis all addresses contained within greenspace boundaries.

2.2.3. Deprivation

Deprivation levels were calculated as Carstairs Deprivation Index (Morgan and Baker, 2006) using 2011 census data at Output Area (OA) scale. OAs are the smallest English census geography with an average population of 309, drawn to be homogenous in terms of dwelling type and household tenure (Office for National Statistics, n.d.). There are 1817 OAs in Sheffield. We used Carstairs index instead of the better-known English Index of Multiple Deprivation (IMD) as the latter are available only at larger geographies. The two indices are closely related: in Sheffield, IMD and Carstairs index calculated at Lower Super Output Area level have a Pearson's correlation coefficient of 0.96 (see Supplementary Material). In general, the highest levels of deprivation are found in the ex-industrial north and east of the urbanised area, with pockets of deprivation also found in three outlying suburbs to the north and south.

2.2.4. Greenspace access points

For each greenspace site, we attempted to identify access points from GIS sources including Sheffield City Council Parks and Countryside Service data; OS Open Greenspace; and access points mapped for a previous project using a combination of OpenStreetMap, OS MasterMap, aerial imagery, Google StreetView and site visits. Where these sources were inadequate, intersections between site boundaries and transport network layers (described below) were used to identify points of access. For sites that still had inadequate access points identified, additional points were mapped manually using aerial photography and Google StreetView.

2.2.5. Transport network

To create a transport network we combined OS Integrated Transport Network (roads and urban paths layers) and OpenStreetMap data (lines layer, only lines with the 'highway' attribute set), as these sources each mapped some footpaths not included by the other (both datasets from 2017). Motorways and motorway links, racetracks and roads under construction were excluded, as these are not used by pedestrians. Publicly accessible access points could not be identified for three sites, so these were excluded from analysis.

2.3. Greenspace distribution measures

2.3.1. Accessibility

Greenspace accessibility was assessed at the level of individual households. We identified areas within 300 m of access points for each greenspace site via the road and path network using the ArcGIS Generate Service Areas tool, which generates polygons covering the areas "served" by a site's access points. We used this to create a layer for each research question indicating all areas within 300 m of a greenspace site meeting the relevant criteria (Table 1). We then used a spatial select query to identify whether each address point lay within the coverage.

[2] PPG17 guidance required local authorities to undertake an assessment of open space, indoor facilities and outdoor sports in order to ensure high standards of provision. PPG17 was replaced in 2012 by the National Planning Policy Framework (NPPF).

Table 2
Descriptive statistics of publicly accessible greenspaces in Sheffield.

Greenspace type	Number	Size (ha) Mean	Median	Min	Max
Accessible	936	4.16	1.35	0.01	87.46
'Good'	81	15.04	7.39	2.00	87.46
Large	381	9.22	4.77	2.00	87.46
High quality	291	6.08	1.35	0.04	87.46
Natural-feeling	646	4.12	1.07	0.03	87.46
Provision for children and young people	120	5.45	1.71	0.02	87.46

2.3.2. Provision

We considered a greenspace to be a part of the provision for an address point if the point fell within the greenspace's service area. We considered the full area of greenspaces to count as provision (as opposed only to the area within 300 m), as the 300 m distance is relevant to travel *to* parks rather than how far people travel *within* parks after entry. For each address point, the provision was the sum of area of greenspaces with service areas in which the address point fell.

2.3.3. Population pressure

Our measure of population pressure assumes that all households visit a nearby greenspace simultaneously. As actual usage data for our greenspaces were not available, we assumed that residents are equally likely to visit all greenspaces within 300 m. First, we calculated the population pressure for each greenspace. As individuals can only visit one greenspace at a time, we adjusted the weighting for each address point by taking the reciprocal of the number of greenspace service areas in which that point fell (such that a household in the service area for a single greenspace added 1 to the population pressure numerator, whereas a household in three service areas added 1/3 for each of the three greenspaces); however, we were unable to adjust for headcounts within individual households due to a lack of data. To obtain a household-level measure of population pressure, we took the area-weighted mean population pressure across greenspaces considered to be within the provision for that address point. Additional details of GIS processing are given in the Supplementary Material.

2.4. Statistical analysis

For statistical testing, we placed individual households into deciles according to Carstairs index for the OA to which the household belongs (decile counts are slightly uneven due to all households in each OA having the same value). We tested for relationships between greenspace accessibility and household deprivation decile using binomial ANOVAs, and post-hoc Tukey multiple comparison tests based on estimated marginal means. Statistical analyses were carried out in R v3.4.2, with the emmeans library used to perform multiple comparison tests (Lenth, 2018; R Core Team, 2017). We also calculated odds ratios to facilitate comparisons between deciles, and between households in lower (deciles 1–5) versus higher (deciles 6–10) deprivation areas.

A two-stage (hurdle) model was required for parametric analysis of provision and population pressure, due to the large number of zeroes arising from households with no greenspace access points within 300 m. The first stage therefore was identical to the accessibility assessment (binomial ANOVA), while the second stage assessed inter-decile variability only for households with access to at least one greenspace. This second stage comprised an ANOVA, with post-hoc Tukey multiple comparison tests based on estimated marginal means. All provision and population pressures required log-transformation, except the 'good' greenspace population pressure variable, which required square root transformation. To facilitate inter-decile and high vs. low deprivation comparisons, we calculated the mean values of provision (including households with zero provision) and population pressure per group and compared these to the mean for the lowest deprivation group.

2.5. Sensitivity testing

Our greenspaces dataset includes only greenspaces within Sheffield's borders, whilst some households near the borders may be served by greenspaces in nearby towns and villages (especially Rotherham, which is contiguous with Sheffield in the north-east). We therefore performed sensitivity testing excluding households within 300 m of the border, i.e. the same distance as the service areas (n = 9694, about 4% of the total).

The results of the sensitivity tests were very similar to those for the full datasets, indicating that border areas were not causing bias in our analyses. The results of sensitivity testing are shown in the Supplementary Material, but due to their similarity to the main results are not discussed elsewhere.

3. Results

All ANOVAs testing for relationships between socioeconomic deprivation and aspects of greenspace distribution in Sheffield show very low proportions of deviance (a measure of goodness of fit) explained: 1–5% for accessibility, 2–7% for provision and 5–11% for population pressure. Despite this, all are statistically highly significant ($p < 0.001$). We therefore note that Carstairs decile explains only a small proportion of the variation in greenspace distribution, but also highlight the statistically significant patterns that are nevertheless observed.

3.1. Equity of distribution of greenspaces

A total of 936 greenspace sites were included in this analysis, i.e. all publicly accessible greenspaces, with a mean size of 4.16 ha and median size of 1.35 ha (Table 2). Fig. 1 shows the spatial distribution of greenspaces and the locations of households within 300 m of any greenspace. Areas without access are in clusters to the west and north of the urbanised area. Isolated houses in the rural west of the study area also tend to be more than 300 m from the nearest greenspace, though these are fewer in number.

3.1.1. Accessibility

There is a clear monotonically increasing likelihood of being within 300 m of a publicly accessible greenspace with increasing levels of deprivation (Fig. 2a), with a total of 73.5% of households meeting this criterion. The odds ratio of living within 300 m of any greenspace is 5.49 for the most versus least deprived deciles, and 2.50 for the more versus less deprived half of deciles (Table 3).

3.1.2. Provision and population pressure

Once variation in accessibility has been accounted for (i.e. considering only households with access to at least one greenspace), the relationship between deprivation and provision is less clear (Fig. 2b), although there are still significant differences due to large sample sizes. The least deprived deciles have the lowest population pressure within that provision; this peaks at intermediate levels of deprivation (Fig. 2c). The more deprived half of deciles have 52% greater population pressure than the less deprived half (Table 3). There is, however, considerable variation, with standard deviations larger than means.

It should be noted that significant differences do not always mirror differences in means as shown in the Figures, as they are computed based on estimated marginal means that account for variation in numbers of households in each decile (due to different numbers being within 300 m). Additionally, due to the sometimes high proportions of households without any greenspace provision, sample sizes become much smaller (n = 185188 for any greenspace, 51,232 for 'good' greenspaces and 67,353 for greenspaces with provision for children and

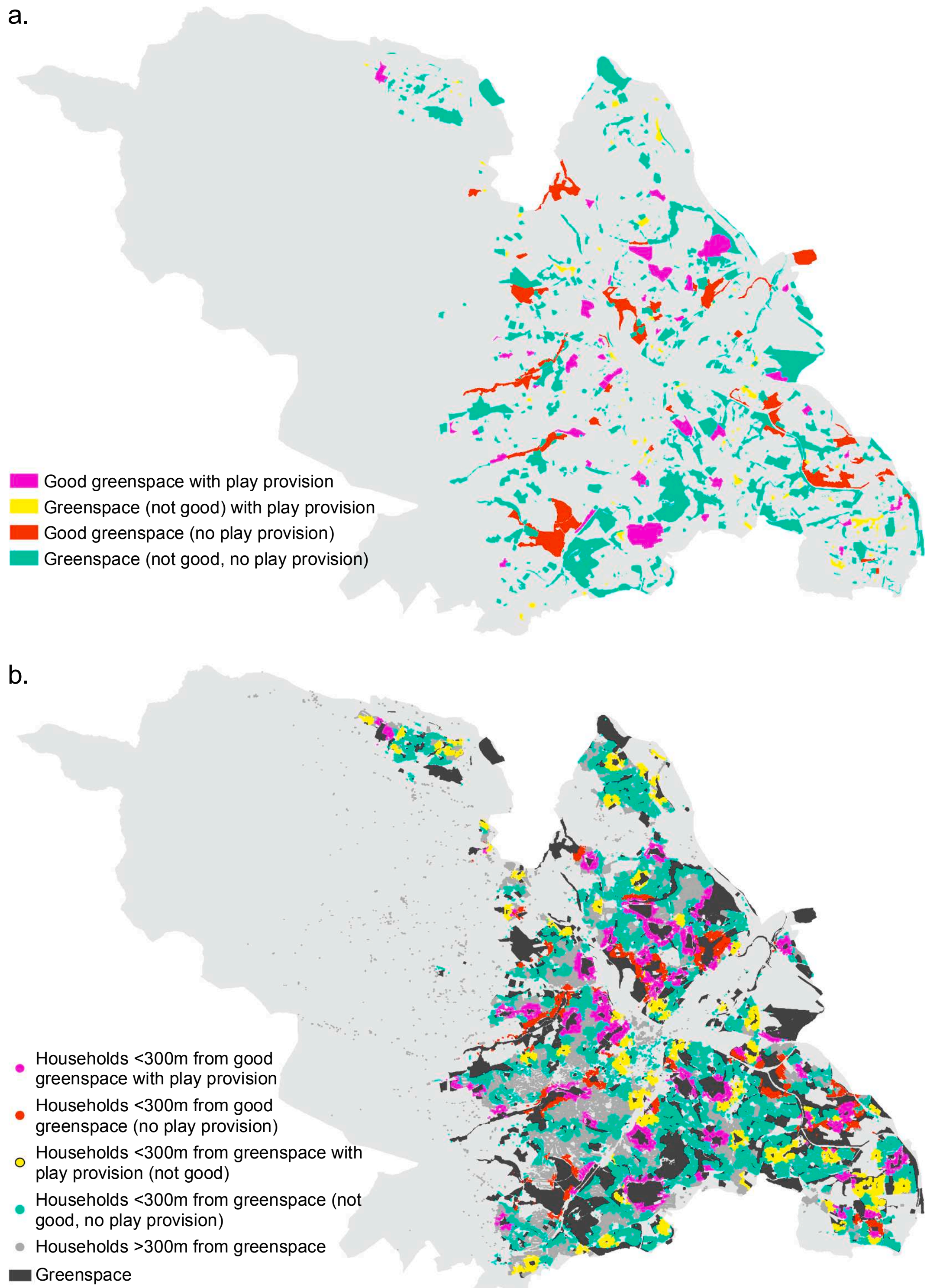

Fig. 1. (a) Greenspaces meeting different criteria. (b) Households with access to greenspaces meeting different criteria within 300 m by the transport network.

young people, compared to the full sample size of 252023) and substantial statistical power is lost.

When taking both presence/absence and levels of provision into account (by calculating means across all households, including those with no access), the tendency for areas of high deprivation to have greater provision can still be observed (Table 3): the more deprived half of OAs have 30% more provision on average than the less deprived half.

3.2. Equity of distribution of 'good' greenspaces

The entire study area is poorly provisioned by 'good' greenspaces, with only 8.7% of greenspaces (n = 81) meeting all three criteria (see Table 1). These tend to be larger sites on average, partly but not wholly due to the inclusion of a size criterion, with a mean size of 15.04 ha and median size of 7.39 ha (Table 2).

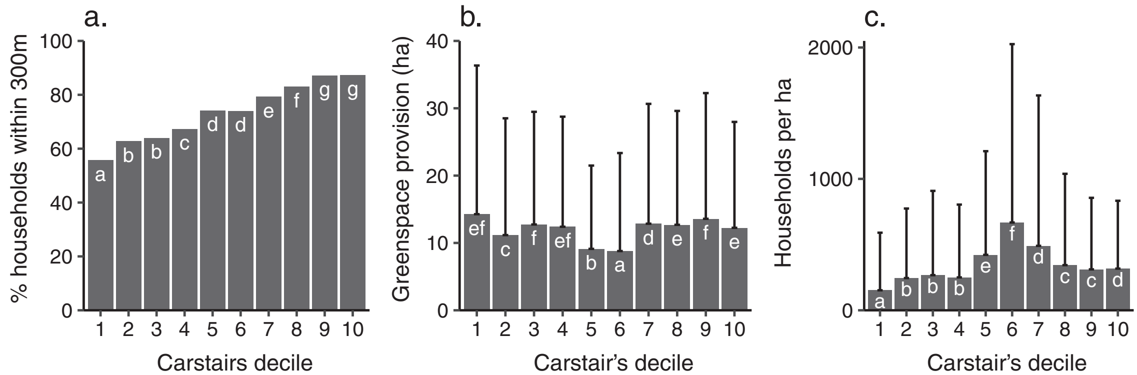

Fig. 2. Variation in greenspace distribution (any greenspace) with socioeconomic deprivation level. (a) Proportion of households within 300 m of a greenspace entrance. Mean (b) total area and (c) area-weighted mean population pressure of greenspaces with entrances within 300 m of households, for households with at least one greenspace within 300 m (error bars show 1 standard deviation). Different letters indicate significant differences among deciles, e.g. 'a' indicates a decile that is significantly different to 'b' but not different to other deciles marked 'a'; while a decile marked 'ab' is not significantly different to those marked either 'a' or 'b' (Tukey's test at $\alpha = 0.05$).

3.2.1. Accessibility

In contrast to the distribution of access to any greenspace, which shows relatively small clusters of houses without access surrounded by a majority of households lying within 300 m, there are small clusters of households with access to 'good' greenspaces surrounded by many areas without (Fig. 1b). Only 20.3% of households are within 300 m of an access point, and there are large sections of urbanised Sheffield where the distance to a 'good' greenspace is substantially more than 300 m, for example in the south or north.

There is not a clear linear relationship between access to 'good' greenspaces and deprivation levels, despite the highly significant ANOVA result; although the two deciles of lowest deprivation have significantly lower probability of access than the other deciles, and the two deciles with highest deprivation have some of the highest probabilities (Fig. 3a). The flattening of the relationship indicates that while greenspace as a whole is particularly well provisioned in areas with higher deprivation, many of the greenspaces in those areas are less likely to provide health benefits, due to being small, low quality, or not being natural-feeling. The odds ratios are also much smaller, with a maximum ratio of 2.27 for the second-most deprived decile, and 1.24 for more vs. less deprived halves of deciles (Table 3).

3.2.2. Separating out size, quality and natural-feeling

To investigate in more detail which criteria are causing the apparent lack of relationship, we repeated the accessibility analysis separating out the three components of size, quality and natural-feeling. More than two thirds of greenspace sites are natural-feeling (n = 646), and there is a similar pattern of accessibility by deprivation decile as there is to any greenspace (Fig. 4a), suggesting that natural-feeling greenspaces are equitably accessible.

Sites that are either high quality (n = 291) or large (n = 381), however, are substantially less common in Sheffield; although again, around two thirds of those that do meet one of these criteria are also natural-feeling (natural-feeling + high quality n = 203; natural-feeling + large n = 236). Adding either of these as a second criterion in network analysis still shows a relatively clear and linear relationship between accessibility and deprivation (Fig. 4b and c), although with a substantial drop in proportions of households. It therefore appears to be the specific combination of high quality and large greenspaces that are *relatively* less well distributed in more deprived areas (compared to all greenspaces), in addition to being in inadequate supply across Sheffield as a whole in absolute terms.

3.2.3. Provision and population pressure

With regards to provision, there is again no clear pattern once variation in accessibility has been accounted for, although the decile of lowest deprivation has greatest provision (Fig. 3b). There is a generally positive relationship between deprivation and population pressure

Table 3
Comparison of accessibility (acc.), provision (prov.) and population pressure (p.p. – only including households with at least some provision) of greenspaces meeting different criteria, by decile of Carstairs deprivation. Accessibility: odds ratios compared to odds for first decile (lowest deprivation), and deciles grouped into high vs. low deprivation. Provision: decile means compared to first decile; includes households with zero provision. Population pressure: decile means compared to first decile; excludes households with zero provision.

Comparison	Any greenspace			'Good' greenspace			Greenspace with provision for children and young people		
	Acc.	Prov.	P.p.	Acc.	Prov.	P.p.	Acc.	Prov.	P.p.
Deciles									
1	1	1	1	1	1	1	1	1	1
2	1.34	0.88	1.61	0.81	0.68	2.18	1.14	2.12	0.96
3	1.41	1.03	1.77	1.75	0.98	1.99	1.82	2.87	0.70
4	1.64	1.05	1.66	1.44	1.01	2.10	1.56	2.76	0.86
5	2.29	0.86	2.77	1.87	0.88	2.96	2.15	2.77	1.05
6	2.26	0.82	4.38	1.11	0.70	2.51	1.51	1.51	3.17
7	3.05	1.29	3.22	1.77	1.19	2.47	2.60	2.24	3.91
8	3.88	1.33	2.30	1.47	0.96	2.97	2.90	1.94	2.63
9	5.39	1.49	2.08	2.27	1.32	3.15	2.74	2.41	2.59
10	5.49	1.35	2.10	1.85	1.30	2.49	2.94	2.50	6.68
High vs. low deprivation									
Low	1	1	1	1	1	1	1	1	1
High	2.50	1.30	1.52	1.24	1.20	1.28	1.66	0.92	4.26

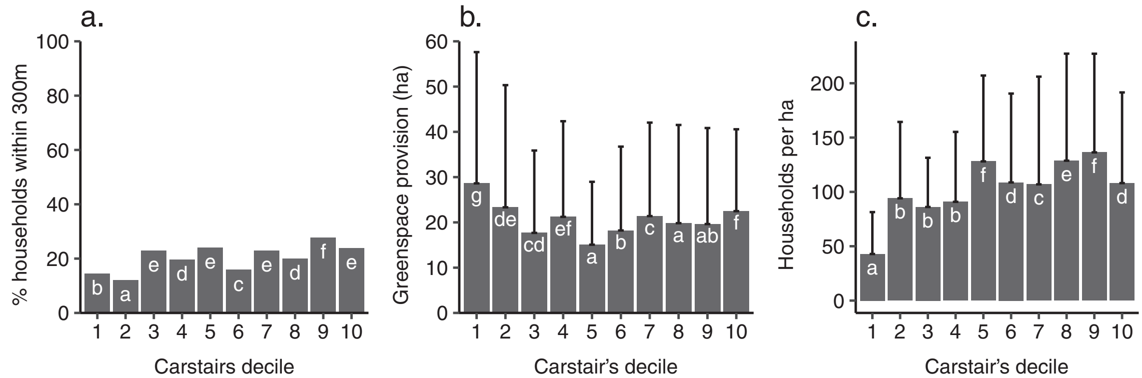

Fig. 3. Variation in 'good' greenspace distribution with socioeconomic deprivation level. (a) Proportion of households within 300 m of a greenspace entrance. Mean (b) total area and (c) area-weighted mean population pressure of greenspaces with entrances within 300 m of households, for households with at least one greenspace within 300 m (error bars show 1 standard deviation). Different letters indicate significant differences among deciles, e.g. 'a' indicates a decile that is significantly different to 'b' but not different to other deciles marked 'a'; while a decile marked 'ab' is not significantly different to those marked either 'a' or 'b' (Tukey's test at $\alpha = 0.05$).

(Fig. 3c), with the more deprived half of deciles having 28% greater population pressure than the less deprived half (Table 3). In particular, the least deprived decile has notably lower population pressure than the rest. When provision across all households (including those with no access) is considered, the more deprived half of deciles have 20% greater provision, although the pattern for individual deciles is not strongly linear (Table 3).

3.3. Equity of distribution of greenspaces with provision for children and young people

There are 120 greenspace sites with provision for children and young people in Sheffield, or 12.8% of the total (Fig. 1a). These sites are only slightly larger than the average for all sites (mean size = 5.45 ha, median = 1.71 ha; Table 2).

3.3.1. Accessibility

Fig. 1b shows that the spatial pattern of accessibility for greenspaces with provision for children and young people is different to that for either all greenspaces or 'good' greenspaces. Access to play provision tends to be good near to the city centre (although not in the city centre itself), with sections of the southeast and north of the urbanised areas relatively well served compared to the west and southwest.

There is a general, though not exact, correspondence between high levels of deprivation and better access to greenspace with play provision for children and young people, which is less clear at intermediate deprivation levels (Fig. 5a). These greenspaces serve a total of 26.7% of households. This is only 6.4% more than are served by 'good' greenspaces, despite there being 50% more greenspaces meeting this criterion. The more deprived half of deciles have 66% greater odds of being within 300 m, compared to the less deprived half (Table 3).

3.3.2. Provision and population pressure

Amongst those households with access to at least one greenspace with provision for children and young people, the decile of lowest deprivation also has the some of the lowest provision, but other less-deprived deciles have greater provision than the more deprived half of deciles (Fig. 5b). This is reflected in the means across all households, including those with no provision: unlike provision of any or 'good' greenspaces, less deprived households are in a more favourable situation, with 9% more provision than more deprived households (Table 3).

Differences in population pressure are also more extreme, with the more deprived half of deciles suffering four times as much population pressure as the less deprived half (Table 3, Fig. 5c). This is especially driven by the most deprived decile, which has exceptionally high population pressure (and also a very large standard deviation), but the pattern is still present when this decile is not considered.

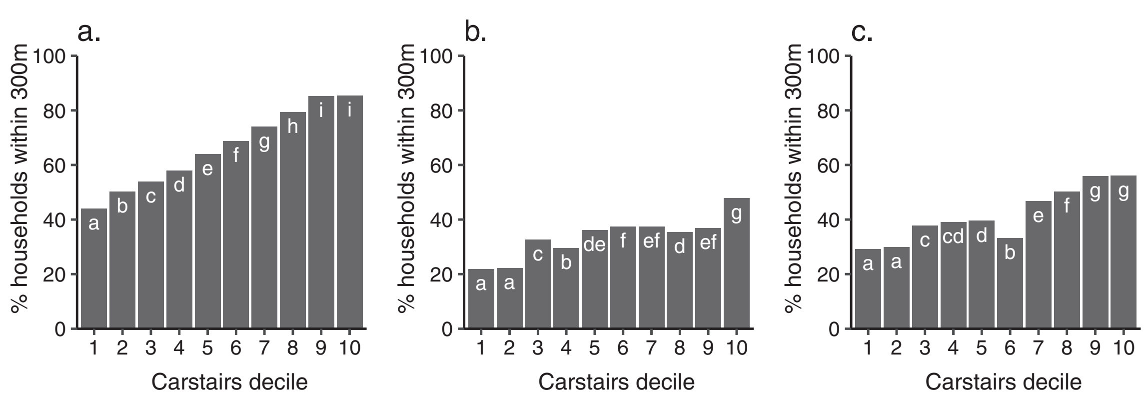

Fig. 4. Proportion of households within 300 m of greenspaces meeting one or more components of the criteria used to define 'good' greenspaces, by decile of Carstairs Deprivation Index, as assessed by network analysis: (a) natural-feeling only; (b) natural-feeling and large; (c) natural-feeling and high quality. Different letters indicate significant differences among deciles, e.g. 'a' indicates a decile that is significantly different to 'b' but not different to other deciles marked 'a'; while a decile marked 'ab' is not significantly different to those marked either 'a' or 'b' (Tukey's test at $\alpha = 0.05$).

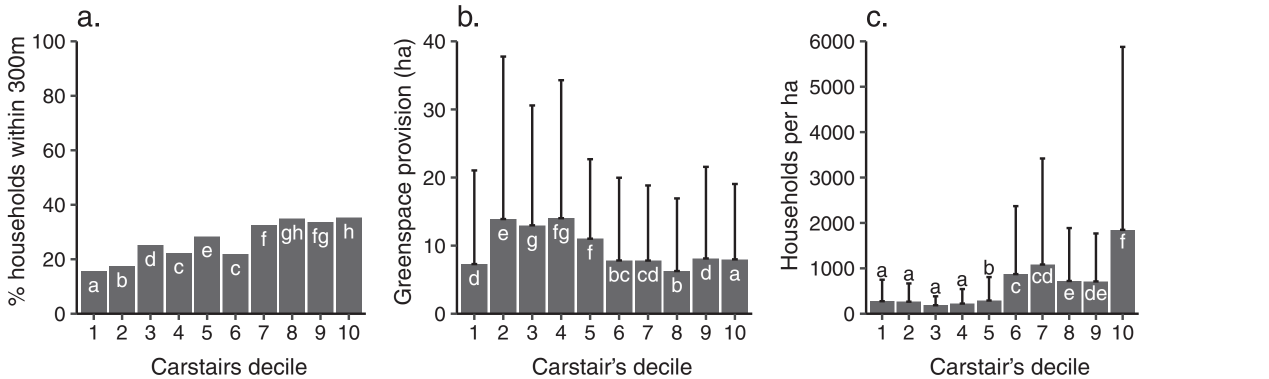

Fig. 5. Variation in distribution of greenspaces with provision for children and young people with socioeconomic deprivation level. (a) Proportion of households within 300 m of a greenspace entrance. Mean (b) total area and (c) area-weighted mean population pressure of greenspaces with entrances within 300 m of households, for households with at least one greenspace within 300 m (error bars show 1 standard deviation). Different letters indicate significant differences among deciles, e.g. 'a' indicates a decile that is significantly different to 'b' but not different to other deciles marked 'a'; while a decile marked 'ab' is not significantly different to those marked either 'a' or 'b' (Tukey's test at $\alpha = 0.05$).

4. Discussion

4.1. Equity of greenspace access in Sheffield

Our network analysis of publicly accessible greenspaces in Sheffield finds that only one in five households have access within 300 m to a greenspace of suitable type (predominantly natural-feeling), size (2 ha +), and quality (rated good or better) to have a high probability of providing a range of benefits to people (Lee et al., 2015). This compares to nearly three-quarters that are within 300 m of any publicly accessible greenspace, and reflects the small proportion of greenspace sites that are both large enough and maintained to a high enough standard to potentially provide health benefits (Fig. 1a). Importantly, these criteria also reflect factors likely to determine the extent to which greenspaces are actually used and thereby convey the full potential of their benefits (Bedimo-Rung et al., 2005; Ekkel and de Vries, 2017; Haq, 2011; Lee et al., 2015). Access to greenspaces with specific provision for children and young people is also low, with just over one quarter of households having access.

A previous Sheffield-based network analysis study found that more income-deprived groups lived, on average, closer to both any publicly accessible greenspace and to municipal parks (Barbosa et al., 2007). We also find that more deprived households are more likely to have access to any greenspace, despite including a different set of greenspaces and measuring deprivation differently (Fig. 2a, Table 3). This suggests that the groups most in need of the benefits greenspace can provide, and least likely to be able to travel long distances (Talen, 2003), have better access. However, the relationship is weaker when looking at greenspaces with provision for children and young people (Fig. 5a), and near-absent when looking at 'good' greenspaces (Fig. 3a). This is significant given that quality, as well as quantity, has benefits to health (Sugiyama et al., 2018; van Dillen et al., 2012).

When considering only households with access to at least one greenspace, there is generally less greenspace provision to households with greater socioeconomic deprivation across all three types of greenspace, although (with the exception of the decile of lowest deprivation) this is clearest for greenspace with provision for children and young people (compare Fig. 5b with Figs. 2b and 3b). However, if households with zero provision are included in calculations, households with greater deprivation have greater mean provision of all and 'good' greenspaces, due to larger numbers of households with access (Table 3). Less deprived households still have greater provision of greenspace with provision for children and young people.

Further complicating the picture, population pressure of all types of greenspace generally increases with deprivation, although this relationship is not necessarily linear across all deciles (Figs. 2c, 3c, 5c; Table 3).

4.2. Causes of conflicting results

A key message from our study is that the accessibility and provision of greenspace in Sheffield does not privilege socioeconomically advantaged groups, i.e. there is no evidence of "deprivation amplification" or a "double inequity" (Apparicio et al., 2016; Macintyre, 2007). However, if equity is assessed in terms of population pressure, or potential congestion of greenspaces, then more deprived households are on average in a less favourable situation. Our results reflect the difficulty in identifying consistent patterns in the socioeconomic equity of greenspace distribution that we noted in the Introduction.

Some inconsistencies can be explained by methodology. One key difference is that of equity conceptualisation (Kimpton, 2017); indeed, our study found that while areas of greater socioeconomic deprivation are in a better situation with regards to greenspace accessibility, this was less clear for provision and the other way around for population pressure. Studies also vary in what is counted as greenspace, varying from any small area of green identified on aerial imagery (Barbosa et al., 2007) to formally designated parks and gardens (Heckert, 2013). Again, we found quite different results when we considered subsets of greenspaces meeting specific criteria, highlighting the importance of clearly defining which aspects of greenspace are believed to be valuable. Other methodological causes of differences include how the concept of equity is operationalised, e.g. distance measured by network vs. straight-line distance (Oliver et al., 2007) and size of population aggregation units (Tan and Samsudin, 2017); and choice of deprivation metric, whether a formal index (Barbosa et al., 2007; Hoffimann et al., 2017; Mavoa et al., 2015), or proxy such as income, housing value, unemployment or race (Boone et al., 2009; Shen et al., 2017; Wolch et al., 2005; Wüstemann et al., 2017).

Other studies that compare multiple equity operationalisations, greenspace definitions etc. also usually find some conflicting results between them (Heckert, 2013; Jones et al., 2009; Kimpton, 2017; Mavoa et al., 2015; Talen, 1997; Tan and Samsudin, 2017; Wolch et al., 2005; Wüstemann et al., 2017). However, it is not possible to identify patterns in positive vs. negative relationships in the existing literature according to any methodological details, or according to location of the study (Apparicio et al., 2016; Astell-Burt et al., 2014; Barbosa et al., 2007; Boone et al., 2009; Dai, 2011; Heckert, 2013; Hoffimann et al., 2017; Jones et al., 2009; Kessel et al., 2009; Kimpton, 2017; Mavoa et al., 2015; Shen et al., 2017; Talen, 1997; Wolch et al., 2005; Wüstemann et al., 2017). This is also true of the small number of studies looking specifically at high quality greenspaces (Engelberg et al., 2016; Hoffimann et al., 2017; Kimpton, 2017). We found only two studies addressing whether the distribution of greenspaces for children and young people is socioeconomically equitable (Kimpton, 2017; Wolch et al., 2005), which in contrast to our study found worse accessibility for more children living in more deprived areas; but this an inadequate sample to generalise from.

It is not necessarily surprising that consistent patterns are not observed, as greenspaces are complex, multidimensional entities that are influenced by a variety of factors at multiple temporal, spatial and institutional scales. Greenspace has long been a political issue, but initiatives to establish equity have had varying success over varying periods of time (Boone et al., 2009; Wolch et al., 2005). In the US, the long history of racial segregation and planning practices has led to environmental inequity in exposure to hazards and access to amenities, including greenspace, despite both early recognition of the health benefits of urban parks and more recent attempts to reduce inequities (Boone et al., 2009; Wolch et al., 2005). To take two examples finding similar results to ours, studies from Baltimore and Los Angeles both find greater park accessibility in more deprived areas, but also greater population pressure, i.e. potential park congestion. In Baltimore, relatively equitable accessibility likely arises from blacks moving into formerly white neighbourhoods following "white flight" after economic depression in the 1950s (Boone et al., 2009). In Los Angeles, recent spending on urban parks has been targeted towards less wealthy neighbourhoods – although not enough to achieve equity, despite monitoring by social justice organisations (Wolch et al., 2005).

While racial injustices have played a less extreme role in shaping social inequities in the UK, an examination of the historical context may yield insight into the relationship between higher levels of deprivation and greater greenspace accessibility in Sheffield – especially given that across the UK as a whole, and using larger spatial units, more deprived areas have less greenspace provision (Mitchell and Popham, 2008). The first UK urban parks were established in the mid-nineteenth century as a measure to improve the living conditions of the urban working class, following the realisation that the cost of their ill-health was greater than that of improving those conditions (Crompton, 2013). To fulfil this function, parks had to be located within walking distance of working-class neighbourhoods, which in Sheffield meant the city centre and working class east end (Abercrombie, 1924). Many of Sheffield's parks have been in place ever since the city grew up around them (M. Mears, personal observation). Thus the distribution of Sheffield's parks today remains strongly influenced by the spatial dimension of socioeconomic conditions in the Victoria era and following decades; and despite having largely lost its industrial character, the east end remains deprived today (Abercrombie, 1924; Department for Communities and Local Government, 2011; Mears, 2010).

More recent developments have most likely also influenced the equity of greenspace distribution. Overall, there has been a general decline in the quality of Britain's urban parks and other open spaces as a result of under-investment and failure of effective place-keeping since the 1970s (Dempsey and Burton, 2012; Reeves, 2000). Lower quality parks are less likely to be used (Bedimo-Rung et al., 2005; Giles-Corti et al., 2005; Lee et al., 2015), and therefore may be targeted by cost-cutting measures, resulting in a vicious circle. We noted during data preparation that several greenspaces included in this analysis have had housing built on part or all of their land since 2007. While there is no relationship between area deprivation and the location of these particular greenspaces (M. Mears, personal observation), it is possible that past sell-offs occurred in more deprived areas.

An additional factor behind continuing greenspace inequities at larger scales in the US is that cities must compete for national funding. Richer cities have better resources with which to prepare bids, and are thus more likely to succeed (Rigolon et al., 2018). While parks in the UK are largely funded by local authorities (Dempsey and Burton, 2012), there are nevertheless a number of competitive funding sources with their own agendas, e.g. the Parks for People scheme (Clark and Maeer, 2008). Parks in deprived areas may be less likely to receive investment from such schemes for similar reasons.

Another reason for apparent positive relationships between deprivation and greenspace accessibility is the inclusion of very small greenspaces (Wüstemann et al., 2017); areas with small parks and high housing density may result in biased accessibility metrics (Wolch et al., 2005). Given that excluding small greenspaces changed the relationship in our study (compare Fig. 4a and b), and that there exists a weak correlation between Carstairs deprivation index and address density at OA level in Sheffield ($r = 0.26$; see Supplementary Material), this may be part of the explanation.

It is clear that both methodology and local context have large influences on the findings of studies of greenspace social equity. In order to understand contextual influences in such a way that it becomes possible to synthesise and generalise findings, there is therefore a need to work towards standardisation of definitions and techniques. To this end, further studies providing comparisons of methodological approaches would provide a platform for, for example, identifying appropriate buffer distances.

In working towards contextual understanding, there is a need for further research conducted at the level of individual households that is able to consider cultural and demographic differences in greenspace use and values. Such research would enable planners and policy makers to increase inclusivity by meeting the greenspace needs of marginalised groups. At present, most studies use census tracts/blocks (e.g. Dai, 2011; Hoffimann et al., 2017; Mavoa et al., 2015; Wolch et al., 2005), which while drawn to be demographically homogenous nevertheless can contain substantial variation. This study also uses an OA-level measure of deprivation; we only found one study, by Barbosa et al. (2007), that has used a household-level measure of deprivation. If possible, analysis at the level of individual persons would provide even greater contributions to this aim, although data availability makes both household- and individual-level analyses challenging.

Longitudinal studies, which take into account changes in both greenspace and values over time, would also facilitate understanding of how inequities develop. To date, there do not appear to have been any studies of temporal patterns in equity. Once these limitations in the research base have been addressed, a systematic review to synthesise knowledge and identify remaining research gaps would be a useful way to advance the field.

4.3. Implications

We have measured greenspace distribution equity for different types of greenspace, and using different measures of equity, and found inconsistent results. Similarly, Kimpton's (2017) study of Brisbane captured an exceptional level of complexity of both greenspace and deprivation, and unsurprisingly drew complex conclusions. This apparent hazard of adding complexity is perhaps why we did not find a strong relationship between deprivation and access to 'good' greenspaces, despite the strong positive relationship with access to any greenspace. However, it is clear that capturing more of the complexity of the situation reveals more detail of inequities, with conclusions that are directly relevant to planning policy.

We have identified that the provision of large and high quality greenspaces is poor in many parts of Sheffield, although the provision of smaller, lower quality greenspaces that may not provide maximum potential health benefits is better. Increasing provision presents a challenge. Creating or enlarging greenspaces can be difficult in an already-developed urban matrix; although it may be an easier approach to urban renewal than other approaches, such as new commercial developments (Sugiyama et al., 2018). Joining up existing greenspaces with green corridors, which are themselves a valuable component of urban green infrastructure (Larson et al., 2016), may achieve similar benefits to creating new or expanding existing greenspaces, although this does not appear to have been studied specifically.

Increasing the quality of existing greenspaces also presents challenges. Lack of maintenance, inadequacy of facilities, and a perceived lack of safety or risk of crime are commonly cited, quality-related reasons why people do not use parks (Bedimo-Rung et al., 2005; Lee et al., 2015). The latter reason – fear – is of particular concern to people with a lower income (Zanon et al., 2013). Resolving these issues again requires investment.

Nevertheless, there is potential for the greenspace improvement approach to substantially increase the number of people within 300 m of a 'good' greenspace in Sheffield. At present, 21.5% of households are within 300 m of a large, natural-feeling, but poor quality greenspace. If all of these greenspaces were improved to a higher quality, it would more than double the number of households near a 'good' greenspace. Such improvements would benefit larger numbers of households in more deprived deciles, resulting in a pattern of accessibility more similar to that for all greenspaces (numbers shown in Supplementary Material). This pattern may arise if greenspaces in deprived neighbourhoods, such as those established for reasons of public health, have been neglected in greater numbers than those in less deprived areas. There are also a number of greenspace corridors that can be observed on Fig. 1a, particularly along the river corridors running from the city centre to the north east and to the west. If made contiguous and maintained at a high quality, these greenspaces could make a substantially greater improvement to health.

Given that different groups of users have varying preferences, care should also be taken to define the target groups when discussing quality (Bedimo-Rung et al., 2005; Seaman et al., 2010; Zanon et al., 2013). Of particular relevance, groups with lower socioeconomic status tend to value facilities for socialising, while groups with higher socioeconomic status place higher value on opportunities for individual recreation (de la Barrera et al., 2016; Gobster, 2002; Kabisch and Haase, 2014; Zanon et al., 2014). While some aspects of the quality ratings used in this study are likely to be universal (e.g. cleanliness, vandalism), others may be less so. Failure to attend to park design and maintenance can thus lead to greenspace becoming 'contested space' with the potential for conflict, with some groups being discouraged from visiting (Gobster, 2002; Payne and Reinhard, 2015; Seaman et al., 2010; Wolch et al., 2014). This is even true for children, amongst whom territorialism and perceptions of exclusion can arise by the early teenage years (Day and Wager, 2010).

It is not necessarily clear that inequitable greenspace distribution leads to poorer health outcomes. Despite the general association between living in a greener environment and better health (James et al., 2015), the health benefit of living in a green neighbourhood is not always greater for those living in more deprived areas (Ruijsbroek et al., 2017). Many studies addressing health are limited by poor design, residual confounding, or by being observational in nature (James et al., 2015; Lee et al., 2015; Lee and Maheswaran, 2011). Again, methodological details are likely to impact heavily on results: for example, a study of deprived communities in Scotland found that people living in areas with more greenspace had lower cortisol levels throughout the day, yet did not have lower self-reported stress levels (Ward Thompson et al., 2012).

A final cautionary point is that improving the greenspace infrastructure of neighbourhoods has the potential to gentrify areas, thus worsening outcomes for the displaced residents (Anguelovski et al., 2018; Cole et al., 2017; Wolch et al., 2014). The challenge here is to make neighbourhoods "just green enough" (Wolch et al., 2014) by attending to the needs of local residents and avoiding the traditional, middle class models of green neighbourhoods to prevent house price increases.

4.4. Limitations

A limitation of this work is that we have only addressed supply of greenspace; we have not been able to address its use. This is significant as many benefits are likely to derive from physical use of greenspace, rather than its presence (Lee et al., 2015). As discussed above, the availability of greenspace is only one factor affecting use: use also varies with individual socioeconomic factors, values and constraints, and perceptions of cultural/social inclusion (Bedimo-Rung et al., 2005; Seaman et al., 2010; Zanon et al., 2013). Importantly, people living in deprived areas may have more negative perceptions of local greenspaces and therefore be less likely to use them (Jones et al., 2009), although this is not always the case (Hoffimann et al., 2017).

Our analysis included only greenspaces identified as part of Sheffield's PPG17 assessment (Strategic Leisure Limited, 2008). Notably, this assessment did not include rural open space, most significantly the Peak District National Park, part of which lies within Sheffield's borders. The rural open space is, however, not within 300 m of the majority of the population, so this is unlikely to have biased results. The assessment also did not include incidental green (e.g. street trees, verges) or private gardens. Exposure to both of these may have beneficial effects additional to those provided by the types of greenspace that we investigated (Coolen and Meesters, 2012; de Vries et al., 2003; van Dillen et al., 2012).

We limited our analysis to a maximum 300 m distance between households and greenspaces. While people living very close to a greenspace use greenspaces much more regularly than those who live further away (Schipperijn et al., 2010), more distant greenspaces can nevertheless have a positive effect on health (Browning and Lee, 2017); although it is not clear whether this holds for the most deprived groups who may be least able to travel (Talen, 2003). We acknowledge that people are likely to travel further in particular to visit large, high quality parks, but maintained a consistent distance in our analysis for comparison purposes. We also note that studies of urban walking generally indicate a greater average distance for recreational walks (Kang et al., 2017; Millward et al., 2013). However, studies indicate that visitation frequency for greenspaces specifically falls dramatically after 300 m from home, and that this is particularly the case for women and elderly people – groups that tend to be disadvantaged compared to men and younger people (Grahn and Stigsdotter, 2003; Nielsen and Hansen, 2007; Rojas et al., 2016; Schipperijn et al., 2010). Given our focus on equity, we therefore consider it reasonable to use a relatively conservative distance, to ensure that we do not over-estimate accessibility for less mobile groups.

A limitation related to the available data is that we were not able to obtain data relating to a consistent date. The greenspace data were created in 2008; deprivation relates to 2011; while household locations and the transport network are from 2017. We observed that some areas that were public greenspaces in 2008 had been converted to housing by 2017. We were able to exclude houses located within greenspaces from analysis, but we were not able to account for other changes to greenspace (e.g. changes to boundaries not involving housing, changes in quality).

There are also limitations associated with the aggregated deprivation index (calculated at OA level), which limited our ability to perform a truly household-level assessment, and necessitated the division of households into quantiles of deprivation instead of using a continuous scale. Related to this, assessing at the level of households rather than individual persons may be a source of bias, as there may be spatial variation in average headcount per household across the city. Finally, the local contextual factors driving relationships between greenspace distribution and deprivation in Sheffield may not apply elsewhere.

5. Conclusions

The equity of greenspace distribution is an important environmental justice issue due to the potential for greenspace to improve health, and even reduce deprivation-related health inequalities (Boone et al., 2009; Maas et al., 2009; Mitchell and Popham, 2008; Wolch et al., 2005).

Assessing equity is not, however, a straightforward task, and care must be taken to articulate which aspects of distribution are being assessed (and why they matter), as well as who is benefiting. Our analysis of greenspace in Sheffield demonstrates how the distribution may favour people living in more deprived areas when relatively basic criteria are used (e.g. is distance to any greenspace equitable?), yet the opposite may be found when more specific questions are formulated (e.g. is the potential greenspace congestion experienced by users of provision for children and young people equitable?).

The local historic context is also critical to understanding results. The distribution of greenspace in Sheffield seems driven by the location of working-class neighbourhoods in the Victorian era, when parks were created to help improve poorer residents' health. This context, and its legacy, also need to be considered when attempting to generalise or make comparisons. At present, there are a number of large, natural-feeling, but poor quality greenspaces in these more deprived areas, which if improved may have the potential to reduce health inequities associated with deprivation.

In general, introducing more complexity into the question being asked seems likely to increase the complexity of the answer – yet it is this complexity that should be of interest to those involved in urban planning, to facilitate identification of the groups and areas most likely to benefit from improvements to greenspace infrastructure.

Acknowledgements

We thank Jie Qi, Will Allsworth and Luke Ferriday for their contributions to mapping greenspace access points. We are grateful to two anonymous reviewers, whose comments helped to strengthen our manuscript.

This work was completed as part of the Valuing Nature Programme, a five year £6.5 M research programme which aims to improve understanding of the value of nature both in economic and non-economic terms, and improve the use of these valuations in decision making. It funds interdisciplinary research and builds links between researchers and people who make decisions that affect nature in business, policy-making and in practice. See www.valuing-nature.net.

This work was supported by the Natural Environment Research Council, ESRC, BBSRC, AHRC & Defra [NE/N013565/1]. The funding sources had no involvement in the study design; collection, analysis and interpretation of data; writing of the report; or the decision to submit for publication.

Census data were sourced from the Office for National Statistics and are © Crown Copyright 2018.

Declarations of interest

None.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoforum.2019.04.016.

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