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The importance of ecological quality of public green and blue spaces for subjective well-being

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HIGHLIGHTS

- We investigate how deficiency in access to nature relates to subjective well-being in London, UK.
- We use novel Deficiency to Nature mapping along walking routes from access points.
- Ecological quality of urban natural environments is important for well-being.
- Providing or improving wildlife habitat in London is likely to achieve environmental and health co-benefits.

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ABSTRACT

There is now considerable evidence that the natural environment provides health and well-being benefits in urban environments. However, little is understood about the role of *ecological quality* in maximising well-being gains. We examine the relationship between the accessibility of public natural spaces of high ecological quality and two measures of subjective well-being for adults, using the British Household Panel Survey (BHPS), a large, longitudinal panel dataset. We then compare this relationship with that found with all Public Open Spaces, regardless of their ecological quality. We use the designation of Sites of Importance for Nature Conservation (SINC) as an objective indication of high-quality green- or bluespace, and life satisfaction and mental distress as measures of well-being. We use the Areas of Deficiency dataset from Greenspace Information for Greater London CIC (GiGL) to identify residential areas with more than a 1 km walk from a SINC, based on actual walking routes from known access points. Postcode-level analysis using regression modelling reveals that living beyond a 1 km walk of a SINC decreases an individual's life satisfaction by 0.117 points on a scale of 1 to 7. No relationship is found for mental distress. We also do not find any significant relationship between either well-being measure and all Public Open Spaces. These findings suggest that the ecological quality of publicly accessible open spaces is important for the well-being of residents in Greater London and highlights the need for improving the provision of high-quality green- and bluespaces in urban areas.

1. Introduction

Natural environments are important determinants of human well-being (Sandifer et al., 2015), and can be particularly important for the well-being of people living in urban areas (Cox et al., 2018). Urban green- and bluespaces are natural environments that comprise an element of vegetation and water respectively, such as parks, woodlands, domestic gardens, rivers, and canals. Urban green- and bluespaces have been associated with a range of benefits, such as improved self-esteem and mood (Barton & Pretty, 2010), psychological restoration (Wood et al., 2018), lower levels of self-reported depression, anxiety and stress (Mennis et al., 2018), and higher levels of subjective well-being (Mavoa et al., 2019). Subjective well-being describes how people think about, experience, and evaluate their own lives and is an important tool for informing policymaking (Dolan & Metcalfe, 2012; OECD, 2013). However, there is little understanding of which specific features of green- and bluespaces are important for providing these well-being benefits (Bratman et al., 2019).

The majority of studies categorise natural spaces without distinguishing between their ecological qualities and characteristics (Marselle et al., 2021). Furthermore, in the small body of literature that does examine the association between ecological quality and well-being,

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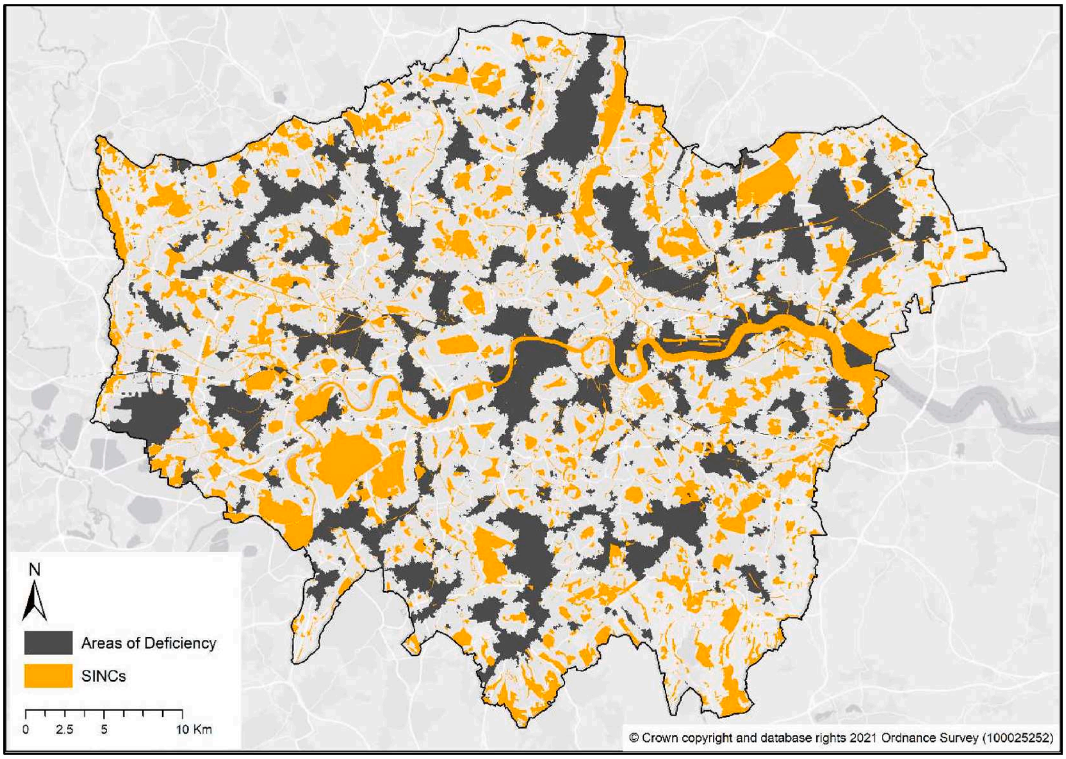

Fig. 1. Sites of Importance for Nature Conservation (SINCs) and Areas of Deficiency to Metropolitan and Borough SINCs, as modelled by Greenspace Information for Greater London CIC (GiGL) [obtained 12th December 2019].

the findings remain contradictory and unclear (Houlden et al., 2021). This is likely due to the variety of ways in which ecological quality, most commonly represented in terms of biodiversity, has been measured, such as subjective measures or single taxa (Lovell et al., 2014; Pett et al., 2016). More robust evidence on the relationship between well-being and the different objective ecological qualities of green- and bluespaces is required (Houlden et al., 2021).

One objective measure of ecological quality is the conservation designation of a site. Designation implies a level of significant natural importance and biodiversity, and is increasingly seen as a meaningful mechanism in policy and practice intervention for achieving biodiversity and well-being co-benefits (Bonet-García et al., 2015; Jones et al., 2020). For example, visits to sites with protected designation status have been associated with psychological restoration and feeling more connected to nature (Wyles et al., 2019). Importantly, residential proximity to protected sites has been found to provide health and well-being benefits. In an English study, Wheeler et al. (2015) found positive associations between residential proximity to protected sites (e.g. Sites of Special Scientific Interest, Ramsar designated wetlands) and self-reported good health, and similarly negative associations with self-reported bad health. However, the study uses a cross-sectional design and given the national scale of the analysis, Wheeler et al. (2015) were only able to include statutory designated sites and no other protected areas that potentially make important contributions to both human well-being and ecological networks.

Here, we address these issues by combining longitudinal data from the British Household Panel Survey (BHPS) with high-resolution, high-quality green- and bluespace data from Greater London, UK to assess whether a relative residential deficiency to sites of important wildlife habitat is associated with lower levels of well-being. We use the formal designation Sites of Importance for Nature Conservation (SINCs) to identify green- and bluespace areas with significant biodiversity importance (GiGL, 2021) and use data from Greenspace information for Greater London CIC (GiGL) that employs a novel method for estimating deficiency in access to SINCs. The Areas of Deficiency (AoD) mapping used network analysis tools to model walking distances along actual routes from known entry points to each SINC, and accounts for the total distribution of surrounding green- and bluespaces. This provides a highly accurate categorisation of all locations deficient in accessible, high-quality nature in the city. We then repeated the analysis for deficiency to all Public Open Spaces (POS) to determine if the same relationships hold when considering all POS rather than only those of high ecological quality.

2. Methods

2.1. Greater London as a case study

Greater London in the UK includes the City of London, 12 Inner London boroughs, and 20 Outer London boroughs, and covers an area of 1,572 km^2. In 2019, the UK Office for National Statistics (ONS) estimated Greater London's population at 8.962 million, with a population density of 5,701 individuals per km^2 (Office for National Statistics, 2020a). London is the largest city in the UK and became the world's first National Park City in 2019. It is ranked tenth out of 30 global cities for public greenspace percentage area per capita (World Cities Culture Forum, 2017), comparable to Rome, Madrid, and Rio de Janeiro, and above New York and Berlin. Overall, 47% of Greater London is considered 'green', with 33% classed as natural habitat within open spaces, an additional 14% classed as vegetated private domestic garden land and a further 10% classed as private domestic garden land (not vegetated; GiGL, 2019). Just over 2% of Greater London's area is categorised as blue space, such as rivers, canals, and reservoirs (GiGL, 2019).

Residents of London have greater access to public greenspace than the national average; 44% of Londoners live within a 5-minute walk of a park, compared to 28% of people across Britain (Office for National Statistics, 2020b). However, Londoners have just 18.96 m^2 of greenspace land provision per person, which is almost half the British average (Fields in Trust, 2020). London supports a wide diversity of wildlife habitats, with over 13,000 species recorded over the last 50 years

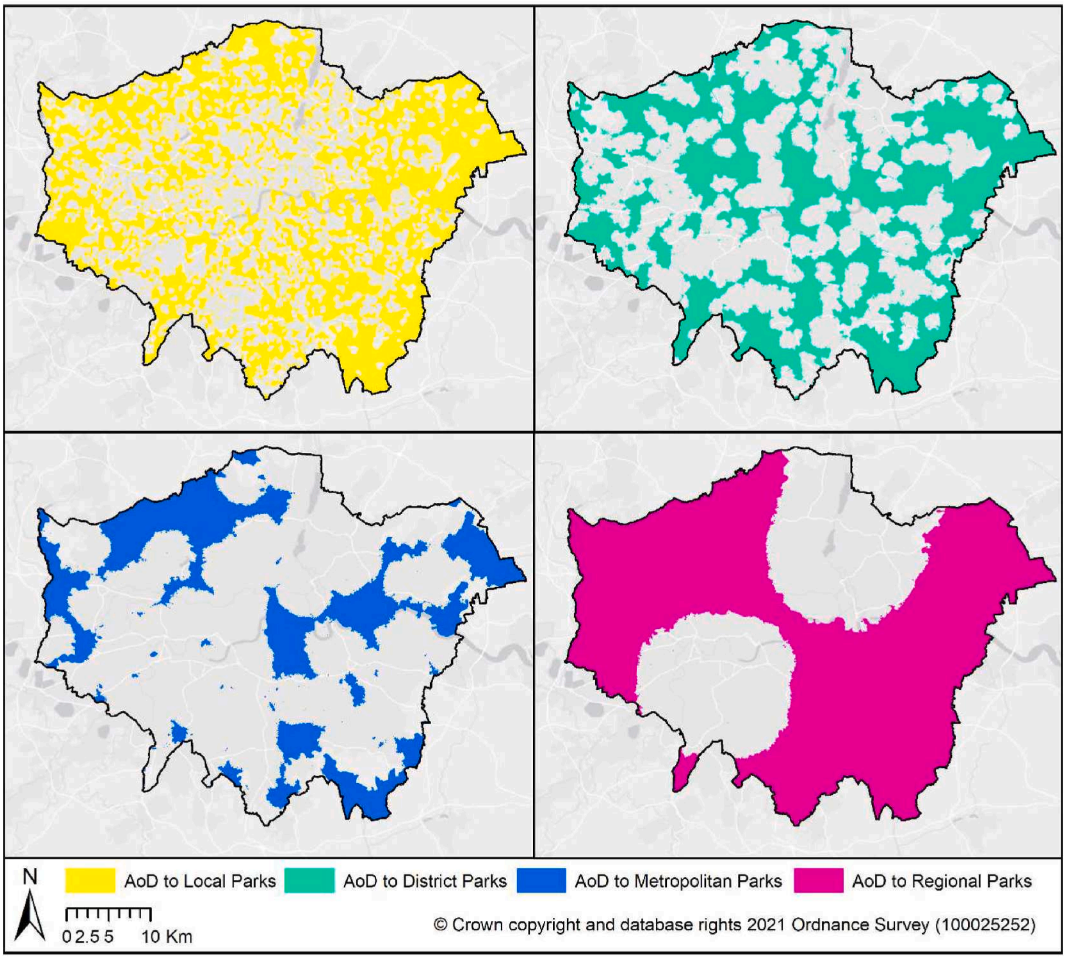

Fig. 2. Areas of Deficiency to Public Open Space, as modelled by Greenspace Information for Greater London CIC (GiGL) [Dataset obtained 7th June 2019]. Areas of Deficiency to Local Parks, District Parks, Metropolitan Parks, and Regional Parks.

(London Wildlife Trust, 2015). The London Plan 2021 requires Local Councils across London to identify areas within their boroughs that are deficient in access to nature and to take action to reduce this, by creating new SINCs, increasing the quality of existing sites, or improving access to sites (Greater London Authority, 2021). There are 1,602 SINCs in Greater London covering 18.97% of the city's area (GiGL, 2019).

2.2. Green- and bluespace data for London

The Mayor of London's Environment Strategy and The London Plan provide a benchmark for the provision of publicly accessible green- and bluespace across the capital, setting out criteria and procedures for identifying SINCs and categorising Public Open Spaces (POS) according to their size, facilities, and local importance (Greater London Authority, 2021). Local Authorities identify sites in their Local Plans that qualify for protection as SINCs and POS, and GiGL maintains a London-wide database of these sites on behalf of the Greater London Authority. Deficiency maps are modelled using actual walking distances around each SINC or POS, using all possible walking routes such as roads, bridges, and paths from known site access points, using an automated approach based on RouteFinder GIS.

2.2.1. Areas of Deficiency in Access to Sites of Importance for Nature Conservation

We used the Areas of Deficiency in Access to Nature dataset calculated by GiGL (Fig. 1). GiGL defines Areas of Deficiency (AoD) in Access to Nature as '*Areas where people have to walk more than one kilometre to reach an accessible* Site of Importance for Nature Conservation (SINC) of Metropolitan or Borough Importance' (GiGL, 2021). The AoD in Access to Nature (AoD to SINCs from here on) dataset is modelled only for Borough/District and Metropolitan grade SINCs and includes sites that have national or international statutory wildlife conservation designations (e.g. Special Protection Areas). Any location that cannot be reached within 1 km of known SINC access points is identified as being inside an Area of Deficiency in access to SINCs.

2.2.2. Areas of Deficiency in access to Public Open Spaces

Areas of Deficiency in access to Public Open Spaces (AoD to POS) are areas beyond a certain walking distance from sites that meet the POS criteria (Fig. 2). There are several categories of POS defined in the London Plan: Linear Open Spaces, Pocket Parks, Small Open Spaces, Local Parks and Open Spaces, District Parks, Metropolitan Parks and Regional Parks. Linear Open Spaces run along routes such as rivers and railways. Pocket Parks, Small Open Spaces and Local Parks and Open Spaces are differentiated by size (<0.4 ha, under 2 ha and at least 2 ha respectively) and consist of children's play spaces, sitting out spaces, public gardens and nature conservation areas. District Parks are at least 20 ha and provide a landscape setting with a variety of natural features and opportunities for recreation. Metropolitan and Regional Parks are large areas, corridors or networks of open space providing a range of facilities and features offering recreational, ecological, landscape, cultural or green infrastructure benefits. Metropolitan Parks are a minimum of 60 ha and offer opportunities at a sub-regional level, whereas Regional Parks are larger, a minimum of 400 ha, and provide an offer

Table 1
Model specifications for predicting life satisfaction and General Health Questionnaire (GHQ) scores from living in Areas of Deficiency (AoD) in access to Sites of Importance for Nature Conservation (SINCs) and AoD in access to Public Open Spaces (POS) and sociodemographic variables.

Model	Dependent variable		Model specification
1	Life satisfaction		AoD to SINCs + control variables
2	GHQ		AoD to SINCs + control variables
3	Life satisfaction	a	AoD to Local POS + control variables
		b	AoD to District POS + control variables
		c	AoD to Metropolitan POS + control variables
		d	AoD to Regional POS + control variables
4	GHQ	a	AoD to Local POS + control variables
		b	AoD to District POS + control variables
		c	AoD to Metropolitan POS + control variables
		d	AoD to Regional POS + control variables

unique to London (see Appendix A for full details). Each has a maximum walking distance within which every home in London should be situated and are based on current advice and understanding (Greater London Authority, 2021). POS deficiency mapping consists of four layers, one for each designation of park size: Local, District, Metropolitan, and Regional (Local includes Local Parks and Open Spaces, Small Open Spaces and Pocket Parks, and Linear Parks are excluded from deficiency mapping). Each deficiency layer uses the different respective walking distance to reflect their differing designations, Local 400 m, District (Borough) 1.2 km, Metropolitan 3.2 km, and Regional 8 km (Appendix A). Higher grades of POS count towards alleviating deficiency to lower grades. For example, if a location is not within 1.2 km distance of a District Park, but is within that distance from a Regional park, this does not count as deficiency to District Parks, because an individual can visit the Regional Park instead. Most accessible SINCs are Public Open Spaces, but only sites that provide high-quality wildlife habitat can be designated as a SINC.

2.3. Study population

We used data for 1,606 adults (categorised as 16+ years) from the British Household Panel Survey (BHPS) with a residential location within Greater London. The BHPS is part of the Understanding Society project (University of Essex Institute for Social and Economic Research, 2019), and is a large multi-year panel survey collecting individual and household information from a representative sample population. Demographic, socio-economic, health, and geographic data are collected in the dataset, as well as data pertaining to attitudes, opinions, and values. The BHPS ran from 1991 to 2008 (waves 1–18) and data collection for each wave in the BHPS was undertaken within a sample year. Postcode locations were obtained from the BHPS as eastings and northings, referring to the centroid of a 5–7 digit postcode unit. The UK postcode network is an alphanumeric system for ascribing individual or groups of postal addresses to a specific geographical location. The structure of a full postcode is comprised of two codes that show the post town and a small group of addresses in that post town. The 5–7 digit postcode is a full postcode, offering a highly precise spatial location, representing part of a street or an individual building. There are 146,864 postcode units in Greater London, with a median area of 0.43 ha and mean area of 1.92 ha (the median area for all postcode units in England excluding Greater London is 0.81 ha, with a mean of 9.95 ha).

2.4. Life satisfaction and mental health

We used two measures of subjective well-being from the BHPS survey: life satisfaction and the General Health Questionnaire (GHQ). Life satisfaction is based on the respondents' answer to the following question: 'How dissatisfied or satisfied are you with life overall?' Respondents give a single reply from a Likert scale with options ranging from 7 ('completely satisfied') to 1 ('completely unsatisfied'). To measure mental health, we used the 12-item short form of the GHQ. Respondents are asked to self-assess against six positive and six negative statements (e.g. 'I am capable of making decisions' and 'I think of myself as worthless'). Respondents give a single reply to each statement on a four-point scale, based on their own evaluation of how the "past few weeks" compare with "usual". The scale ranges from 0 (not at all), 1 (no more than usual), 2 (rather more than usual), and 3 (much more than usual). This gives an overall score ranging from 0 (very low mental distress) to 36 (very high mental distress). Both measures are captured in the BHPS. The GHQ is asked in all 18 waves of the BHPS, but the life satisfaction question is only asked in 12 waves. Therefore, the number of observations in the life satisfaction model is lower (9,138 observations from 1,586 individuals) than the GHQ models (14,301 observations from 1,606 individuals). Life satisfaction is the most commonly used measure of well-being internationally (e.g. Helliwell et al., 2020). It is a cognitive and evaluative measure of well-being, allowing the individual to rate their life in context and in comparison to other factors (Kahneman & Krueger, 2006). This is different to the GHQ, which is an experiential and affective measure of recent experiences, and is used to help diagnose mood disorders and as a marker of psychological distress (Gascon et al., 2015; White et al., 2013a). Both measures have been found to have adequate evidence indicating an association with urban greenspace (Houlden et al., 2018).

2.5. Control data

We included individual-, household-, and neighbourhood- level factors as controls in our analysis, as commonly observed predictors of an individual's subjective well-being (Mavoa et al., 2019; Pasanen et al., 2019; White et al., 2013a). Specifically, at the individual level we used age, higher education, relationship status, health, labour force status, commuting time and liking one's neighbourhood. At the household level we use income (adjusted for household size), living with children, residence type, household space and access to a private garden or terrace. A wave variable was included to account for any natural temporal progression in the data (Luechinger, 2010).

We included the English Indices of Multiple Deprivation as neighbourhood-level control variables (Department for Communities and Local Government, 2010). We included four deprivation domains: income, employment, education, and crime to characterise neighbourhood deprivation at the lower super output area (LSOA) level (4,765 LSOAs in London). LSOAs are an administrative geography used to describe small area statistics, defined by population size (between 1000 and 3000) and household count (between 400 and 1200). We used the 2002 LSOA structure throughout the study.

We also included modelled values of annual ambient outdoor NO_2 concentrations as neighbourhood-level control variables representing air pollution (Defra, 2016). NO_2 is a precursor to particulate pollution and low-level ozone and as such highly relevant for human well-being (World Health Organization, 2021). These 1 km × 1 km grids are outputs based on dispersion modelling using point sources of known emission levels and UK meteorological data. Each LSOA was given the pollution value of the nearest NO_2 point to each LSOA population-weighted centroid for the year 2008. The same NO_2 concentration was attributed to every individual residing in a specific LSOA.

2.6. Statistical analysis

Every individual's residential postcode location in the BHPS sample was spatially linked to the Areas of Deficiency (AoD) layers and neighbourhood-level control data. This assigned each location as being either inside (1) or outside (0) the AoD to SINC and AoD to POS layers. This was repeated for every wave of the BHPS, creating a longitudinal dataset of deficiency in access to SINCs and POS for every participant in the sample. We then constructed regression models to examine the

Table 2
Variable descriptions, descriptive statistics for the British Household Panel Survey (BHPS) sample and the estimation samples for models predicting life satisfaction and the General Health Questionnaire (GHQ).

	Variable description	All BHPS		Life satisfaction (models 1 & 3)	GHQ (models 2 & 4)
		N (total) N = 15,682	Mean (St. Dev.) or %	Mean (St. Dev.) or % N = 8,388	Mean (St. Dev.) or % N = 9,139
Life satisfaction	Respondent's self-reported life satisfaction (scale 1 to 7)	9,138	5.15 (1.25)	5.14 (1.26)	–
GHQ	Respondent's self-reported General Health Questionnaire score (scale 0 to 36)	14,301	11.18 (5.41)	–	11.22 (5.46)
AoD to SINCs	Area(s) where residential postcode centroid is beyond a 1 km walk to a Site of Importance for Nature Conservation (yes/no)	15,682	68.11%	68.48%	68.49%
AoD to Local POS	Area(s) where residential postcode centroid is beyond a 400 m walk of a local Public Open Space (yes/no)	15,682	46.03%	47.17%	47.12%
AoD to District POS	Area(s) where residential postcode centroid is beyond a 1.2 km walk of a district Public Open Space (yes/no)	15,682	51.35%	51.36%	51.45%
AoD to Metropolitan POS	Area(s) where residential postcode centroid is beyond a 3.2 km walk of a metropolitan Public Open Space (yes/no)	15,682	81.21%	80.97%	80.97%
AoD to Regional POS	Area(s) where residential postcode centroid is beyond an 8 km walk of a regional Public Open Space (yes/no)	15,682	47.20%	46.42%	46.49%
Spatial control variables					
Income deprivation	Indices of Multiple Deprivation – deprivation relating to low income and social benefit in the LSOA	15,682	0.17 (0.10)	0.16 (0.46)	16.24 (0.10)
Employment deprivation	Indices of Multiple Deprivation – deprivation relating to benefit claimants in the LSOA	15,682	0.09 (0.04)	0.09 (0.04)	0.09 (0.04)
Education deprivation	Indices of Multiple Deprivation – deprivation relating to school performance and higher education rates in the LSOA	15,682	13.77 (10.74)	13.49 (10.61)	13.54 (10.72)
Crime deprivation	Indices of Multiple Deprivation – deprivation relating to the risk of personal and material victimisation in the LSOA	15,682	0.35 (0.59)	0.34 (0.60)	0.34 (0.60)
NO_2	Mean annual ambient nitrogen dioxide (NO_2) in respondent's residential LSOA in 2008 ($\mu g/m^3$)	15,682	28.73 (5.90)	34.65 (6.54)	34.64 (6.57)
Age (years)					
16–25	Respondent's age is between 16 and 25 years (yes/no)	15,682	17.71%	16.21%	16.33%
26–35	Respondent's age is between 26 and 35 years (yes/no)	15,682	21.56%	20.45%	20.45%
36–45	Respondent's age is between 36 and 45 years (yes/no)	15,682	18.24%	18.75%	18.88%
46–55	Respondent's age is between 46 and 55 years (yes/no)	15,682	16.21%	15.86%	15.69%
56–65	Respondent's age is between 56 and 65 years (yes/no)	15,682	12.00%	13.47%	13.42%
66–75	Respondent's age is between 66 and 75 years (yes/no)	15,682	7.93%	9.04%	8.97%
> 75	Respondent's age is over 75 years (yes/no)	15,682	6.34%	6.22%	6.26%
University-level qualification	Respondent has a university –level qualification (yes/no)	15,098	27.75%	30.66%	30.66%
In a relationship	Respondent is married or living as a couple (yes/no)	15,676	58.03%	58.92%	58.84%
Living with children	Living with own children (<16 years old) (yes/no)	15,682	24.00%	23.19%	23.42%
Annual household income	Log equivalent annual household income (income divided by square root of household size (number of people))	15,176	7.18 (0.84)	7.32 (0.83)	7.31 (0.85)
Health condition	Respondent self-reports a health condition that limits the type of work or amount of work they can do (yes/no)	15,610	16.22%	15.98%	16.03%
Neighbourhood satisfaction	"Overall, do you like living in this neighbourhood?" (yes/no)	14,712	88.76%	89.76%	89.74%
Access to private open space	"Does this accommodation have a place to sit outside e.g. a terrace or garden?" (yes/no)	10,223	86.64%	86.78%	86.76%
Employment status					
Employed	Respondent is employed (yes/no)	15,613	61.34%	62.35%	62.32%
Unemployed	Respondent is unemployed or disabled (yes/no)	15,613	7.06%	6.25%	6.17%
Retired	Respondent is retired (yes/no)	15,613	16.17%	17.45%	17.51%
Caring for family	Respondent is caring for family (yes/no)	15,613	7.92%	7.22%	7.13%
In training	Respondent is in training (yes/no)	15,613	6.95%	6.18%	6.30%
Other	Respondent is in another type of status (yes/no)	15,613	0.56%	0.55%	0.57%
House type					
Detached	Respondent lives in a detached house (yes/no)	15,030	6.81%	9.68%	7.65%
Semi-detached	Respondent lives in a semi-detached house (yes/no)	15,030	25.40%	23.29%	25.37%
Terraced	Respondent lives in a terraced house (yes/no)	15,030	34.88%	36.35%	36.35%
Flat	Respondent lives in a flat (yes/no)	15,030	30.88%	29.18%	29.11%
Other	Respondent lives in another type of dwelling e.g. bedsit (yes/no)	15,030	2.02%	1.50%	1.52%
Household space					
< 1 room per person	<1 room per person in the house (yes/no)	15,275	7.55%	6.83%	6.74%
1 - < 3 rooms per person	Between 1 and under 3 rooms per person in the house (yes/no)	15,275	77.55%	76.35%	76.38%
3+ rooms per person	Three or more rooms per person in the house (yes/no)	15,275	14.90%	16.82%	16.88%
Commuting time					
None	Respondent has no commute (yes/no)	14,427	41.77%	40.23%	40.23%
≤15 mins	Respondent has a commute of 15 min or less (yes/no)	14,427	16.05%	15.89%	15.88%
16–30 mins	Respondent has a commute of 16–30 min or less (yes/no)	14,427	16.75%	17.05%	17.10%
31–50 mins	Respondent has a commute of 31–50 min or less (yes/no)	14,427	12.41%	12.86%	12.80%
>50 mins	Respondent has a commute of over 50 min (yes/no)	14,427	13.01%	13.97%	13.99%
Other					
Wave	BHPS wave (1–18)	15,682	–	–	–

Table 3
Results from the fixed effects regression analyses predicting life satisfaction and General Health Questionnaire (GHQ) scores from living in Areas of Deficiency (AoD) in access to SINCs and sociodemographic variables. We show unstandardised and standardised coefficients and the standard error. Significant results are in bold and significance levels are shown as ***p < 0.001, **p < 0.01, *p < 0.05.

	Life satisfaction			GHQ		
	b	SE	β	b	SE	β
AoD to SINCs	**−0.120***	**0.059**	**−0.044***	−0.248	0.267	−0.021
Spatial control variables						
Income deprivation	−0.647	0.718	−0.052	−2.066	3.250	−0.038
Employment deprivation	2.223	1.335	0.078	2.989	6.042	0.024
Education deprivation	−0.005	0.004	−0.042	0.011	0.017	0.021
Crime deprivation	−0.075	0.060	−0.035	0.090	0.269	0.010
NO_2	0.004	0.006	0.023	0.017	0.027	0.021
Age (yrs) (reference category: 46-55yrs)						
16–25	**−0.377****	**0.123**	**−0.111*****	0.918	0.554	0.062
26–35	**−0.312*****	**0.092**	**−0.100*****	**0.926***	**0.418**	**0.068***
36–45	**−0.204*****	**0.061**	**−0.064*****	0.407	0.280	0.029
56–65	**0.155***	**0.063**	**0.042***	**−1.108*****	**0.286**	**−0.069*****
66–75	0.185	0.108	0.042	−0.757	0.492	−0.040
75+	0.077	0.148	0.015	−0.388	0.674	−0.017
University-level qualification	**−0.235***	**0.111**	**−0.086***	0.167	0.502	0.014
In a relationship	**0.268*****	**0.052**	**0.105*****	−0.336	0.237	−0.030
Living with children	−0.056	0.052	−0.019	−0.376	0.235	−0.029
Annual household income	−0.014	0.020	−0.009	−0.046	0.086	−0.007
Health condition	**−0.396*****	**0.044**	**−0.115*****	2.009***	0.196	0.135***
Like neighbourhood	**0.177*****	**0.047**	**0.043*****	−0.285	0.212	−0.016
Access to private open space	**0.182*****	**0.048**	**0.049*****	−0.683**	0.221	−0.042**
Employment status (reference: employed)						
Unemployed	**−0.287*****	**0.071**	**−0.055*****	**1.144*****	**0.323**	**0.050*****
Retired	0.108	0.075	0.033	−0.521	0.342	−0.036
Caring for family	0.087	0.071	0.018	0.363	0.319	0.017
In training	−0.019	0.083	−0.004	−0.674	0.369	−0.030
Other	**−0.364***	**0.151**	**−0.021***	0.638	0.675	0.009
House type (reference category: detached)						
Semi-detached	**−0.164***	**0.076**	**−0.057***	0.028	0.344	0.002
Terraced	−0.117	0.082	−0.045	−0.068	0.369	−0.006
Flat	−0.062	0.088	−0.022	−0.155	0.395	−0.013
Other	**−0.321***	**0.133**	**−0.031***	0.680	0.576	0.015
Household space (reference category: 1 - < 3 rooms per person)						
<1 room per person	−0.082	0.064	−0.017	**0.753***	**0.293**	**0.035***
3 ≥ rooms per person	0.027	0.053	0.008	−0.261	0.240	−0.018
Commuting time (reference category: None)						
≤ 15 mins	0.025	0.059	0.007	−0.176	0.263	−0.012
16–30 mins	0.097	0.057	0.029	**−0.649***	**0.257**	**−0.045***
31–50 mins	0.104	0.062	0.028	−0.309	0.275	−0.019
≥ 50 mins	0.088	0.062	0.024	−0.026	0.276	−0.002
Other						
Wave	**−0.015****	**0.005**	**−0.047****	**0.057****	**0.022**	**0.038****
R^2	0.05	–	–	0.04	–	–
Observations	8,388	–	–	9,139	–	–
Individuals	1,586	–	–	1,606	–	–
Mean obs per person	5.3	–	–	5.7	–	–

Table 4
Results from the fixed effects regression analyses predicting life satisfaction and General Health Questionnaire (GHQ) scores from living in Areas of Deficiency in access to Sites of Importance for Nature Conservation (SINCs) and Public Open Spaces (POS). We show unstandardised and standardised coefficients and the standard error. Significant results are in bold and significance levels are shown as ***p < 0.001, **p < 0.01, *p < 0.05.

	Life satisfaction			GHQ		
	b	SE	β	b	SE	β
AoD to SINCs	**−0.120***	**0.059**	**−0.044***	−0.248	0.267	−0.021
AoD to Local POS	−0.048	0.048	−0.019	0.240	0.219	0.022
AoD to District POS	−0.073	0.052	−0.029	−0.327	0.235	−0.030
AoD to Metropolitan POS	0.085	0.070	0.027	−0.356	0.321	−0.026
AoD to Regional POS	−0.006	0.077	−0.003	0.062	0.049	0.006

relationship between subjective well-being and deficiency in access to SINCs and POS. We built four model specifications (Table 1). The main specification examined the effect of deficiency in access to SINCs, adjusting for a range of control variables, for both life satisfaction (model 1) and the GHQ (model 2). We repeated models 1 and 2, replacing the AoD to SINCs with AoD to POS to create model 3 and 4. We used the AoD to POS layers for each category of POS (Local, District, Metropolitan and Regional). We used unweighted BHPS variables due to the subsample size, geographic limit, and variability in longitudinal survey membership of individuals.

We constructed the equation using fixed effects regression:

$$SW_{ijt} = \beta_0 + \beta_1 A_{jt} + \beta_2 L_{jt} + \beta_3 X_{it} + \beta_4 T_t + \varepsilon_{ijt}$$

where SW is a measure of subjective well-being (life satisfaction or GHQ), for an individual *i*, at a given location *j* and in a given year *t*. It is a function of living inside an Area of Deficiency (A_{jt}), a vector of LSOA neighbourhood factors (L_{jt}) and individuals' socio-economic and demographic characteristics (X_{it}), and a wave variable (T_t). ε_{ijt} is the error term (all remaining unaccounted for variation).

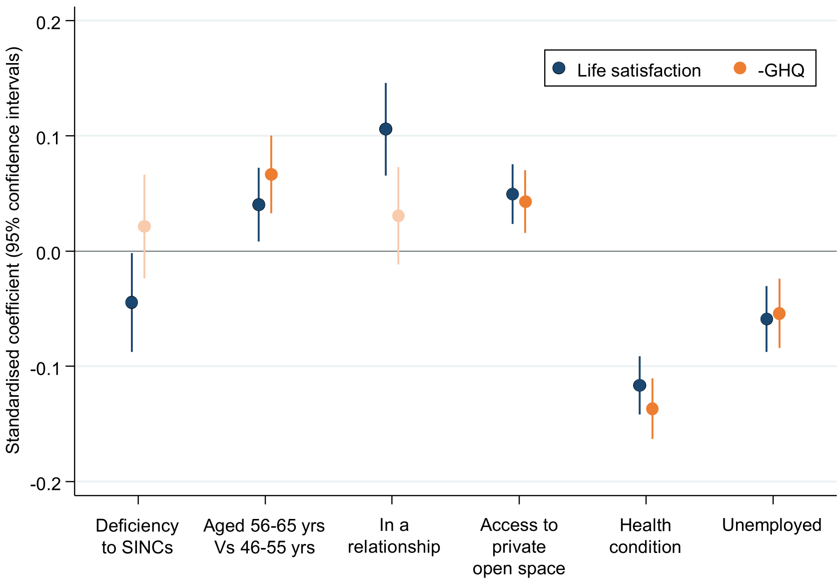

Fig. 3. Standardised coefficients (models 1 and 2), showing the comparative significant effect sizes between deficiency in access to SINCs and other selected covariates in both the life satisfaction and GHQ models. The pale data points represent non-significant coefficients. The GHQ scale has been inverted here so that positive coefficients reflect better mental health. The category 'Aged 56–65 yrs' shows the effect size when the reference category is 'Aged 46–55 yrs, and similarly with 'Unemployed' with a reference category of 'Employed'.

All analysis was carried out in the UK Data Service Secure Lab environment. Spatial analysis was carried out using ArcGIS v10 (ESRI, 2011) and regression analysis using the regress and xt suites in Stata 16 software (StataCorp, 2019).

3. Results

3.1. Sample

Table 2 provides a description and descriptive statistics of each variable in the total dataset for Greater London, and that pertaining to the estimation samples for each model. Neither estimation subsample varied considerably from the overall BHPS sample. Mean life satisfaction (5.15) and GHQ (11.18) scores indicate average levels of well-being, both reflecting lower levels of well-being than the BHPS sample for England (5.20 and 5.76 respectively) used in White et al. (2013a). Approximately 40% of the sample are aged 16–35 years old, 35% aged 36–55 years old, and 25% aged 55+ years old, which is reflective of the age profile for Greater London. Nearly 60% of the sample are in a relationship, 61% employed, and 16% self-report a health condition. Approximately 68% of adults in the sample live in areas that are deficient in access to SINCs, with associated proportions for Local, District, Metropolitan and Regional POS as 46%, 51%, 81% and 47% respectively.

Higher levels of life satisfaction and lower scores of the GHQ are positively associated with having access to private open space and being aged between 56 and 65 years old when compared to being 46–55 years old (Table 3). Both measures of well-being are negatively associated with having a health condition that limits one's ability to work and being unemployed (when compared to being employed). Several variables are significantly associated with only one of either life satisfaction or the GHQ. For example, life satisfaction is positively associated with being in a relationship (compared to being single), but there is no such relationship with the GHQ. In contrast, lower GHQ scores are positively associated with having a commute length of 16–30 min (compared to no commute) but there is no such association in relation to life satisfaction. We also find a significant association between the wave variable and both life satisfaction and the GHQ, indicating a reduction in subjective well-being through time.

3.2. Areas of deficiency to SINCs and POS

We find a significant negative relationship between well-being and deficiency in access to SINCs in Greater London. We find that residential deficiency in access to a SINC is associated with a decrease in an individual's life satisfaction by 0.12 points on a scale of 1 to 7 (Table 4; $b = -0.120$, $p = 0.047$). We do not find a significant relationship between mental health (GHQ) and deficiency in access to nature ($b = -0.248$, $p = 0.353$). We also do not find any significant relationships between both well-being measures and all POS categories (Table 4). Full POS model results can be found in Appendix B.

Using standardised regression coefficients in the life satisfaction model (Fig. 3), we find that the effect size of living inside an Area of Deficiency in access to SINCs ($\beta = -0.044$) is similar to the effect size of being unemployed ($\beta = -0.055$, $p < 0.001$), or approximately one third of the effect of having a health condition ($\beta = -0.115$, $p < 0.001$). We note that the effect size of being deficient in access to SINCs is similar to the positive effect size of having access to private open space ($\beta = 0.049$, $p < 0.001$).

4. Discussion

Our study aimed to understand the importance of ecological quality of the natural environment when exploring the relationship between subjective well-being and residential deficiency in access to public green- and bluespaces in London. We used Sites of Importance for Nature Conservation (SINCs) to represent sites with objectively high ecological quality and compared them to all Public Open Spaces (POS), regardless of their ecological quality. We addressed key methodological issues by using a novel approach to measuring residential proximity to urban green- and bluespaces by using walking distance along actual known routes and access points, as well as employing longitudinal well-being data and fixed effects regression.

4.1. Quality of public green- and bluespaces

Our results suggest that living further than a 1 km walk of a high quality public natural site (SINC) is related to lower levels of life satisfaction. This relationship was not significant when repeating the analysis for all Public Open Spaces (POS) and therefore not accounting for whether they contain important habitat for wildlife. This suggests that the ecological quality of the natural environment, specifically its importance for nature conservation, is an important factor when considering the well-being benefits gained from public natural spaces. This supports a small but growing body of literature that finds ecological quality indicators of green- and bluespaces are strong predictors of health and well-being (Wheeler et al., 2015; Wyles et al., 2019). Despite the effect size being relatively small on the life satisfaction Likert scale, it is comparable to that of other major determinants of well-being controlled for in the analysis, such as access to private open space and unemployment. Additionally, the negative effect size for one individual is greatly amplified when considering the number of people who are not able to access SINCs. Therefore, aggregated community-level effects of living in areas that are deficient of access to high quality nature will be quite significant (White et al., 2013a).

We capture sites that have been considered to be important for nature conservation; SINCs are sites of biological significance that provide habitat to support local biodiversity. SINCs support 91% of the protected species in Greater London and nearly all of the city's Biodiversity Action Plan priority species (London Wildlife Trust, 2015). Previous studies suggest that higher levels of biodiversity are related to higher levels of well-being (Cameron et al., 2020; de Bell et al., 2020; Methorst et al., 2021; Wood et al., 2018). More biodiverse environments may provide more opportunities for psychological and physiological restoration. For example, environments that provide opportunities for 'soft' distraction, such as noticing habitats or birds, as opposed to 'hard' distraction such as car noise and traffic lights, have been associated with greater cognitive functioning and lower heart rates. Alternatively, it might be that places of higher or important biodiversity, particularly in urban areas, are seen as special, rare, or different (Cameron et al., 2020). This might be particularly important in highly urbanised areas, where opportunities to connect to nature are few (Carrus et al., 2015).

We did not find a relationship between either well-being measure and any category of POS. This lack of association between well-being and residential green- and bluespace has also been found in other studies (e.g. Houlden et al., 2017; Triguero-Mas et al., 2017) where natural spaces have not been disaggregated by ecological quality (Hunter & Luck, 2015). Our findings suggest it is important to account for the differences in ecological quality of urban green- and bluespaces when aiming to understand the association between well-being and the natural environment.

We also find that the relationship between well-being and the natural environment differs with the metric of well-being being observed. Deficiency in access to SINCs was important for life satisfaction only, and not our measure of mental distress. This supports research that shows the relationship between domains of subjective well-being and residential greenspace in London have the best fit and highest effect sizes with life satisfaction, when compared to happiness and feelings of worth (Houlden et al., 2019b). These findings are also supported by other research that finds nature exposure has a stronger effect on positive rather than negative emotions (McMahan & Estes, 2015; White et al., 2017). Life satisfaction and the GHQ have also been found to have distinct relationships with bluespace. For example, coastal proximity has been found to be associated with the GHQ but not with life satisfaction (White et al., 2013b). Indeed, differences across other measures of subjective well-being and bluespace have also been found (Garrett et al., 2019; Pasanen et al., 2019). These different relationships may explain the contrasting findings in this study, as we do not separate green and bluespace. These differences are likely to be underpinned by the different mechanisms and causal pathways that are suggested to explain the relationships found between well-being and the natural environment (Markevych et al., 2017).

4.2. Strengths, limitations, and further work

This study benefits from using highly detailed green- and bluespace data for our study site, which is an important improvement on previous work which uses aggregated neighbourhood data or more generalised environmental statistics such as remotely sensed green indices (Rugel et al., 2017; White et al., 2013a). Using site categorisation based on ecological characteristics, for example SINCs, as an alternative to other biodiversity metrics (e.g. species richness) avoids some of the known issues concerning the use of other biodiversity metrics such as the reliance on single taxa and is a meaningful policy and practice mechanism. As we do not separate greenspace and bluespace in this analysis, future work could examine how the ecological characteristics of greenspace and bluespace are differentially associated with well-being.

We use a dataset modelled by GiGL that uses a deficiency measure calculated using walking distance along actual known routes and access points. This is a more sophisticated method compared with commonly used approaches such as neighbourhood or buffer statistics (Krekel et al., 2016; White et al., 2013a), and improves upon network analysis studies that do not account for site access points (Houlden et al., 2019a). The modelled walking distances are detailed in The London Plan (Greater London Authority, 2021) and are designed as the maximum distance an individual should live from a SINC or POS in London, based on site size and function. However, no legal requirements exist for residential distances to green- and bluespaces and this has led to several alternative recommendations also existing in the UK. The UK Government's Accessible Natural Greenspace Standard (ANGSt) recommends a 300 m walk from home for all spaces above 2 ha (Natural England, 2010), and Fields in Trust calculate their Green Space Index using an 800 m Euclidean distance (Fields in Trust, 2020). It is possible that the different distances themselves affect the relationship between well-being and nature (Labib et al., 2020) and that different types and qualities of green- and bluespace require different distance metrics. Further research could examine the relationship between well-being benefits and the quality of green- and bluespaces across different recommended distances to establish reliable and consistent recommendations.

We use highly precise postcode unit residential locations which is seen as the gold standard in health research (Mizen et al., 2015), and despite limiting our study to London, we are able to use a large sample size of individuals from the BHPS. Using a large panel dataset allowed us to employ longitudinal well-being data and use fixed effects to reduce endogeneity bias in our analysis (White et al., 2013a). Fixed effects regression has a significant advantage over cross-sectional correlations as it allows us to isolate within-person variation as opposed to between-person variation by controlling for time-invariant omitted variables (e.g. personality traits) and is an important improvement on previous cross-sectional analyses.

Despite these methodological improvements, the model specifications still explained only a small amount of the variation in well-being (R^2 values are between 0.04 and 0.05). This suggests that there is still a large amount of variance being unaccounted for in our models and may be explained by time-varying omitted variables in our model specifications. However, this is in-line with other similar studies that estimate well-being and nature relationships, for example R^2 = 0.04–0.05 in Alcock et al. (2014) and R^2 = 0.05–0.06 in White et al. (2013a), and reflects the complexity in capturing the determinants of well-being in humans. Additionally, we are still not fully able to imply a causal relationship, for example, we cannot rule out that some individuals with higher subjective well-being will chose to live closer to more biodiverse natural sites. Future work to better understand causality could employ quasi-experimental designs such as instrumental variables regression, or evaluative approaches of nature-based interventions (Hunter et al., 2019).

It is also possible that our findings are conservative. Lynn and Borkowska, (2018) analysed attrition and representativeness across the waves of the BHPS and despite finding relatively low levels of attrition, they find that attrition was greater amongst younger age groups, men, black people, and participants on lower incomes. This reported under-representation of certain demographics in the BHPS over time may suggest that our findings underplay the negative effect of living in deficiency to nature as these groups have been shown to often benefit the most from access to good quality open spaces (Roe et al., 2016; Sharifi et al., 2021).

5. Conclusions

How people are exposed to, and therefore receive benefits from, natural environments in urban settings is complex. Our paper highlights the importance of objectively measured ecological *quality* of public open spaces for well-being and suggest that the SINCs network is an important part of the capital's land use infrastructure for individual well-being in the city. The benefits of focussing policies towards improving well-being have been widely recognised (Environment Agency, 2020) and our findings suggest that conserving and protecting existing green- and bluespaces, as well as developing new high-quality natural spaces in areas that are deficient, is important for both ecological and health benefits. Despite this being highlighted as a priority in The London Plan, SINCs are coming under increasing pressure due to demand for land from development, and some SINCs have been developed or encroached on (London Wildlife Trust, 2015). Future research is required to enable informed recommendations for how public open spaces could be protected and modified to enhance their potential to deliver well-being benefits. Our paper highlights the need for further analyses of the associations between ecological characteristics and different well-being measures using robust methods such as quasi-experimental studies to provide further insight into causality. Future work should differentiate between greenspace and bluespace, and attempt to understand the sociodemographic, health and cultural inequalities in access to high quality open space. Studies conducted outside of London would also contribute to these findings and establish if they are more widely applicable.

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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Appendix A

Table A1

Table A1
Public open space (POS) categorisation according to The London Plan (Table 8.1 in The London Plan pp320.

Open Space categorisation	Size Guideline	Distances from homes
Regional Parks Large areas, corridors or networks of open space, the majority of which will be publicly accessible and provide a range of facilities and features offering recreational, ecological, landscape, cultural or green infrastructure benefits. Offer a combination of facilities and features that are unique within London, are readily accessible by public transport and are managed to meet best practice quality standards.	400 ha	3.2 to 8 km
Metropolitan Parks Large areas of open space that provide a similar range of benefits to Regional Parks and offer a combination of facilities at a sub-regional level, are readily accessible by public *trans*-port and are managed to meet best practice quality standards.	60 ha	3.2 km
District Parks Large areas of open space that provide a landscape setting with a variety of natural features providing a wide range of activities, including outdoor sports facilities, and playing fields, children's play for different age groups and informal recreation pursuits.	20 ha	1.2 km
Local Parks and Open Spaces Providing for court games, children's play, sitting out areas and nature conservation areas.	2 ha	400 m
Small Open Spaces Gardens, sitting out areas, children's play spaces or other areas of a specialist nature, including nature conservation areas.	Under 2 ha	<400 m
Pocket Parks Small areas of open space that provide natural surfaces and shaded areas for informal play and passive recreation that sometimes have seating and play equipment.	Under 0.4	<400 m
Linear Open Spaces Open spaces and towpaths alongside the Thames, canals, and other waterways; paths, disused railways; nature conservation areas; and other routes that provide opportunities for informal recreation. Often characterised by features or attractive areas which are not fully accessible to the public but contribute to the enjoyment of the space.	Variable	Wherever feasible

Appendix B

Table B1

Table B1
Results from the fixed effects regression analyses predicting life satisfaction and General Health Questionnaire (GHQ) scores from living in Areas of Deficiency in access to Public Open Spaces and sociodemographic variables. We show unstandardised and standardised coefficients and the standard error, full results sociodemographic results from the deficiency in access to District POS model. Significant results are in bold and significance levels are shown as ***p < 0.001, **p < 0.01, *p < 0.05.

	Life satisfaction			GHQ		
	b	SE	β	b	SE	β
Deficiency to Local POS	−0.048	0.048	−0.019	0.240	0.219	0.022
Deficiency to District POS	−0.073	0.052	−0.029	−0.327	0.235	−0.030
Deficiency to Metropolitan POS	0.085	0.070	0.027	−0.356	0.321	−0.026
Deficiency to Regional POS	−0.006	0.077	−0.003	0.062	0.049	0.006
Spatial control variables						
Income deprivation	−0.767	0.716	−0.061	−2.380	3.247	−0.044
Employment deprivation	2.337	1.336	0.082	3.342	6.048	0.027
Education deprivation	−0.005	0.004	−0.040	0.011	0.017	0.021
Crime deprivation	−0.072	0.060	−0.034	0.093	0.269	0.010
NO_2	0.003	0.006	0.018	0.017	0.027	0.020
Age (yrs) (reference category: 46-55yrs)						
16–25	**−0.385****	**0.123**	**−0.113****	0.904	0.554	0.061
26–35	**−0.317*****	**0.092**	**−0.102*****	**0.918***$^{}$	**0.417**	**0.068***$^{}$
36–45	**−0.203*****	**0.061**	**−0.063*****	0.414	0.280	0.030
56–65	**0.156***$^{}$	**0.063**	**0.043***$^{}$	**−1.113*****	**0.286**	**−0.069*****
66–75	0.188	0.108	0.043	−0.754	0.492	−0.039
75+	0.077	0.148	0.015	−0.392	0.674	−0.017
University-level qualification	**−0.229***$^{}$	**0.111**	**−0.084***$^{}$	0.182	0.502	0.015
In a relationship	**0.265*****	**0.052**	**0.104*****	−0.331	0.237	−0.030
Living with children	−0.060	0.052	−0.020	−0.387	0.235	−0.030
Annual household income	−0.013	0.020	−0.009	−0.043	0.086	−0.007
Health condition	**−0.398*****	**0.044**	**−0.116*****	**2.002*****	**0.196**	**0.134*****
Like neighbourhood	**0.178*****	**0.047**	**0.043*****	−0.288	0.212	−0.016
Access to private open space	**0.183*****	**0.049**	**0.049*****	**−0.675****	**0.221**	**−0.042****
Employment status (reference: employed)						
Unemployed	**−0.289*****	**0.071**	**−0.056*****	**1.140*****	**0.323**	**0.050*****
Retired	0.105	0.075	0.032	−0.531	0.342	−0.037
Caring for family	−0.063	0.088	−0.023	−0.156	0.395	−0.013
In training	−0.019	0.083	−0.004	−0.673	0.369	−0.030
Other	**−0.360***$^{}$	**0.151**	**−0.021***$^{}$	0.650	0.675	−0.009
House type (reference category: detached)						
Semi-detached	**−0.166***$^{}$	**0.076**	**−0.058***$^{}$	0.026	0.343	0.002
Terraced	−0.111	0.082	−0.043	−0.047	0.369	−0.004
Flat	−0.063	0.088	−0.023	−0.156	0.395	−0.013
Other	**−0.319***$^{}$	**0.133**	**−0.031***$^{}$	0.664	0.576	0.015
Household space (reference category: 1 - < 3 rooms per person)						
<1 room per person	−0.079	0.064	−0.016	**0.763****	**0.293**	**0.035****
3≥ rooms per person	0.032	0.053	0.009	−0.244	0.240	−0.017
Commuting time (reference category: None)						
≤15 mins	0.025	0.059	0.007	−0.177	0.263	−0.012
16–30 mins	0.093	0.057	0.028	**−0.658***$^{}$	**0.257**	**−0.045***$^{}$
31–50 mins	0.098	0.062	0.026	−0.327	0.275	−0.020
≥50 mins	0.082	0.062	0.023	−0.044	0.276	−0.003
Other						
Wave	**−0.016****	**0.005**	**−0.047****	**0.057****	**0.022**	**0.038****
R^2	0.06	–	–	0.05	–	–
Observations	8388	–	–	9139	–	–
Individuals	1586	–	–	1606	–	–
Mean obs per person	5.3	–	–	5.7	–	–

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