The relative effects of access to public greenspace and private gardens on mental health

Landscape and Urban Planning 240 (2023) 104902

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

The relative effects of access to public greenspace and private gardens on mental health

Rebecca M. Collins [a,*], Dianna Smith [a], Booker O. Ogutu [a], Kerry A. Brown [b], Felix Eigenbrod [a,1], Rebecca Spake [c,1]

[a] Geography and Environmental Science, University of Southampton, University Road, Southampton SO17 1BJ, UK
[b] Department of Geography Geology and the Environment, Kingston University, Penrhyn Road, Kingston Upon Thames KT1 2EE, UK
[c] School of Biological Sciences, University of Reading, Whiteknights Campus, Reading RG6 6AS, UK

HIGHLIGHTS

- Predicted effects of parks and domestic gardens on mental health varied by gender.
- Domestic gardens had a greater effect on men's mental health than public parks.
- Domestic gardens had a minimal effect on women with access to public parks.
- Domestic gardens were beneficial for older women without public greenspace.

ARTICLE INFO

Keywords:
Mental wellbeing
Domestic gardens
Deprivation
Counterfactual
Statistical matching

ABSTRACT

Although the beneficial effects of urban greenspace on mental health are widely accepted, the comparative effects of public greenspace and private (domestic) gardens on mental health are poorly understood. Here, an assessment is provided of the effect of local public greenspace on a person's mental health for those with and without a private garden in Britain. Individual level data on private garden ownership and mental health status are obtained from a nationally representative survey (the British Household Panel Survey). A combination of statistical matching and regression models are used to account for individual and area-level confounders and to test for interactions. Individuals with (n = 4,454) and without (n = 338) private gardens are analysed separately and their predicted probability of poor mental health in response to public greenspace presence is compared. Results show that the predicted positive effect of having a private garden varies depending on gender and age. Specifically, having a private garden substantially reduces the maximum predicted probability of poor mental health for men regardless of their access to local public greenspace. Whereas, for women, the presence of local public greenspace results in comparable mental health for those with and without a garden. Women without access to local public greenspace, having a private garden reduces the predicted probability of poor mental health later in life. Given the results, it is recommended that the provision of private gardens is considered within greenspace guidance and policy, which is currently dominated by the provision of, or access to, public greenspaces.

1. Introduction

A consensus has emerged that greenspace in cities has beneficial effects on the mental health and wellbeing of residents (for reviews see; Collins et al., 2020; Hartig et al., 2014; Houlden et al., 2018). Time spent in greenspace can promote good mental health via psychological restoration (Kaplan & Talbot, 1983) and stress reduction (Ulrich, 1983). In addition, access to greenspace can encourage physical activity and social cohesion which are both associated with improved mental health outcomes (e.g., Maas et al., 2009; Marselle et al., 2019; McEachan et al., 2016; Sullivan et al., 2004; Ward Thompson et al., 2016). With 68% of the world's population projected to live in cities by 2050 (United

* Corresponding author at: Geography and Environmental Science, University of Southampton, University Road, Southampton SO17 1BJ, UK.
E-mail address: R.Collins@soton.ac.uk (R.M. Collins).
[1] Felix Eigenbrod and Rebecca Spake should be considered the joint senior author.

https://doi.org/10.1016/j.landurbplan.2023.104902
Received 21 December 2022; Received in revised form 18 September 2023; Accepted 21 September 2023
Available online 26 September 2023

Nations, 2018), populations are becoming increasingly dependent on a small and restricted network of greenspace for mental health benefits.

However, critical knowledge gaps exist in our understanding of the greenspace and mental health relationship in cities, which must be addressed to effectively inform future urban planning. Specifically, research that quantifies the relationship between greenspace and mental health rarely defines or differentiates between public greenspace and private (domestic) gardens (Taylor & Hochuli, 2017), despite their differences in accessibility. Given the beneficial effects of gardens and gardening on mental health (for reviews see; Clatworthy et al., 2013; Howarth et al., 2020; Soga et al., 2017), the aggregation of public greenspaces (e.g., parks and woodland) and private gardens into measures of total greenspace amount (e.g., an area's total greenness) may lead to incorrect inferences about the relative importance of public greenspaces to mental health. Consequently leading to poor urban planning decisions that widen social and health inequalities; indeed, those who are at greatest risk of poor mental health may already have little access to greenspace (Allen et al., 2014). Most studies focus on either private gardens or public greenspace in their analysis, rather than attempting to disentangle the effects of private gardens and public greenspace access on mental health. For instance, Houlden et al. (2019) report on the improved mental wellbeing of local residents exposed to urban public greenspaces such as parks. Similarly, studies have shown that access to private gardens and gardening, which present an immediate opportunity to observe or engage with nature (Gaston et al., 2005), can improve mental health (e.g., Corley et al., 2021; de Bell et al., 2020; Fjaestad et al., 2023; Soga et al., 2017). Whilst other studies have demonstrated positive associations between mental health and area-level coverage of public greenspace and private gardens combined (e.g., Alcock et al., 2014; White et al., 2017). Alcock et al. (2014) found that the inclusion of private gardens in total greenspace calculations did not affect the categorisation of individuals into those moving to greener or less green areas. However, whether or not individuals have private gardens can influence their engagement or interaction with other forms of greenspace (de Bell et al., 2020). Therefore, it is essential that private garden access is explicitly considered at an individual level (as opposed to an area-level aggregation) to understand the relative importance of private gardens and public greenspace on health outcomes. A key difficulty in disentangling the effects of private gardens and public greenspace is that their access is often confounded with individual, household and area-level characteristics that can also influence mental health (Allen et al., 2014). For example, a person with greater access to greenspace – either through a private garden or by being able to afford housing in 'greener' areas – may be less likely to experience poor mental health through having a higher income, stable housing, employment, or access to private healthcare (Allen et al., 2014). It is therefore critical to separate the confounding effects of greenspace access from individual and area-level drivers.

In this paper, we present an assessment of the contingent effects of urban public greenspace and private (domestic) gardens on the probability of poor mental health in Britain (England, Scotland and Wales). Here we used established pathways proposed by Hartig et al. (2014) to explore the possible relationship between our variables. We hypothesised that access to greenspace (whether it be public parks or private gardens) will reduce the probability of poor mental health. As such, we expected to find a stronger effect of public greenspace on the probability of poor mental health for those without private gardens. Similarly, we expected the effect of having a private garden on the probability of poor mental health to be stronger for those without access to public greenspace. However, we had no prior expectation for the comparative effect of public and private gardens on the probability of poor mental health for individuals with or without access to both, due to the gap in comparative studies of public greenspace and private gardens.

2. Methods

We adopt a counterfactual approach (Rosenbaum & Rubin, 1983) and explicitly distinguish between the effects of public greenspace and private gardens from individual and area-level confounding factors. We use individual level (n = 5,248) mental health outcomes from survey data in Britain, the British Household Panel Survey (BHPS; University of Essex, 2018), together with the Ordnance Survey MasterMap (OSMM) Greenspace Layer (Ordnance Survey, 2017), to separate public parks and public gardens (i.e., accessible greenspaces) from the overall greenspace provision in a person's local area. We separately test the effects of public greenspace and private gardens on the probability of poor mental health, distinguishing individuals by their ownership of a private garden. For those with and without a garden, we account for individual level and area-level factors that confound the greenspace and mental health relationship by applying statistical matching and regression models, which strengthens causal inference from observational datasets (Stuart, 2010).

2.1. Description of data

2.1.1. Public green space

A map of public greenspace was derived from the OSMM Greenspace Layer (version April 2020), a fine-scale vector dataset of urban greenspaces in Britain which included both publicly accessible and private greenspaces including golf courses and institutional grounds (Ordnance Survey, 2017). We selected polygons corresponding to public parks or public gardens (i.e., spaces that are accessible to the public). To create a binary variable for the presence or absence of public greenspace within an individual's local area, an 800 m buffer was applied to the 2011 Lower Layer Super Output Area (LSOA) or, for Scotland, Data Zone population-weighted centroids. LSOAs and Data Zones are commonly used units (proxy neighbourhoods) to report small-area statistics and have previously been used to establish the greenspace and mental health relationship (e.g., Alcock et al., 2014). An 800 m buffer was selected to represent the average distance travelled in a ten-minute walk which aligns with the Fields in Trust's Guidance for Outdoor Sport and Play access guidance (Fields in Trust, 2020). From a planning perspective, the chosen 10-minute walk aligns with the '20-minute neighbourhoods' concept which stipulates that people should be able to meet most of their everyday needs within a 20-minute return walk from their residence (Emery & Thrift, 2021). The concept has been implemented by local authorities and city planners in Melbourne (Victoria State Government Department of Environment, 2021) and Scotland (O'Gorman & Dillon-Robinson, 2021).

2.1.2. Mental health

This study used data from the BHPS, a nationally representative longitudinal survey of more than 5,000 households in the United Kingdom (UK) that ran annually for 18 years from 1991 to 2008 (University of Essex, 2018) as a measure of individual level mental health. Each year of the survey is referred to as a "wave". A household geographic identifier was used to link BHPS respondents to a LSOA (England and Wales) or Data Zone (Scotland). Although the BHPS has a representative sample for the UK, we restricted our analysis to individuals in Britain and excluded individuals living in Northern Ireland due to the availability of spatial datasets (namely public greenspace and deprivation).

Mental health in the BHPS was measured using the 12-item General Health Questionnaire (GHQ-12). The GHQ-12 is a validated screening tool used to assess a person's risk of common mental disorders, such as anxiety and depression (Goldberg & Hillier, 1979) and is considered robust across genders, ages and education (Goldberg et al., 1997). The responses to the 12-items of the GHQ-12 consist of two lower categories and two higher categories which were coded as 0 and 1 and then summed to create a scale from 1 to 12 (Hankins, 2008). Following previous work (e.g., Riva & Smith, 2012; Shelton & Herrick, 2009; Weich et al., 2006) and recommendations for using the GHQ-12 to assess the presence of common mental disorders (Goldberg & Williams, 1988), scores were converted to a binary (0/1) variable "poor mental health" with $\geq$3 indicating poor mental health.

2.1.3. Individual and household-level characteristics

The BHPS retrieved information on a range of variables including individuals' private garden access, income, age, gender, marital status, and level of education, which are potential confounders of poor mental health (Allen et al., 2014). Monthly total household income was adjusted for household size and composition using the BHPS variable "afieqfca" to create the variable "equivalised household income". Unlike previous studies using the BHPS (e.g., White et al., 2013), individual level variables such as hours of physical activity, commute time, and presence of physical health conditions were disregarded because they were considered post-treatment variables (i.e., not independent of access to public greenspace), which can bias estimates of treatment effects in causal models (Montgomery et al., 2018). We did not include ethnicity as a confounding variable in this analysis due to the low sample sizes of Black, Asian, and Minority Ethnic respondents.

2.1.4. Area-level characteristics

We took a systematic approach to identify potential area-level variables that moderate the effect of greenspace exposure on mental health. Variables were identified by reviewing studies included in a systematic map that collated studies quantifying greenspace-mental health relationships (Collins et al., 2020). From these, we first collated a comprehensive list of area-level characteristics that have been previously included as confounders or modifiers of greenspace effects on mental health. Second, this full list was then reviewed to determine whether the variables were relevant to and supported by appropriate data for urban areas in Britain. The data assessment identified a total of seven area-level characteristics which were used in this analysis and are summarised in Table 1.

2.2. Analysis

2.2.1. Sample stratification

In order to limit inference to urban areas in Britain, the sample was restricted to urban LSOAs, identified using the 2011 Urban Rural Classification (Office for National Statistics, 2017). All outliers and individuals with missing data were excluded (details provided in Appendix A). All waves of the BHPS were used to maximise the sample size available for analysis. Individuals that had not lived at an address for >12 months were excluded to ensure a minimum exposure to greenspace and to minimise potential effects on mental health caused by moving to an area with more or less green space (Alcock et al., 2014). To remove any potential non-independence among members of the same household and waves, one person from each household was selected at random. A random wave was selected for individuals that participated in multiple survey waves.

Data exploration showed that most individuals (94%) who responded to the BHPS were surveyed in the autumn and winter months. Low sample sizes in the summer and spring precluded the modelling of seasonal variation effects on mental health and were, therefore, removed from the sample, leaving respondents interviewed between September 1st and March 1st. The sample was then separated into two samples for subsequent analysis: individuals with and individuals without a private garden. These samples were analysed separately because private garden access is strongly correlated with other socio-demographic factors that confound mental health (Office for National Statistics, 2020).

2.2.2. Statistical matching

We used statistical matching to control for confounding variables that influence mental health. We classified public greenspace access as a

Table 1
Area-level characteristics that were hypothesised to influence mental health directly or indirectly by modifying the influence of greenspace.

Area-level characteristic	Proxy variable	Data source and processing
Greenness	Normalised Difference Vegetation Index (NDVI)	NDVI was calculated using Landsat 8 surface reflectance products (United States Geological Survey, 2017) at a resolution of 30 m × 30 m. Images were processed in Google Earth Engine and the maximum NDVI values over eight years were obtained. NDVI values for LSOAs were abstracted as the mean value within the population-weighted centroid 800 m circular buffer.
Diversity	Bird species richness	Bird species recorded at a 10 km resolution (Gillings et al., 2019) were used to calculate species richness. The species richness at each LSOA population-weighted centroid was extracted. Rarer species recorded at coarser resolutions (>10 km) were not used as these species would have generally not been seen by the majority of people and therefore the majority of people do not interact with them (Gaston et al., 2018).
Protected sites	Ancient, veteran or notable trees Common Database of designated areas (CDDA)	Point data noting the location of the ancient, veteran or notable trees (Woodland, 2020) were combined with location data for protected areas from the CDDA (European Environment European Environment, 2019). A binary variable was then created to represent whether either feature was present within an 800 m buffer around the population-weighted centroid.
Social cohesion	Townsend deprivation score	Townsend deprivation score from the 2011 Census was used to determine deprivation for LSOAs in England and Wales and Data Zones in Scotland (UK Data Service, 2017). Higher scores indicate the most socially and materially deprived areas, while lower (or negative) scores indicate the least deprived areas in a relative measure which includes unemployment, non-car ownership, non-home ownership, household overcrowding.
Air pollution	$PM^{2.5}$	Modelled $PM_{2.5}$ concentrations at a 100 m resolution from (Phillips et al., 2021) were used to extract the mean exposure to $PM_{2.5}$ within an 800 m buffer around the population-weighted centroid.
Noise pollution	Road noise pollution (Yes/No)	24-hour annual average noise levels from roads were extracted from the England, Wales and Scotland strategic noise maps (Department for Environmental Food & Rural Affairs, 2017; Scotland's Environment, , 2017; Welsh Government, 2017) and were converted into 25 m resolution. As the noise maps were derived along major traffic routes only a large number of LSOAs contained no noise pollution. To accommodate the large number of zero cases, noise pollution was converted into a binary variable. This variable groups together LSOAs that contain noise pollution from major roads (within an 800 m buffer of the population-weighted centroid) and those with no noise pollution from major roads.
Spatial and temporal sunshine	Hours of sunshine	The sunshine hours for the individual's LSOA population-weighted centroid for the month in which the individual was interviewed was extracted from 1 km resolution data (Met Office, 2020).

binary variable denoting whether public greenspace was present within 800 m of the population-weighted centroid. Greenspace access was designated as the focal treatment variable to which the following individual- and area-level confounders were matched: age, equivalised household income, marital status (married/not married), higher education attainment (yes/no), gender, Townsend deprivation score, presence of designated areas (yes/no), bird species richness, Normalised Difference Vegetation Index (NDVI), air pollution, presence of noise pollution (binary) and daylight hours.

Three widely used matching methods were implemented using the R package 'MatchIt' (Ho et al., 2011): nearest neighbour matching, optimal full matching, and Mahalanobis distance matching. The matching method that yielded the "best" matched samples was selected for regression analysis, which corresponded to the method that minimised the standardised mean differences in variables between the control and treatment groups (Schleicher et al., 2020; Stuart, 2010). While matched samples were similar across all methods, the nearest neighbour matching method achieved marginally better matching (Appendix B1). Statistical matching reduced the BHPS sample from 6,702 to 4,454 individuals with a private garden and from 1,111 to 338 individuals without a private garden. Descriptive statistics for the two matched samples are shown in Table 2.

2.2.3. Multimodel inference

To quantify the effect of greenspace presence on the risk of poor mental health, Generalised Linear Models (GLMs) with a logistic link function were fitted to two matched datasets, corresponding to samples of individuals with and individuals without a private garden. We constructed a 'base model' for each sample that included the following confounders of mental health: equivalised household income, marital status, age, gender, and highest educational attainment. The samples included multiple individuals per LSOA. The degree of non-independence was greater for the sample of garden owners (1 to 22 individuals, median = 1), than for the no garden sample (1 to 4 individuals, median = 1). Using the base models, we explored whether the inclusion of a random intercept term, identifying individuals from a common LSOA, improved model fit for each sample. Base models with and without the random intercept were compared using a log-likelihood ratio test. In both samples, the inclusion of a random intercept term did not improve the model fit and the intercept terms were not included in the base models. The base models were compared with models that varied in their inclusion of the following variables: public greenspace, Townsend deprivation score, a quadratic function of age, and interactions between public greenspace, gender, and age. These interactions and the quadratic function of age were examined because of their support in the literature (e.g., Astell-Burt et al., 2014). This yielded a total of 56 plausible models for comparison.

The 'dredge' function from the R package 'MuMIn' (Bartoń, 2020) was used to run and compare the 56 plausible model fits using the Akaike information criterion (AIC). The top-performing models were identified using a ΔAIC threshold of <6 (Burnham et al., 2011; Harrison et al., 2018). The goodness of fit (pseudo-R^2) of each top-performing model was estimated using Nagelkerke (1991). Multicollinearity tests (including variance inflation factors) were used to ensure models were robust to collinearity (Fox, 2015). Model assumptions were checked by plotting residuals versus fitted values against each covariate in the global model (including all variables) and again for the reduced model (variables in the averaged model) using the R package 'DHARMa' (Hartig, 2018).

The top-performing models (ΔAIC <6) explained 3.50–3.57% and 6.06–10.88% of the variation in mental health for the private garden and no private garden samples, respectively. These models were used to predict the risk of poor mental health in response to public greenspace presence (details of model selection and prediction averaging in Appendix B.2 and B.3). We interpreted results on an additive scale, plotting changes in absolute probabilities of individual level poor mental health, as this is the scale more relevant to policymaking than the multiplicative modelling scale used (Spake et al., 2023). To visualise the relationship between covariates and the predicted probabilities of poor mental health, we plotted the average predicted probabilities from the top-performing models (Cade, 2015), whilst holding all other covariates at their median or mode value for numerical and categorical variables, respectively. Mean and modal covariate values were calculated from the combined private garden and no private garden samples (Appendix B.4). The mode value for public greenspace was "access" and the mode value for gender was "women" and were used to generate Fig. 2, see Appendix B.4, for the corresponding figures for "no access" and "men". As a key decision with statistical matching concerns the variables used to match on, additional models were fitted using data that matched only socio-demographic variables and data with no matching to see how the matched variables influenced model results (Appendix B.5). Indeed, the difference in predicted poor mental health between individuals with and

Table 2
Descriptive statistics for the matched BHPS data, private garden, and no private garden samples. For continuous variables, the mean is reported with the standard deviation (*s*) in parentheses.

		Private garden		No private garden	
Categorical variables		n	%	n	%
Individuals		4,454	100.00	338	100.00
No public greenspace		2,227	50.00	169	50.00
Poor mental health		1,154	25.91	100	29.59
Gender:	Male	2,066	46.39	174	51.48
	Female	2,388	53.61	164	48.52
Married		2,406	54.02	88	26.04
Not married		2,048	45.98	250	73.96
Higher education		754	16.93	55	16.27
No higher education		3,700	83.07	283	83.73
Presence of protected areas		2,190	49.17	189	55.92
No protected areas		2,264	50.83	149	44.08
Presence of noise pollution		3,837	86.15	302	89.35
No noise pollution		617	13.85	36	10.65
Continuous variables		***n***	**Mean (*s*)**	***n***	**Mean (*s*)**
Age		4,454	42.39 (16.04)	338	41.20 (17.49)
Equivalised household income (£)		4,454	2,126.31 (1100.71)	338	2,064 (1167.56)
Townsend deprivation score		4,454	-0.78 (-2.89)	338	0.68 (2.97)
NDVI		4,454	68.90 (7.47)	338	66.50 (7.96)
Bird species richness		4,454	200.25 (30.88)	338	195.43 (28.77)
Air pollution ($PM_{2.5}$)		4,454	0.16 (0.04)	338	0.17 (0.04)
Hours of sunshine		4,454	3.58 (1.08)	338	3.65 (1.08)

without a garden is different without statistical matching (Appendix B.5, Fig. B.5.3). Therefore, without using statistical matching, erroneous conclusions could have been made.

3. Results

For individuals aged 18–75 years old living in urban areas of Britain, the peak in the predicted probability of poor mental health is less for those with a private garden (Fig. 1). The magnitude of this observed difference varies according to access to public greenspace, gender and age (Fig. 1). Women with access to public greenspace show the smallest difference in the predicted probability of poor mental health between those with and without private gardens (Fig. 1). At age 45 (the average age in peak probability of poor mental health for all individuals) the observed difference was approximately 0.02 (Table 3). For women with no access to public greenspace, the difference in probability was more pronounced at age 45; the difference in probability of poor mental health was 0.07 and this difference in probability continued into older age (Table 3). Women aged 56 with no private garden and no access to public greenspace had the highest predicted probability of poor mental health, and this peak was experienced much later in life compared to women with a private garden (aged 41 for both public greenspace and no public greenspace).

For men who are likely to have poor mental health, the effects of a private garden exceeded those of public greenspace on mental health (Table 3). For instance, the predicted probability of poor mental health

Table 3
The predicted probability of poor mental health averaged across the top-performing models (ΔAIC < 6, see text) for individuals with and without a private garden in relation to access to public greenspace (within 800 m of the population-weighted centroid of their LSOA) and gender. Predictions were made for individuals that were aged forty-five, corresponding to an average age where the risk of poor mental health peaked for garden and non-garden owners. All other covariates were held at their median or mode (See Methods).

Access to public greenspace	No private garden		Private garden		Difference	
	Men	Women	Men	Women	Men	Women
No public greenspace	0.33	0.34	0.20	0.27	0.13	0.07
Public greenspace	0.31	0.31	0.21	0.29	0.10	0.02
Difference	0.02	0.03	0.01	0.02	NA	NA

between men with no public greenspace access and public greenspace access was 0.02 (for men without a private garden), while it was 0.13 between those with and without private gardens (for men without access to public greenspace). Men's garden ownership marginally altered the magnitude of the predicted effect of public greenspace access on the probability of poor mental health (between 0.02 and 0.01, Table 3).

The effect of private garden ownership on mental health varies with age and gender: for younger individuals (aged under 25 and 32 for men and women, respectively) having a private garden slightly increased the probability of poor mental health. For older individuals, the trend is dependent on whether they had access to public greenspace. The benefit

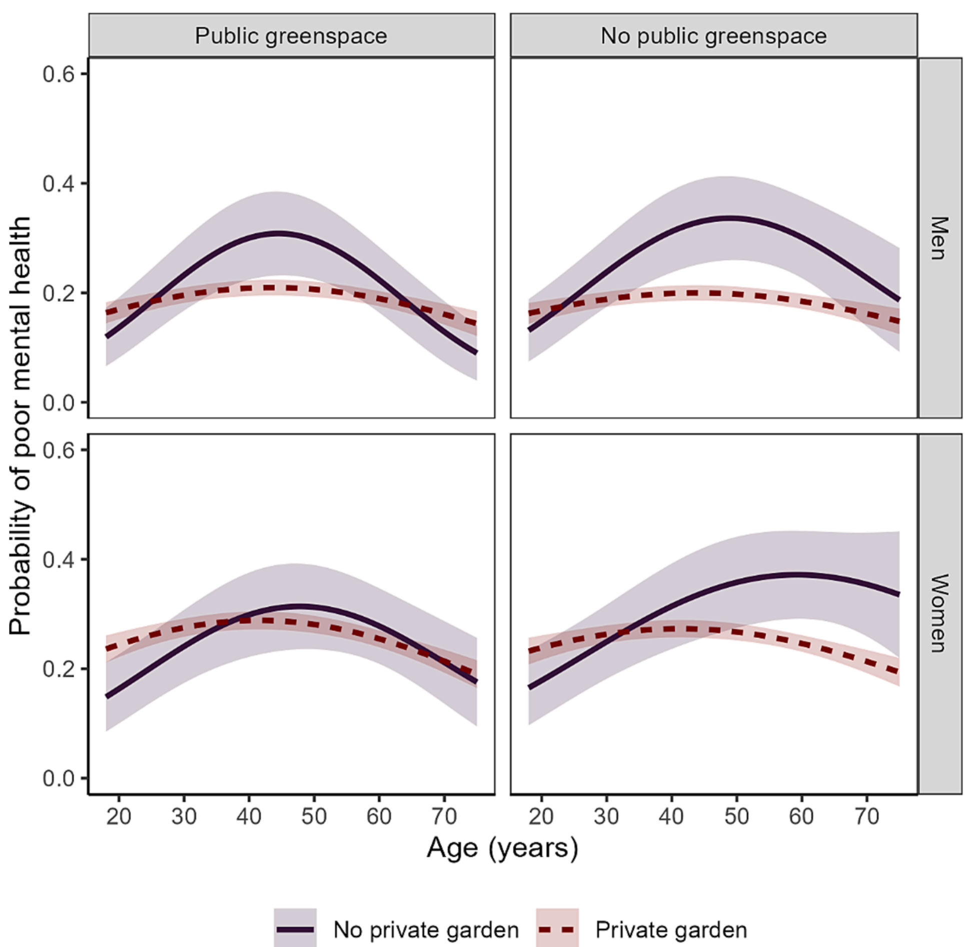

Fig. 1. The predicted probability of poor mental health averaged across the top-performing models (ΔAIC <6, see text) for individuals without (purple line, n =338) and with (red line, n =4,454) a private garden in relation to access to public greenspace (within 800 m of the population-weighted centroid of their LSOA or Data Zone), gender, and age. All other covariates were held at the median or mode of the combined samples (equivalised income = £2,126.31, married, no higher education, Townsend deprivation score = −0.78). Shaded region shows the standard error for the predicted interval.

of garden ownership on the probability of poor mental health continued in older age for men and women with no public greenspace (Fig. 1). However, in older men with access to public greenspace, owning a private garden increased the predicted probability of poor mental health (Fig. 1).

For most individual level covariates (equivalised household income, married, and Townsend deprivation score), predicted probability of poor mental health was generally not contingent on garden ownership (Fig. 2). The greatest difference in the predicted probability of poor mental health between individuals with and without a private garden was observed for those who had attained higher education. Individuals with higher education and no access to a private garden were predicted to have a higher risk of poor mental health compared to those with access to a private garden (Fig. 2). In addition, the predicted probability of poor mental health was not contingent on access to public greenspace. Fig. 2 presents the predicted probabilities of poor mental health with access to public greenspace (i.e., the mode – see Methods); similar predicted responses were observed for no access to public greenspace (Fig. B.4.1, Appendix B.4). Similarly, sensitivity tests were performed for the compare effect of gender on the predicted probability of poor mental health (Appendix B.4). Like for women, the predicted probability of poor mental health for men was not contingent on access to public greenspace (Figs. B.4.2 and B.4.3, Appendix B.4). However, compared to women (Fig. 2) there were more pronounced differences between men with and without private gardens; men with access to private gardens had a lower predicted probability of poor mental health compared to men with gardens (Fig. B.4.1, Appendix B.4).

4. Discussion

We expected access to public greenspaces to more strongly influence the predicted probability of poor mental health for individuals without gardens, but support of this hypothesis was mixed and varied with gender. Supporting this hypothesis, we found that women with no private garden had a lower peak in the probability of poor mental health with access to greenspace compared to no access to greenspace (Fig. 1). Importantly, for women, access to public greenspace results in a minimal difference between the predicted probability of mental health for garden and non-garden owners (difference = 0.02, Table 3). This suggests that access to public greenspaces can act as a buffer against levels of poor mental health for women and could help reduce health inequalities between the garden and non-garden owners.

For men, we found no support for the hypothesis that public greenspace would more strongly influence the probability of poor mental health for individuals without gardens; public greenspace effects on poor mental health did not detectably vary between men with or without a private garden (Fig. 1). Moreover, the predicted effects of public greenspace on mental health for men were relatively small (difference = 0.01–00.2, Table 3) compared to effects from private gardens (difference = 0.10–0.13, Table 3). Indeed, having a private garden substantially reduced predicted poor mental health for men (Fig. 1). We expected the effect of having a private garden on the probability of poor

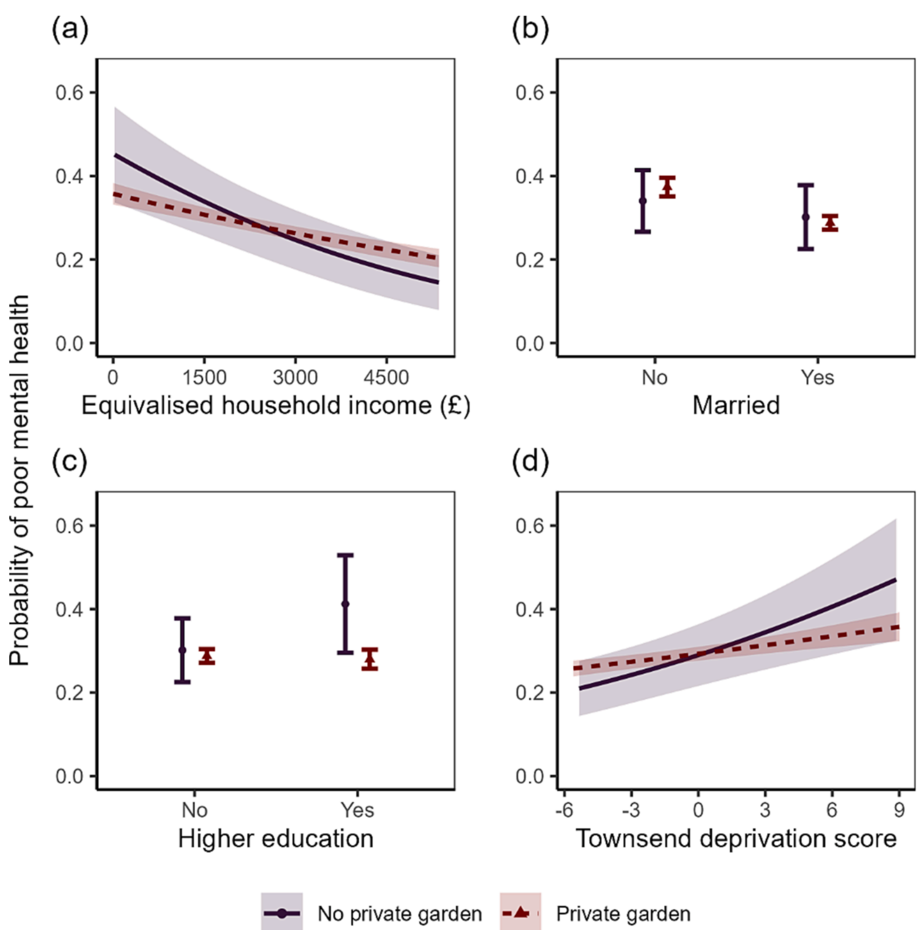

Fig. 2. The predicted probability of poor mental health averaged across the top-performing models (ΔAIC <6, see text) for individuals without (purple line, $n = 338$) and with (red line, $n = 4{,}454$) a private garden in relation to; (a) equivalised household income (£), (b) marital status (Yes/No), (c) higher education attainment (Yes/No), and (d) Area-level deprivation as measured by the Townsend deprivation score (-6 least deprived and 9 most deprived). For each graph, all other covariates were held at the median or mode of the combined samples (access to public greenspace, equivalised income = £2,126.31, married, no higher education, Townsend deprivation score = -0.78, age = 42.39, gender = women). Shaded region shows the standard error for the predicted interval.

mental health to be stronger for those without access to public greenspace – the predicted beneficial effect of private gardens were comparable for men with and without access to public greenspace (difference = 0.10–0.13, Table 3). Contrastingly, for women, we see some support for our hypothesised trend, where the difference between private garden owners and no private garden owners are 0.02 and 0.07 for women with and without access to public greenspace, respectively (Table 3). The relative protective effect of private gardens compared to public greenspaces supports findings from previous research into health deprivation (Dennis & James, 2017).

The stronger predicted effect of private gardens on mental health outcomes for men and older women without access to public greenspace has clear policy implications. Urban greenspace is typically planned using a recreational standards approach (Boulton et al., 2018), which ignores private gardens in their assessments and focuses on public spaces. For example, the focus in the United States (US) remains on the delivery of public greenspaces as opposed to private gardens, as evidenced by $150 million that will be distributed to local communities through the Outdoor Recreation Legacy Partnership grant program to create close to home outdoor recreation experiences (U.S. Department of the Interior, 2021). Similarly, in England, local authorities, are guided by the National Planning Policy Framework and the National Design Guide (Ministry of Housing Communities & Local Government, 2021a, 2021b) both of which focus on the provision of public and shared open spaces. The lack of policy around private gardens is particularly important as the average garden size is decreasing in many countries. In England, 12% of residential gardens were converted for residential use between 2017 and 2018 (Ministry of Housing, 2021). Similar patterns are apparent outside of Britain, in Germany, the average garden size has decreased from 450 m^2 in 1991 to 311 m^2 in 2015 (Petzke et al., 2021). Without changes to applicable guidance, the proportion and/or size of private gardens in urban areas is likely to decline with negative consequences on mental health. However, little is known about how strategies to promote private gardens will affect disadvantaged urban residents; such strategies could lead to the widening of social inequalities which have been observed in the past. For example, an increase in greenspace has been associated with an increase in house prices in Los Angeles, US (Conway et al., 2010), and Beijing, China (Wu et al., 2022).

Urban land is both a limited and expensive resource and with increased housing demands to accommodate growing urban populations, it is understandable why policies do not encourage the allocation of land to private domestic gardens. Furthermore, in the context of widening social inequalities and increased demand for land for urban development, it is unclear whether allocating more space for domestic gardens, as opposed to a "public good" will result in conflict between urban residents. In the UK, access to public greenspace is more evenly distributed than access to private gardens, and parks are deemed most accessible in the poorest areas (Office for National Statistics, 2020), so investment in public parks may be more effective in reducing socioeconomic inequalities. It is possible that shared gardens (i.e., a communal outdoor space that local residents are permitted to use) may offer a way to mitigate the trade-offs between the negative equity and space implications of increasing private gardens and their mental health benefits. Research into allotment or community gardening, where local residents grow fruit and vegetables for their own consumption, provides promising evidence of the beneficial effects of mental health within a shared space (Lampert et al., 2021). However, currently, there is little research into the effect of shared gardens on mental health and the security, privacy and agency of a person in a private garden may be an important dimension in the provision of mental health benefits (Cameron et al., 2012; de Bell et al., 2017). A small sample meant we were unable to explore the effect of a shared garden on the probability of poor mental health in this study; more research in this area should be a future priority. Attitudes to shared greenspaces (i.e., shared gardens, community gardens, or public greenspaces) may also vary between countries. Indeed, the predicted beneficial effects of private gardens observed in this study may not be generalizable beyond Britain. Future studies in other countries are needed to explore the potential effects of attitudes and culture on the relationship between public greenspace, access to private gardens, and mental health.

4.1. Limitations

While the data and the methodological approach enabled us to compare the effects of public greenspace access and garden ownership on mental health, our study has important limitations. First, statistical matching reduces sample sizes and subgroups that are already small are made smaller post-matching. The relatively small sample sizes of Black, Asian and Minority Ethnic respondents in the BHPS meant we were unable to account for an individual's ethnicity which, in Britain, is correlated with garden ownership (Office for National Statistics, 2020). Future research that adopts targeted sampling rather than representative sampling (Rothman et al., 2013) is required to untangle the potential confounding effects of ethnicity and access to a private garden.

Secondly, due to data availability, all greenspace has been treated equally; we do not consider differences in the quality of public greenspace, nor do we differentiate between garden types. As a result, an individual with a large garden with significant shrub cover is not distinguished from an individual with a small paved garden. By matching area-level characteristics, we have accounted for some characteristics that are used as indicators of greenspace quality in previous studies; e.g., bird species richness (Fuller et al., 2007; Taylor et al., 2018; Wheeler et al., 2015), NDVI (Cox et al., 2017; Taylor et al., 2018), and protected sites (Annerstedt et al., 2012; Wheeler et al., 2015). We recognise that these characteristics may not capture all meaningful characteristics of greenspace that are beneficial for mental health. For example, bird species richness may not be correlated with other important aspects of biodiversity for mental health such as plant species richness (Methorst et al., 2021). In addition, we have not accounted for other area-level characteristics including blue spaces (e.g., lakes, ponds, and coastal zones) which can be associated with improved mental health outcomes (McDougall et al., 2021; White et al., 2021).

Thirdly, access to greenspace has been measured at 800 m – the distance typically travelled in a ten-minute walk (Fields in Trust, 2020). From a planning perspective, this links to the increasingly popular 20-minute neighbourhoods concept (Emery & Thrift, 2021). However, there is limited research into the correct scale for access and we were unable to test alternative scales due to limitations in creating a balanced sample with statistical matching.

Finally, the GHQ-12 – our measure of poor mental health – was developed as a screening tool to identify mental disorders, which are only one aspect of mental health. As recommended we used a threshold of ≥ 3 to indicate poor mental health (Goldberg & Williams, 1988) and the corresponding distribution of GHQ-12 scores using the full 12-point scale is presented in Appendix B.6. Mental health is multi-faceted (World Health Organization, 2016) and by using a measure of mental distress we may not be adequately capturing positive dimensions of mental health such as happiness and life satisfaction. As a result, we may be underestimating the effect of public greenspace and private gardens on mental health.

5. Conclusion

Our findings have important implications for both future research and policy concerning greenspace and health. Future research that aims to quantify the impact of green infrastructures on health should distinguish among, and account for, access to multiple types of greenspace, both public and private. As we have shown here, the relative importance of private gardens and public greenspace access for mental health varies across the life course, and among men and women. Aggregating exposure to all types of greenspace and overlooking the relative contributions and interactive effects of individual level access may lead to incorrect inferences about the importance of greenspace to mental health. However, given space restrictions for future developments to provide both public greenspace and private gardens more research is needed to inform what characteristics of these spaces are beneficial for mental health. For example, what are the relative importance of garden size, species composition and diversity, and canopy cover? Do lawns with artificial grass deliver similar benefits for mental health as natural vegetation? Such characteristics can therefore be prioritised in the design of urban greenspace (both public and private gardens) to maximise mental health benefits.

From a policy perspective, our study has highlighted the importance of access to private gardens (particularly for men) and public greenspace (for women) for lowering the predicted risk of poor mental health. Therefore, current policy guidance needs to be amended to not just focus on a recreational standards approach that favours the delivery of public greenspaces, but instead develop strategies that balance the provision of urban private gardens and public greenspaces and target areas without access. While challenging without exacerbating socio-demographic inequalities, it is vital to ensure equitable access to both public and private green spaces to deliver improved mental health outcomes for growing urban populations.

Author contributions

R.M.C. conceived the research question; R.M.C. and R.S. designed the analysis; R.M.C. performed the analysis; all authors interpreted the results and contributed to the writing of the paper.

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.

Data availability

The data that has been used is confidential.

Acknowledgements

Supported by a scholarship (awarded to R.M.C.) co-funded by the University of Southampton and the ERC Starting Grant 'SCALEFORES' (grant no. 680176) awarded to F.E.

References

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal effects on mental health of moving to greener and less green urban areas. *Environmental Science & Technology, 48*, 1247–1255. https://doi.org/10.1021/es403688w

Allen, J., Balfour, R., Bell, R., Marmot, M., World Health Organization, & Calouste Gulbenkian Foundation. (2014). Social determinants of mental health. *International Review of Psychiatry, 26*, 392–407. https://doi.org/10.3109/09540261.2014.928270

Annerstedt, M., Östergren, P.-O.-O., Björk, J., Grahn, P., Skärbäck, E., & Währborg, P. (2012). Green qualities in the neighbourhood and mental health – results from a longitudinal cohort study in Southern Sweden. *BMC Public Health, 12*, 337. https://doi.org/10.1186/1471-2458-12-337

Astell-Burt, T., Mitchell, R., & Hartig, T. (2014). The association between green space and mental health varies across the lifecourse. A longitudinal study. *Journal of Epidemiology and Community Health, 68*, 578–583. https://doi.org/10.1136/jech-2013-203767

Boulton, C., Dedekorkut-Howes, A., & Byrne, J. (2018). Factors shaping urban greenspace provision: A systematic review of the literature. *Landscape and Urban Planning, 178*, 82–101. https://doi.org/10.1016/J.LANDURBPLAN.2018.05.029

Burnham, K. P., Anderson, D. R., & Huyvaert, K. P. (2011). AIC model selection and multimodel inference in behavioral ecology: Some background, observations, and comparisons. *Behavioral Ecology and Sociobiology, 65*, 23–35. https://doi.org/10.1007/s00265-010-1029-6

Cade, B. S. (2015). Model averaging and muddled multimodel inferences. *Ecology, 96*, 2370–2382. https://doi.org/10.1890/14-1639.1

Cameron, R. W., Blanuša, T., Taylor, J. E., Salisbury, A., Halstead, A. J., Henricot, B., & Thompson, K. (2012). The domestic garden–Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening, 11*, 129–137.

Clatworthy, J., Hinds, J., & Camic, P. M. (2013). Gardening as a mental health intervention: A review. *Mental Health Review Journal, 18*, 214–225. https://doi.org/10.1108/MHRJ-02-2013-0007

Collins, R. M., Spake, R., Brown, K. A., Ogutu, B. O., Smith, D., & Eigenbrod, F. (2020). A systematic map of research exploring the effect of greenspace on mental health. *Landscape and Urban Planning, 201*, Article 103823. https://doi.org/10.1016/j.landurbplan.2020.103823

Conway, D., Li, C. Q., Wolch, J., Kahle, C., & Jerrett, M. (2010). A spatial autocorrelation approach for examining the effects of urban greenspace on residential property values. *Journal of Real Estate Finance and Economics, 41*, 150–169. https://doi.org/10.1007/S11146-008-9159-6

Corley, J., Okely, J. A., Taylor, A. M., Page, D., Welstead, M., Skarabela, B., … Russ, T. C. (2021). Home garden use during COVID-19: Associations with physical and mental wellbeing in older adults. *Journal of Environmental Psychology, 73*, Article 101545. https://doi.org/10.1016/j.jenvp.2020.101545

Cox, D. T. C., Shanahan, D. F., Hudson, H. L., Fuller, R. A., Anderson, K., Hancock, S., & Gaston, K. J. (2017). Doses of nearby nature simultaneously associated with multiple health benefits. *International Journal of Environmental Research and Public Health, 14*, 172. https://doi.org/10.3390/ijerph14020172

de Bell, S., Graham, H., Jarvis, S., & White, P. (2017). The importance of nature in mediating social and psychological benefits associated with visits to freshwater blue space. *Landscape and Urban Planning, 167*, 118–127. https://doi.org/10.1016/j.landurbplan.2017.06.003

de Bell, S., White, M., Griffiths, A., Darlow, A., Taylor, T., Wheeler, B., & Lovell, R. (2020). Spending time in the garden is positively associated with health and wellbeing: Results from a national survey in England. *Landscape and Urban Planning, 200*, Article 103836. https://doi.org/10.1016/j.landurbplan.2020.103836

Dennis, M., & James, P. (2017). Evaluating the relative influence on population health of domestic gardens and green space along a rural-urban gradient. *Landscape and Urban Planning, 157*, 343–351. https://doi.org/10.1016/J.LANDURBPLAN.2016.08.009

Department for Environmental Food & Rural Affairs. (2017). *Strategic noise mapping, 2017*. [WWW Document]. URL https://uk-air.defra.gov.uk/library/annualreport/assets/documents/annualreport/air_pollution_uk_2017_Compliance_Assessment_Summary_Issue1.pdf (accessed 24.08.2021).

Emery, T., & Thrift, J. (2021). *20-Minute Neighbourhoods-Creating Healthier, Active, Prosperous Communities An Introduction for Council Planners in England* [WWW Document]. URL https://www.tcpa.org.uk/Handlers/Download.ashx?IDMF=f214c4b8-ba4d-4196-9870-e9d240f86645 (accessed 24.09.2021).

European Environment Agency. (2019). *CDDA dataset*. [WWW Document]. URL https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-15/cdda (accessed 12.06.2022).

Fields in Trust. (2020). CHAMPION: The ten-minute walk and why it's important [WWW Document] accessed 8.24.21 https://www.fieldsintrust.org/News/the-ten-minute-walk-and-why-its-important.

Fjaestad, S. L., Mackelprang, J. L., Sugiyama, T., Chandrabose, M., Owen, N., Turrell, G., & Kingsley, J. (2023). Associations of time spent gardening with mental wellbeing and life satisfaction in mid-to-late adulthood. *Journal of Environmental Psychology, 87*, Article 101993. https://doi.org/10.1016/j.jenvp.2023.101993

Fox, J. (2015). *Applied Regression Analysis and Generalized Linear Models* (3rd ed.). Los Angeles: SAGE.

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

Gaston, K. J., Soga, M., Duffy, J. P., Garrett, J. K., Gaston, S., & Cox, D. T. C. (2018). Personalised Ecology. *Trends in Ecology & Evolution, 33*, 916–925. https://doi.org/10.1016/j.tree.2018.09.012

Gaston, K. J., Warren, P. H., Thompson, K., & Smith, R. M. (2005). Urban domestic gardens (IV): The extent of the resource and its associated features. *Biodiversity and Conservation, 14*, 2227–3349. https://doi.org/10.1007/s10531-004-9513-9

Gillings, S., Balmer, D. E., Caffrey, B. J., Downie, I. S., Gibbons, D. W., Lack, P. C., … Fuller, R. J. (2019). Breeding and wintering bird distributions in Britain and Ireland from citizen science bird atlases. *Global Ecology and Biogeography, 28*, 866–874. https://doi.org/10.1111/geb.12906

Goldberg, D. P., & Williams, P. (1988). *The user's guide to the general health questionnaire* (1st ed.). United Kingdom: Windsor.

Goldberg, D. P., Gater, R., Sartorius, N., Ustun, T. B., Piccinelli, M., Gureje, O., & Rutter, C. (1997). The validity of two versions of the GHQ in the WHO study of mental illness in general health care. *Psychological Medicine, 27*, 191–197. https://doi.org/10.1017/S0033291796004242

Goldberg, D. P., & Hillier, V. F. (1979). A scaled version of the General Health Questionnaire. *Psychological Medicine, 9*, 139–145. https://doi.org/10.1017/S0033291700021644

Hankins, M. (2008). The factor structure of the twelve item General Health Questionnaire (GHQ-12): The result of negative phrasing? *Clin. Pract. Epidemiol. Ment. Heal., 4*, 10. https://doi.org/10.1186/1745-0179-4-10
Harrison, X. A., Donaldson, L., Correa-Cano, M. E., Evans, J., Fisher, D. N., Goodwin, C. E. D., … Inger, R. (2018). A brief introduction to mixed effects modelling and multi-model inference in ecology. *PeerJ, 6*, e4794.
Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health, 35*, 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443
Hartig, F. (2018). *DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models*. R Package version 0.4.1 [WWW Document]. URL https://cran.r-project.org/package=DHARMa (accessed 03.07.2022).
Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2011). MatchIt: Nonparametric preprocessing for parametric causal inference. *Journal of Statistical Software, 42*. https://doi.org/10.18637/jss.v042.i08
Houlden, V., Porto de Albuquerque, J., Weich, S., & Jarvis, S. (2019). A spatial analysis of proximate greenspace and mental wellbeing in London. *Applied Geography, 109*, Article 102036. https://doi.org/10.1016/J.APGEOG.2019.102036
Houlden, V., Weich, S., de Albuquerque, J. P., Jarvis, S., & Rees, K. (2018). The relationship between greenspace and the mental wellbeing of adults: A systematic review. *PLoS One1, 13*, e0203000.
Howarth, M., Brettle, A., Hardman, M., & Maden, M. (2020). What is the evidence for the impact of gardens and gardening on health and well-being: A scoping review and evidence-based logic model to guide healthcare strategy decision making on the use of gardening approaches as a social prescription. *BMJ Open, 10*, e036923.
Bartoń, K. (2020). R Package version 1.43.17 [WWW Document].(accessed 2022 *MuMIn: Multi-Model Inference., 03*, 07 https://cran.r-project.org/package=MuMIn.
Kaplan, S., & Talbot, J. F. (1983). Psychological benefits of a wilderness experience. In *Behavior and the Natural Environment* (pp. 163–203). Boston: Springer.
Lampert, T., Costa, J., Santos, O., Sousa, J., Ribeiro, T., & Freire, E. (2021). Evidence on the contribution of community gardens to promote physical and mental health and well-being of non-institutionalized individuals: A systematic review. *PLoS One1, 16*, e0255621.
Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Heal. Place., 15*, 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006
Marselle, M. R., Warber, S. L., & Irvine, K. N. (2019). Growing resilience through interaction with nature: Can group walks in nature buffer the effects of stressful life events on mental health? *International Journal of Environmental Research and Public Health, 16*, 986. https://doi.org/10.3390/ijerph16060986
McDougall, C. W., Hanley, N., Quilliam, R. S., Bartie, P. J., Robertson, T., Griffiths, M., & Oliver, D. M. (2021). Neighbourhood blue space and mental health: A nationwide ecological study of antidepressant medication prescribed to older adults. *Landscape and Urban Planning, 214*, Article 104132. https://doi.org/10.1016/j.landurbplan.2021.104132
McEachan, R. R. C., Prady, S. L., Smith, G., Fairley, L., Cabieses, B., Gidlow, C., … Nieuwenhuijsen, M. J. (2016). The association between green space and depressive symptoms in pregnant women: Moderating roles of socioeconomic status and physical activity. *J. Epidemiology Community Health., 1*, 253–259. https://doi.org/10.1136/jech-2015-205954
Methorst, J., Bonn, A., Marselle, M., Böhning-Gaese, K., & Rehdanz, K. (2021). Species richness is positively related to mental health–a study for Germany. *Landscape and Urban Planning, 211*, Article 104084. https://doi.org/10.1016/j.landurbplan.2021.104084
Nagelkerke, N. J. D. (1991). A note on a general definition of the coefficient of determination. *Biometrika, 78*, 691–692. https://doi.org/10.1093/biomet/78.3.691
Ministry of Housing Communities & Local Government. Land Use Change Statistics in England: 2017-18. Land Use Change Statistical Release [WWW Document]. URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005759/NPPF_July_2021.pdf (accessed 30.09.2021).
Ministry of Housing Communities & Local Government. (2021a). National Design Guide [WWW Document] accessed 30.09.2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962113/National_design_guide.pdf.
Ministry of Housing Communities & Local Government. (2021b). National Planning Policy Framework [WWW Document] accessed 30.09.2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005759/NPPF_July_2021.pdf.
Montgomery, J. M., Nyhan, B., & Torres, M. (2018). How Conditioning on Posttreatment Variables Can Ruin Your Experiment and What to Do about It. *Am. J. Pol. Sci., 62*, 760–775. https://doi.org/10.1111/ajps.12357
O'Gorman, S., & Dillon-Robinson, R. (2021). 20 Minute Neighbourhoods in a Scottish Context. *Edinburgh*. https://doi.org/10.7488/era/808
Office for National Statistics. (2020). One in eight British households has no garden [WWW Document] accessed 03.08.2022 https://www.ons.gov.uk/economy/environmentalaccounts/articles/oneineightbritishhouseholdshasnogarden/2020-05-14.
Office for National Statistics. (2017). Rural Urban Classification (2001) of LSOAs in England and Wales [WWW Document] accessed 03.08.2022 https://ons.maps.arcgis.com/home/item.html?id=8b5cca720a044bee8559628c52d0a806.
Ordnance Survey. (2017). OS MasterMap Greenspace Layer Technical Specification [WWW Document] accessed 09.09.2022 https://www.ordnancesurvey.co.uk/documents/osmm-greenspace-layer-technical-specification.pdf.
Petzke, N., König, B., & Bokelmann, W. (2021). Plant protection in private gardens in Germany: Between growing environmental awareness, knowledge and actual behaviour. *European Journal of Horticultural Science, 86*, 59–68. https://doi.org/10.17660/eJHS.2021/86.1.7
Phillips, B. B., Bullock, J. M., Osborne, J. L., & Gaston, K. J. (2021). Spatial extent of road pollution: A national analysis. *The Science of the Total Environment, 773*, Article 145589. https://doi.org/10.1016/j.scitotenv.2021.145589
Riva, M., & Smith, D. M. (2012). Generating small-area prevalence of psychological distress and alcohol consumption: Validation of a spatial microsimulation method. *Social Psychiatry and Psychiatric Epidemiology, 47*, 745–755. https://doi.org/10.1007/s00127-011-0376-6
Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*. https://doi.org/10.1093/biomet/70.1.41
Rothman, K. J., Gallacher, J. E. J., & Hatch, E. E. (2013). Why representativeness should be avoided. *International Journal of Epidemiology, 42*, 1012. https://doi.org/10.1093/IJE/DYS223
Schleicher, J., Eklund, J., Barnes, D. M., Geldmann, J., Oldekop, J. A., & Jones, J. P. G. (2020). Statistical matching for conservation science. *Conservation Biology, 34*, 538–549. https://doi.org/10.1111/cobi.13448
Scotland's Environment. (2017). Round 3 noise exposure statistics reported to Europe [WWW Document] accessed 03.07.2022 https://noise.environment.gov.scot/.
Shelton, N. J., & Herrick, K. G. (2009). Comparison of scoring methods and thresholds of the General Health Questionnaire-12 with the Edinburgh Postnatal Depression Scale in English women. *Public Health, 123*, 789–793. https://doi.org/10.1016/j.puhe.2009.09.012
Soga, M., Gaston, K. J., & Yamaura, Y. (2017). Gardening is beneficial for health: A meta analysis. *Preventive Medical Reports, 5*, 92–99. https://doi.org/10.1016/j.pmedr.2016.11.007
Spake, R., Bowler, D. E., Callaghan, C. T., Blowes, S. A., Doncaster, C. P., Antao, L. H., … Chase, J. M. (2023). Understanding 'it depends' in ecology: A guide to hypothesising, visualising and interpreting statistical interactions. *Biological Reviews, 2023*. https://doi.org/10.1111/brv.12939
Stuart, E. A. (2010). Matching methods for causal inference: A review and a look forward. *Statistical Science, 25*, 1–21. https://doi.org/10.1214/09-STS313
Sullivan, W. C., Kuo, F. E., & Depooter, S. F. (2004). The fruit of urban nature: Vital neighborhood spaces. *Environment and Behavior, 36*, 678–700. https://doi.org/10.1177/0193841X04264945
Taylor, L., Hahs, A. K., & Hochuli, D. F. (2018). Wellbeing and urban living: Nurtured by nature. *Urban Ecosystem, 21*, 197–208. https://doi.org/10.1007/s11252-017-0702-1
Taylor, L., & Hochuli, D. F. (2017). Defining greenspace: Multiple uses across multiple disciplines. *Landscape and Urban Planning, 158*, 25–38. https://doi.org/10.1016/j.landurbplan.2016.09.024
U.S. Department of the Interior. (2021). Secretary Haaland Announces $150 Million to Create Public Parks, Expand Recreation Opportunities in Urban Areas | U.S. Department of the Interior [WWW Document]. URL https://www.doi.gov/pressreleases/secretary-haaland-announces-150-million-create-public-parks-expand-recreation (accessed 3.17.22).
UK Data Service. (2017). 2011 UK Townsend Deprivation Scores [WWW Document] accessed 03.08.2022 https://www.statistics.digitalresources.jisc.ac.uk/dataset/2011-uk-townsend-deprivation-scores.
Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. In *Behavior and the Natural Environment* (pp. 85–125). Boston: Springer.
United Nations. (2018). World Urbanization Prospects: The 2018 Revision, Department of Economic and Social Affairs [WWW Document] accessed 03.07.2021 https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf.
United States Geological Survey. (2017). Landsat 8 [WWW Document] accessed 2.18.20 https://www.usgs.gov/land-resources/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con.
University of Essex, 2018. British Household Panel Survey: Waves 1-18, 1991-2009 [Data Collection]. 8th Edition. UK Data Service. DOI: 10.5255/UKDA-SN-5151-2.
Victoria State Government Department of Environment, L., 2021. 20-minute neighbourhoods [WWW Document]. URL https://www.planning.vic.gov.au/policy-and-strategy/planning-for-melbourne/plan-melbourne/20-minute-neighbourhoods (accessed 8.24.21).
Ward Thompson, C., Aspinall, P., Roe, J., Robertson, L., & Miller, D. (2016). Mitigating stress and supporting health in deprived urban communities: The importance of green space and the social environment. *International Journal of Environmental Research and Public Health, 13*, 440. https://doi.org/10.3390/ijerph13040440
Weich, S., Twigg, L. I. Z., & Lewis, G. (2006). Rural/non-rural differences in rates of common mental disorders in Britain: Prospective multilevel cohort study. *The British Journal of Psychiatry, 188*, 51–57. https://doi.org/10.1192/bjp.bp.105.008714
Welsh Government. (2017). Environmental Noise Mapping 2017 [WWW Document] accessed 03.08.2021 https://lle.gov.wales/catalogue/item/EnvironmentalNoiseMapping2017/?lang=en.
Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., … Depledge, M. H. (2015). Beyond greenspace: An ecological study of population

general health and indicators of natural environment type and quality. *International Journal of Health Geographics, 14*, 1–17. https://doi.org/10.1186/s12942-015-0009-5

White, M. P., Alcock, I., Wheeler, B. W., & Depledge, M. H. (2013). Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data. *Psychological Science, 24*, 920–928. https://doi.org/10.1177/0956797612464659

White, M. P., Pahl, S., Wheeler, B. W., Depledge, M. H., & Fleming, L. E. (2017). Natural environments and subjective wellbeing: Different types of exposure are associated with different aspects of wellbeing. *Heal. Place., 45*, 77–84. https://doi.org/10.1016/j.healthplace.2017.03.008

White, M. P., Elliott, L. R., Grellier, J., Economou, T., Bell, S., Bratman, G. N., … Nieuwenhuijsen, M. (2021). Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports, 11*, 8903. https://doi.org/10.1038/s41598-021-87675-0

Met Office. (2020). UKCP09: Met Office gridded land surface climate observations - long term averages at 5km resolution [WWW Document] accessed 03.07.2022. http://data.ceda.ac.uk/badc/ukcp09/data/gridded-land-obs/gridded-land-obs-averages-5km/grid/ascii/sunshine.

Woodland Trust, 2020. Ancient Tree Inventory GB and NI. [WWW Document]. URL https://ati.woodlandtrust.org.uk/ (accessed 03.08.2022).

World Health Organization. (2016). *Urban green spaces and health: A review of the evidence*. Copenhagen: WHO Regional Office for Europe.

Wu, L., & Rowe, G. P. (2022). Green space progress or paradox: Identifying green space associated gentrification in Beijing. *Landscape and Urban Planning, 219*, Article 104321. https://doi.org/10.1016/J.LANDURBPLAN.2021.104321