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Review

Is biodiversity of greenspace important for human health and wellbeing? A bibliometric analysis and systematic literature review

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ABSTRACT

Global urbanisation has consequences for human health and relationships with the natural environment. While urban greenspaces are theorised to support health and wellbeing, the role of biodiversity as a mechanism supporting this process is yet to be fully quantified. This review aimed to evaluate existing evidence for a relationship between biodiversity of greenspace and human health and wellbeing, including both self-reported and clinical outcomes. We conducted a systematic database search, thorough article screening and quality assessment, conducting a review of five previous reviews and narrative synthesis of the ten recent studies meeting our inclusion criteria. We also performed a bibliometric analysis of 1,758 studies to chart geographical and temporal trends on the topic. Results revealed that few reviews have holistically analysed the evidence for a relationship between biodiversity in greenspaces and human health directly, finding mixed, or weak evidence for a relationship between biodiversity and various aspects of physical and mental health. Our narrative review discovered evidence supporting associations between health and floral biodiversity, particularly subjective wellbeing and self-reported health, with mixed evidence for other health outcomes or more holistic measures of biodiversity. Consistently defined terminology and integrated methods are required for further research to understand long-term health impacts of exposure to biodiversity through larger-scale longitudinal and controlled case-studies.

1. Introduction

Rapid urbanisation presents a global challenge to support densely populated settlements, which exacerbate pressure on infrastructural, cultural, and natural resources (Montgomery, 2013; Ritchie and Roser, 2019). Human development and subsequent effects on climate change lead to altered living environments and lifestyles, where expanding cities, and their residents, have inequitable access to nature, particularly in areas of greater deprivation, where both public and private greenspaces are less available (Public Health England, 2020). At the same time, society is developing an increasing understanding of the prevalence of non-communicable diseases and, more specifically, the pervasiveness of mental health inequalities, particularly in urban areas (towns and cities) in which 60 % of the world's population now reside (Ritchie and Roser, 2019; Gruebner et al., 2017). This may be due, in part, to differences in living environments; while urban areas generally provide a wealth of opportunities and amenities, they also tend to be more noisy, deprived and polluted, as well as having lower levels of employment and access to green areas (McLennan et al., 2019). International efforts to support future social and economic prosperity, such as through the United Nations' Sustainable Development Goals (SDGs), have included a focus on reduced inequalities (Goal 10), promoting health and wellbeing (Goal 3), resilient infrastructure (Goal 9), and accessible urban greenspaces (Goal 11) (Assembly, 2015).

Nature, defined here as 'physical features and processes of non-human origin' (Hartig et al., 2014), and thus natural environments, provide a range of societal benefits, known as ecosystem services, spanning: physical *provisioning* of goods, such as food and raw materials, *regulating* of pollution, water and climate systems, *supporting* vital processes including nutrient cycling, pollination and habitat formation, and

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cultural human services comprising scientific, spiritual, recreational and therapeutic interactions (Oosterbroek et al., 2016; Assessment, 2005). Moreover, these *cultural* services may be especially important for individual health and wellbeing. The theory of *Biophilia* postulates that humans tend to feel most at home and best able to flourish in environments which mimic those natural spaces in which the species evolved (Wilson, 2017, 1984), although some authors suggest that holistic inclusion of biophilic design within the built environment is a challenging practice. Therefore, incorporating designated natural areas as *greenspaces* in cities may help societies overcome the stressors of modern urban living.

An expanding body of evidence highlights the relationship between nature, or urban greenspace, and health. The World Health Organization defines 'health' as: *"a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity"* (World Health Organization, 2017, A3, p5). Wellbeing here reflects an individual's subjective assessment of their own health, and what is valuable to and good for them. The recent growth of research interest into greenspace and a variety of health outcomes (therefore here considered as comprising physical illness, health behaviours, mental illness and positive mental wellbeing) has predominantly focused on the amount of greenspace (areas of grass, trees, or other vegetation, including urban parks, nature reserves and other amenity spaces) in an individual's local environment (Houlden et al., 2018; Gascon et al., 2015; Public Health England, 2020). In this review, we focus on all urban greenspace, both public and private. While evidence in the field is expanding, there is currently much less understanding around the importance of the qualities and features of such greenspaces, or consensus regarding the mechanisms through which these might operate.

Exposure to nature, through greenspaces in urban environments, may improve general *wellbeing* through restoring fatigued attention, reducing stress and promoting positive feelings, facilitating salutogenic activities such as social interactions and physical activities, while ecosystem services more broadly support a healthy, liveable environment (Lachowycz and Jones, 2013; Hartig et al., 2014). Biodiversity (defined as variety of flora and/or fauna) is additionally a mechanism through which natural spaces may provide ecosystem services, particularly the cultural services which also support human health and wellbeing (Aerts et al., 2018). Conversely, some greenspaces might have negative effects, if they are too isolated, dense, unkempt or poorly lit, which may elicit stress responses, present physical hazards, or encourage undesirable activities, such as drug dealing and gang meetings (Gatersleben and Andrews, 2013; Jacobs, 2016). Jacobs argues, therefore, that greenspaces must be well-designed to encourage visitor flow and societally beneficial use.

Context and composition are therefore important, as relationships between urban greenspaces and health may further differ according to gender, life stage, and individual socio-economic status, while local cultural, infrastructure and societal facets may influence both interactions and subsequent benefits (Lachowycz and Jones, 2013). The World Health Organization's (WHO) Review of Urban Green Space Interventions and Health, for example, concluded that 'urban green space can deliver positive health, social and environmental outcomes for all population groups, particularly among lower socioeconomic status groups' (World Health Organization, 2017, p5).

The *biodiversity hypothesis* proposes that more *biodiverse* environments can further promote healthy immune systems, through exposure to diverse microbiomes (Rook, 2013). Due to human activities, including population growth and urbanisation, nature loss in city greenspaces reduces biodiversity of both the environment and human microbiota, which, in turn, contributes to immune dysfunction, inflammation, and poorer health outcomes. This may have particular consequences for allergy and disease (Haahtela et al., 2013), with other reviews suggesting that early childhood exposure to biodiversity may reduce the risk of developing allergies (Kaesler et al., 2018). More directly, the *dilution hypothesis* postulates that higher species richness reduces the spread of infection, as pathogens are *diluted* amongst a greater range of vectors, and thus transmission between organisms is likely to be reduced, which has evident implications for human health (Schmidt and Ostfeld, 2001). Together, these hypotheses imply that urban greenspace with greater biodiversity may be a valuable asset to support human health.

However, it is not yet known whether the biodiversity of urban greenspaces is a main mechanism through which such associations may operate, as measures of both biodiversity and health vary widely across the literature (Aerts et al., 2018). While some previous reviews have begun to examine the evidence for a relationship between biodiversity and health, where most consider biodiversity as a subset or alternative to 'greenspace', or interchangeably with the concept of 'nature', there is a dearth of quality assessment and systematic protocols within the topic (Lai et al., 2019; Jorgensen and Gobster, 2010). Other non-academic reviews, for example by DEFRA (UK Government's Department for Environment Food and Rural Affairs), advocates that biodiversity is 'critical' for ecosystem function and the delivery of both goods and services which are necessary to support the health and wellbeing of human society (Maxwell and Lovell, 2017; Lovell et al., 2018), while the WHO's evidence review summarised 'promising evidence' for urban greening to improve biodiversity may promote health (World Health Organization, 2017).

The purpose of this review is to identify and evaluate existing literature on the relationship between biodiversity of urban greenspaces and human health. The procedure utilises a systematic search strategy and strict inclusion criteria to identify the most relevant publications. We perform a bibliometric analysis to evaluate the evolution of the field over recent decades. We then conduct a review of reviews to aggregate evidence across the sub-dimensions of these relationships and conduct a quality assessment and narrative review of the original research conducted since the most recent systematic review, to ensure holistic coverage of these findings.

2. Materials and methods

2.1. Search strategy

We followed guidance for Cochrane-standard systematic reviews, which are designed to ensure the highest level of evidence for reporting of health-related studies, through a methodological system of reporting, assessing quality, and summarising findings (please see https://consumers.cochrane.org/cochrane-and-systematic-reviews for further information). Following this guidance, we first developed a search strategy to identify papers related to the keywords, 'biodiversity', 'greenspace' and 'health' (Higgins et al., 2019), to answer the review question '*what is the state of evidence for a relationship between biodiversity of urban greenspace and human health?*'. The strategy was trialled and refined using a search of Web of Science, to ensure it identified the expected studies. The following databases were searched: Web of Science, Elsevier's Scopus, National Library of Medicine (PubMED) and ProQuest. Following a trial in each database, using common synonyms and keywords relating to the main themes, a final set of search terms was refined; the full search criteria are displayed in Table 1. Searches were restricted to those

Table 1
Strategy for bibliographic search. The asterisk (*) refers to a wildcard, where the search will include any extensions of the word, e.g.: Green* will return Green, Greenspace, Greening, etc.

Keyword	Biodiversity	Greenspace	Health
Search Terms	Biodivers*	Green* Park* Blue*	Health*
Location	Title, Abstract, Keywords	Title, Abstract, Keywords	Title, Abstract, Keywords

available in English and relating to research in humans, covering any time period. Searches were run between 26/02/2020 and 02/04/2020.

2.2. Bibliometric analysis

To quantify the evolution of academic interest in the field, we undertook a bibliometric analysis of all records retrieved from Scopus and Web of Science; this was restricted to these two databases due to software compatibility. Using the *bibliometrix* package in R, we descriptively analysed recent thematic, temporal and geographic trends, based on the indexed titles, keywords, locations and citations from these databases (The R Foundation for Statistical Computing, 2014). We focus specifically on the number of publications per year and historic themes in research relating to biodiversity and health.

2.3. Study eligibility criteria

All articles recovered from initial searches were recorded in EndNote, and duplicates removed (The EndNote Team, 2013). Titles and Abstracts were screened for potential relevance by two reviewers independently (Author2 and Author1), and full texts of shortlisted studies retrieved for formal inclusion/exclusion. Any disputed or unclear studies were cautiously retained for full text evaluation.

Criteria for inclusion were also decided in line with Cochrane recommendations, using the *PICOS* format (Higgins et al., 2019). Studies must meet the following, in order to be included: (a) *Population*: human adults over 13, or all age groups (but not studies only including children); (b) *Intervention/Exposure*: must include a measure of biodiversity, or individuals' perceptions of biodiversity, in a green or natural environment; (c) *Control/Comparison Measures*: studies should feature comparisons of more and less biodiverse environments; (d) *Outcome*: any measure of physical or mental health or wellbeing, subjective or objective; studies of emotions were also included; (e) *Study designs*: no study designs were initially excluded, both original research and extant relevant reviews were considered separately, although reports must be available in English. See Table 2 for details of exclusion criteria and example studies that were deemed as 'Irrelevant' for the current study.

After identifying eligible papers, one reviewer (Author1) evaluated study contents by extracting: authors, publication date, country, study design, participants and data collection, biodiversity measures, health outcomes, controls, analysis results and effect sizes. To update previous reviews, a 'review of reviews' was then conducted, followed by a narrative synthesis of original published research from 2018 onwards.

2.4. Quality assessment

The quality of all included studies was analysed using the Cochrane-recommended criteria (Higgins et al., 2019). For cross-sectional studies, the Newcastle-Ottawa Scale (NOS) evaluates three domains: Selection (sample representativeness, survey response, out of 5), Comparability (between different exposures, out of 2) and Outcomes (assessment, out of 3): Good quality studies score at least 3, 1 and 2, respectively, while Fair studies score 2, 1 and 2, and Poor studies rated as 1 or less for each category (Peterson et al., 2011). For example, a highest-quality study would ensure a justified sample representative of the target population, with validated measurement of both biodiversity and health. The study must also control for relevant, potentially confounding factors, and health outcomes must be analysed rigorously and with statistical soundness (Peterson et al., 2011)

The Cochrane Risk-of-Bias (RoB) tool was applied to the three controlled-case studies, assessing potential bias arising from assignment, participant awareness, controlled conditions, and reporting (Higgins et al., 2011). Good quality studies have low risk of bias across all domains, Fair quality have some risk in up to two areas, and Poor quality have high risk in more than one area. For example, studies with a higher risk of bias may have non-random allocation to, or participant awareness of, assignment groups. Missing control or outcome data, as well as non-objective outcome measurement or selective reporting of results, may also signal higher risk of bias (Higgins et al., 2011).

Table 2
Inclusion and Exclusion Criteria.

Exclusion Criteria	Example of Excluded Publication
Studies not of humans	(Farrell et al., 2019)
Studies relating only to children (Studies of *all* age groups were included)	(Soga et al., 2018)
Studies not measuring biodiversity or perceptions of biodiversity	(Nath et al., 2018)
Studies not including a heath outcome	(Ofori et al., 2018)
Studies not presenting original research	(Tzoulas et al., 2007)
Studies not available in English	*Included as search criteria*

3. Results

Initial searches of Topics (which includes Titles, Abstracts and Journal-indexed Keywords) retrieved 2,895 results; after removing duplicates, this was reduced to 1,758.

3.1. Bibliometric analysis

The number of publications per year, on the topic of biodiversity and health, reveal an exponential increase, and a particular leap since 2014. Prior to this, there were consistently fewer than 100 new articles per annum, with no more than 50 before 2007; in 2019, there were over 250 articles, which demonstrates a growing research interest in the field (Fig. 1), although the absolute number of publications is still relatively small. The bibliometric analyses were concerned with charting the evolution of interest in both biodiversity and health literature, particularly the popularity of these terms, and so all returned publications were retained at this stage.

Charting the geographic distribution of these publications since 1990 reveals a strong bias in favour of Western countries, specifically the USA and the UK; this is reflective of patterns observed more broadly in the field. The USA published a considerably greater numbers of relevant articles, over 270, compared to the second most populous of 160 from the UK. Of the ten most productive nations, four are in Europe, two in North America, two in Asia, and just one in each of Oceania and South America; Africa was not represented in the most common locations. Inter-country collaborations were also proportionally higher in Europe, notably the UK, Italy, France and Germany (Fig. 2).

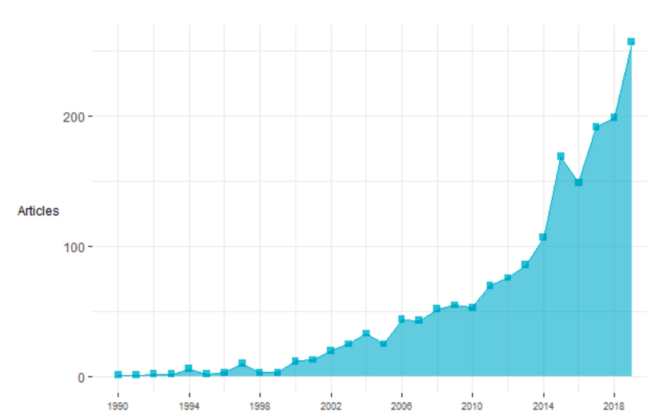

Fig. 1. Publication frequency by year.

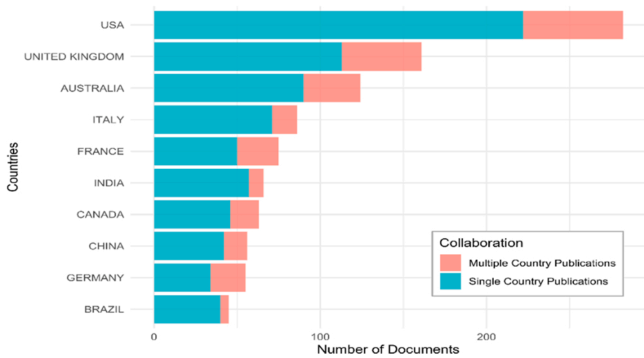

Fig. 2. Geographic distribution of publications.

3.2. *Review findings*

After aggregating articles from all databases, titles and abstracts were screened for obvious irrelevance, leaving 63 research articles for full-text evaluation. The final sample included 17 original studies, 10 of which were published since 2018 (Fig. 3).

In addition, there were 35 reviews obtained from the initial searches; 16 of these were general literature reviews without any systematic approach to searching or aggregating results, although 18 applied a systematic search strategy and only one was found to be a full systematic review including quality assessment of included studies. Of the five relevant reviews, two focussed on greenspace and health (Jorgensen and Gobster, 2010; Lai et al., 2019), one on biodiverse environments and health (Lovell et al., 2014), one on urban biodiversity and mental health (Dean et al., 2011), and the most relevant to our research, from 2018, targeted greenspace, biodiversity and aspects of both physical and mental health (Aerts et al., 2018); all reviews were published between the years of 2010 and 2019.

3.2.1. *Review of reviews*

We found five reviews considering biodiverse environments and health (Jorgensen and Gobster, 2010; Lovell et al., 2014; Aerts et al., 2018; Lai et al., 2019; Dean et al., 2011), which all searched with systematic terms, but only one that implemented a fully systematic approach to selecting relevant studies, alongside a quality assessment tool (Lovell et al., 2014). Of these, only the works by Aerts et al. and Lovell et al. focussed their searches specifically on biodiversity and health; others included studies of either greenspace *or* biodiversity (Lai

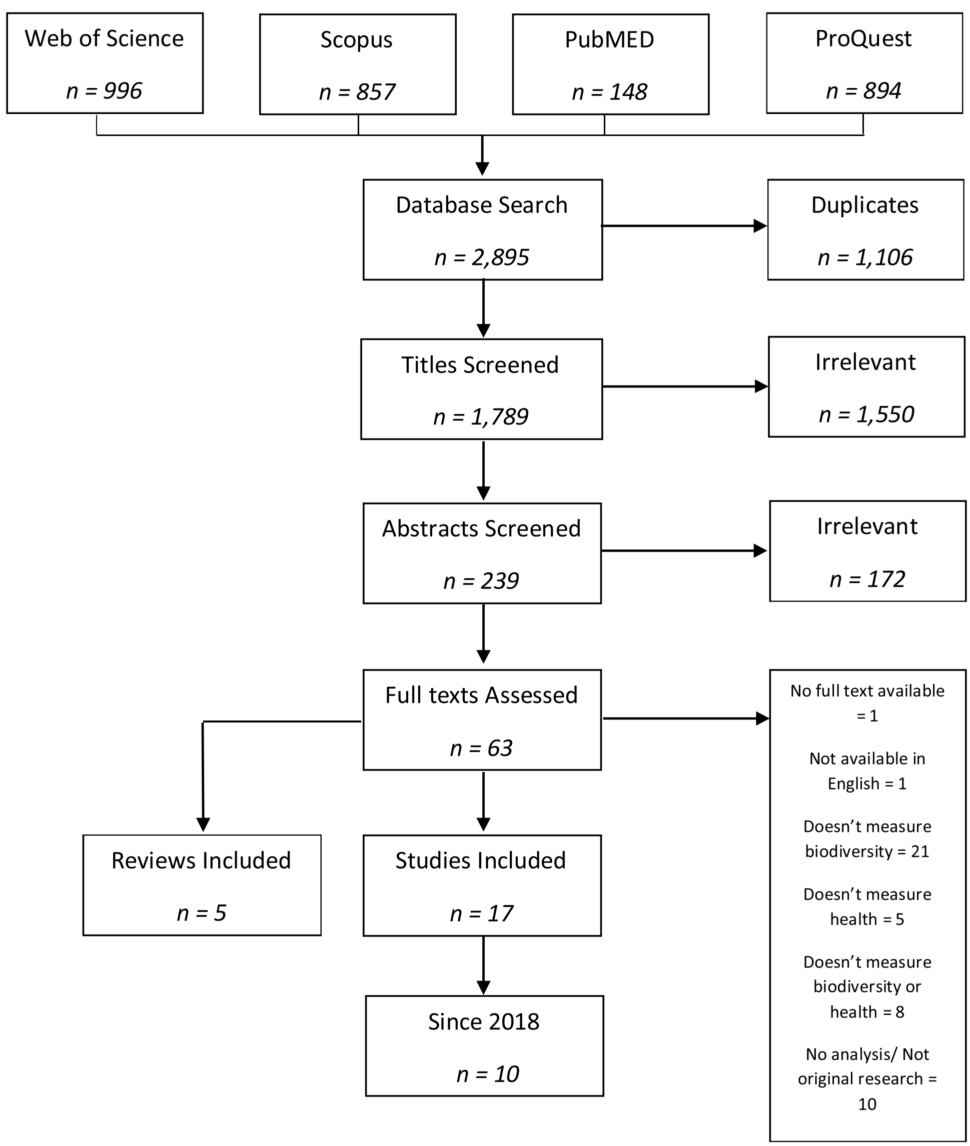

Fig. 3. Study selection process.

Table 3
Summary of Previous Reviews.

Authors	Searches	Systematic Strategy	Quality Assessment	Findings
Aerts et al. (2018)	Biodiversity, Health and Wellbeing	Systematic Search Scoping Review	No	Limited and conflicting evidence for a positive relationship between biodiversity and health. Most evidence for self-report, rather than clinical outcomes
Lovell et al. (2014)	Biodiversity, Health and Wellbeing	Yes	Yes	Some, but inconclusive, evidence for a positive relationship between biodiversity and health
Lai et al. (2019)	Greenspace, and Health or biodiversity	Systematic Search Scoping Review	No	Some evidence for a positive relationship between greenspace and health
Jorgensen and Gobster (2010)	Urban biodiversity or urban greenspace, and health	Systematic Search Scoping Review	No	Evidence for a positive relationship between biodiversity and preference. Greenspace associated with health, but differs for dimensions of health and wellbeing
Dean et al. (2011)	Urban biodiversity and mental health	Systematic Search Scoping Review	No	Only one study found, positive relationship between biodiversity and mental wellbeing

et al., 2019; Jorgensen and Gobster, 2010), or else restricted their health outcomes to mental health only (Dean et al., 2011) (Table 3).

The most relevant previous work was conducted in 2014 by Lovell et al., whose systematic review analysed the evidence for the health and wellbeing benefits of biodiverse environments, through a structed search of 20 academic databases between 1980–2012 (Lovell et al., 2014). Finding 17 studies which met their inclusion criteria, these authors concluded that some evidence suggests that biodiverse natural environments promote better health through exposure to ‘pleasant’ surroundings or encouraging health-promoting behaviours, although inverse relationships detected at a larger scale provide inconclusive results, and many studies were judged to be either ‘acceptable’ or ‘low’ quality Aerts et al.’s scoping review (2018) searched the same topics within three databases up to May 2018, finding 19 relevant publications relating to biodiversity and human health, but did not utilise systematic inclusion criteria or a quality assessment. They reported very few studies which directly measured biodiversity and health, particularly clinical outcomes, concluding that there is some evidence that urban biodiversity may support short-term wellbeing, speculating that this may be partly through provision of ecosystem services.

This focus on a relatively narrow, and often subjective, range of health and wellbeing outcomes, was also identified by Jorgensen and Gobster (2010), for 29 studies of either biodiversity or greenspace published between 1997−2010. Evidence supports a human preference for biodiverse environments, although relationships are likely to differ across socio-cultural contexts, which may contribute to the current paucity of support for direct health benefits. A similar scoping review was conducted by Lai et al. (2019), searching one database (PubMED) between 2007–2017 for analyses of urban greenspace and either biodiversity or health. These authors found that, although greenspace was commonly associated with biodiversity, few studies of greenspace and health examined biodiversity directly. They also highlight an overreliance on cross-sectional studies, inconsistencies in defining greenspace, and a geographical bias towards studies in Western cultures.

Dean et al., focused specifically on mental health outcomes in urban areas (Dean et al., 2011). Analysing their results is more challenging due to a lack of methodological and statistical reporting in their publication. However, they concluded that while substantial literature investigates the general impact of greenspace or nature on mental health, they identified only one original research paper that directly investigated biodiversity and mental health, reporting a positive association (Fuller et al., 2007).

It is clear, therefore, that to date, few reviews have holistically analysed the evidence for a relationship between biodiversity in greenspaces and human health directly through a fully systematic approach.

3.2.2. *Review of original studies*

So as not to duplicate the most recent study by Aerts et al. (2018), we refined our results by those published after the reported review, i.e. 2018-present, retrieving ten potentially relevant studies; two published in 2018, five in 2019 and three in the first quarter of 2020. Two studies were in the UK (Cameron et al., 2020; Hoyle et al., 2019), four in continental Europe (Hussain et al., 2019; Lindemann-Matthies and Matthies, 2018; Meyer-Grandbastien et al., 2020; Young et al., 2020) and four across Australia and/or New Zealand (Mavoa et al., 2019b, a; Schebella et al., 2019; Taylor et al., 2018). Four of the studies were in-situ experiential in nature (Cameron et al., 2020; Hoyle et al., 2019; Hussain et al., 2019, Lindemann-Matthies and Matthies, 2018) while the remainder combined survey questionnaires with map data. One study focused on teenagers (Mavoa et al., 2019b); all others included only adult participants. Sample sizes ranged from 22 to 4912 participants, with data collected between 2010–2017, four had samples of over 1000 (Hoyle et al., 2019; Mavoa et al., 2019a, b; Taylor et al., 2018).

Study designs were divided across three controlled case studies (considered the highest level of evidence (Higgins et al., 2019)) (Hoyle et al., 2019; Hussain et al., 2019; Lindemann-Matthies and Matthies, 2018), one uncontrolled case study, which utilised temporal data but not analyses (Cameron et al., 2020), and the remaining six cross-sectional surveys. A predominance of cross-sectional studies was also reported by Lai et al. (2019) and Aerts et al. (2018), although Lovell et al. (2014) recorded much greater variation in study designs, the majority being case studies, the second most common in this review.

Assessment determined five studies were of Good quality, four were Fair, and only one was rated Poor. The reasons for these lower ratings were primarily participant self-selection in cross-sectional and case studies, alongside non-random sampling and personnel awareness of exposure groups in controlled case studies (Table 4). A summary of the main characteristics of included studies is presented in Table A1 in Supplementary material.

Biodiversity was conceptualised in multiple ways; Fig. 4 represents the distribution of biodiversity and health measure co-occurrence within the 10 original studies, with the majority (five) measuring the relationship between biodiversity of vegetation and human wellbeing, while 4 studied vegetation and restoration. Restoration was the most common health outcome, occurring alongside all biodiversity measures. Several studies combined multiple indicators of biodiversity and/or health. Three equated biodiversity with ‘species richness’ (Lindemann-Matthies and Matthies, 2018; Taylor et al., 2018; Hussain et al., 2019) five

Table 4
Summary of biodiversity and health findings. Definitions shown in quotations. Studies not of 'Good' quality include justification.

Source	Biodiversity definition & measurement	Health definition & measurement	Associations	Quality
Cameron et al. (2020)	"rich in wildlife… bird taxa and defined habitat types" Avian and habitat surveys	"positive affect" Recovering Quality of Life Scale (ReQoL), Inclusion of Nature with Self (INS), Nature Relatedness Scale (NRS), Engagement with Natural Beauty scale (ENWB)	Positive	Good
Hoyle et al. (2019)	"diversity at habitat, ecosystem, species and community scales" Perceived plant and invertebrate diversity. Value of meadow	"perceived restoration" Restorative effect.	Positive	Poor – participant assignment not random, multiple analyses and selective reporting
Hussain et al. (2019)	"species richness" Plant and insect richness. Perceived biodiversity	Health: "a state of physical, mental and social well-being and not merely the absence of disease or infirmity" Wellbeing: "the state of being relaxed and healthy" Pulse rates, blood pressure, perceived stress reduction, attention restoration, well-being	Stress: Negative Wellbeing: Positive	Fair- personnel aware of exposure group assignment. Limited reporting on participant recruitment.
Lindemann-Matthies and Matthies (2018)	"plant species richness" 2 min of word-stress, 2-minute exposure to meadow-like plant arrays	"a state of physical, mental and social well-being and not merely the absence of disease or infirmity" Systolic and diastolic blood pressure	Stress: Negative, non-linear	Fair – personnel aware of exposure group assignment.
Mavoa et al. (2019a)	"includes all life forms, ranges from the diversity of genes present in a location to counts and turnover of species in whole ecosystems." Mean Normalised Difference Vegetation Index (NDVI) and species richness (flora and fauna) in buffers (400, 800 and 1600 m) around homes	"an individual's subjective experience of their life and includes affective and cognitive processes and personality" 7 wellbeing dimensions: standard of living; health; achievements; personal relationships; community connectedness; safety; future security	None	Good
Mavoa et al. (2019b)	"variation in greenness, vegetation diversity, presence of native vegetation" Nature availability index, variation in greenness and vegetation diversity in buffers (400, 800 and 1600 m) around residential neighbourhoods	"emotional wellbeing" World Health Organisation-5 (WHO-5), Reynolds Adolescent Depression Scale-short form (RADS-SF)	Depression: Negative	Good
Meyer-Grandbastien et al. (2020)	"species diversity" Shannon's Diversity Index (SHDI) Perceived biodiversity	"psychological restoration" Psychological restoration and wellbeing	Wellbeing: None Restoration: Positive	Good
Schebella et al. (2019)	"diversity of plant and animal species" Structural heterogeneity and habitat heterogeneity checklists, bird surveys.	"wellbeing" 11-point ordinal scales in response to the question, "how do you think a typical visit to each of these green spaces would improve your stress, mood, concentration and self-esteem?"	Positive, non-linear	Good
Taylor et al. (2018)	"bird species richness" Neighbourhood avian species richness	Health: "An overall state of health, including social, mental and physical factors; more than a lack of disease" Wellbeing: "How humans evaluate and experience their lives overall" WHO-5, Personal Wellbeing Index (PWI), 7-item psychological wellbeing	None	Fair- respondents self-selection and may not be representative of the wider population
Young et al. (2020)	"number of plant species" Number of plant species in garden/allotments, Preference for biodiversity	"three dimensions of restorativeness: being away, fascination and compatibility" Perceived restorativeness, self-reported restoration	Positive	Good

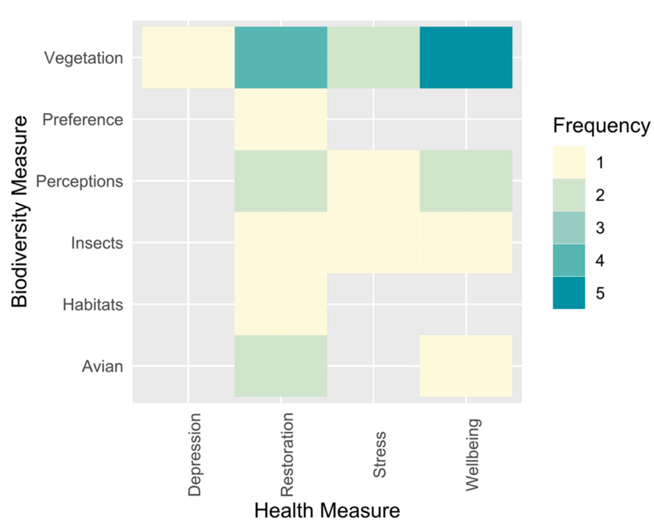

Fig. 4. Heatmap of Biodiversity and Health Measures. Note that several studies include multiple measures.

considered 'diversity' across flora and/or fauna (Hoyle et al., 2019; Mavoa et al., 2019b, a; Schebella et al., 2019; Meyer-Grandbastien et al., 2020), while others focused on abundance of wildlife (Cameron et al., 2020), or simply the 'number of species' (Young et al., 2020). Authors also focused on different types of organism; the majority, in seven cases, captured plant species diversity (Cameron et al., 2020; Hussain et al., 2019; Lindemann-Matthies and Matthies, 2018; Mavoa et al., 2019a, b; Meyer-Grandbastien et al., 2020; Young et al., 2020). Avian surveys were recorded in three studies (Cameron et al., 2020; Schebella et al., 2019; Taylor et al., 2018), while three included fauna (Hoyle et al., 2019; Hussain et al., 2019; Mavoa et al., 2019a). Two surveys also considered individual perceptions of biodiversity (Hussain et al., 2019; Meyer-Grandbastien et al., 2020), while one included preference for biodiverse environments, but was restricted to private greenspaces (gardens and allotments) (Young et al., 2020), whereas the remainder consider public spaces; both of these provide insight into human experiences, and the subjectivity this incurs. This diverse range of definitions and focuses reflects the broad spectrum of studies within the field, which approach the topic from slightly different perspectives, thereby corroborating the assertions of disparate use of terminology, by Lovell et al. (2014).

Health was, in the majority of cases, measured as self-rated:

restoration in five cases (Hoyle et al., 2019; Hussain et al., 2019; Meyer-Grandbastien et al., 2020; Schebella et al., 2019; Young et al., 2020)) and wellbeing in six (Cameron et al., 2020; Hussain et al., 2019; Mavoa et al., 2019a, b; Schebella et al., 2019; Taylor et al., 2018). Two studies included clinical measures, taking pulse measures to indicate rate and blood pressure (Hussain et al., 2019; Lindemann-Matthies and Matthies, 2018). Depressive symptoms were outcomes in one study (Mavoa et al., 2019b), and two also considered individual connections to nature (Cameron et al., 2020; Hoyle et al., 2019). Four analyses included more than one aspect of health (Cameron et al., 2020; Mavoa et al., 2019b; Meyer-Grandbastien et al., 2020; Taylor et al., 2018); all but one study controlled for demographic factors in their analysis (Hussain et al., 2019).

3.2.2.1. Blood pressure. Of the two controlled case studies measuring blood pressure, indicative of stress and relaxation, one reported a significant negative association with biodiversity (i.e. an improvement); both were rated as Fair quality, due to personnel awareness of the exposure groups. The study by Lindemann-Matthies and Matthies (2018) first stressed individuals by using a two minute colour-word stress test, followed by exposure to a 'meadowlike' array of plants of different numbers of species; relaxation was strongest at intermediate species richness (32 species, F = 11.30), whereas greater diversity was not significant. Hussain et al.'s (2019) controlled case study exposed 22 participants to managed and unmanaged meadow environments in the Swiss and Austrian Alps, while also measuring species richness and perceptions of naturalness. Blood pressure was not affected, although perceived restoration was higher in managed environments; the small sample size and lack of reporting on participant recruitment may limit the generalisability. Evidence here is therefore mixed.

3.2.2.2. Restorative effects. Of the studies into self-reported restoration, all used different perceived stress reduction, attention or psychological restoration questionnaires. Two observed individual responses during case study exposure to natural environments, (Hoyle et al., 2019; Hussain et al., 2019). Both reported a positive association between perceived naturalness and biodiversity, but only the study by Hoyle et al., of 1,411 participants walking in different environments, reported a strongly significant and positive association to restorative effects (0.423), measured through self-reported restorative feelings, although the high risk of bias, due to non-random exposure group assignment and multiple reporting, limits the quality of the study to Poor. However, Hussain et al.'s Fair quality study was controlled, and revealed potential benefits of more managed environments ($F = 5.047$, $p = 0.036$).

Two other Good quality cross-sectional studies (Meyer-Grandbastien et al., 2020; Schebella et al., 2019) used questionnaires and neighbourhood characteristics to measure landscape heterogeneity, both reporting moderate positive associations with perceived restoration ($R = 0.64$, $p = 0.018$ and $F = 10.443$, $p < 0.01$, respectively). One of these, situated in France, determined that individuals were able to perceive landscape biodiversity, which was also associated with restoration (Meyer-Grandbastien et al., 2020).

A Good cross-sectional study of 301 gardeners in Switzerland, by Young et al. (2020), asked respondents to rate the number of plant species in their garden or allotment, as well as their preferences for diversity and subsequent restorative effect. Results indicated that being an allotment gardener was strongly associated with higher levels of restoration, compared to domestic gardeners, but associations were only significant between the number of plant species and perceived restoration ($B = 0.184$, $p = 0.003$). These findings, alongside the conclusions drawn by Aerts et al. (2018), support the notion that there is some, limited evidence of an association between biodiversity and restoration.

3.2.2.3. General wellbeing. Five Good quality studies, and one Fair quality (Hussain et al., 2019), analysed general wellbeing outcomes. Two of these used case study approaches with relatively small samples (Hussain et al., 2019; Cameron et al., 2020). An uncontrolled case study, by Cameron et al. (2020) used an app-based survey in Sheffield, to determine how people respond emotionally to different environments (Cameron et al., 2020). Despite a sample size of 144 adults, targeted sampling was utilised to reduce potential skewness of app user demographics. Respondents reported feeling happier (on a five-point scale) in sites with greater avian biodiversity ($r = 0.78$, $p < 0.01$) and a wider variety of habitats ($r = 0.72$, $p < 0.02$). Interestingly, when participants thought the site was wildlife rich, they reported more positive emotions, even when actual avian biodiversity levels were not necessarily enhanced. Conversely, the Alps-based controlled case study of exposure to meadows reported marginally lower wellbeing in environments with more insect diversity ($r = -0.82$, $p = 0.043$), although, as described above, this study's limitations may reduce statistical power (Hussain et al., 2019).

Mavoa et al. report on findings from two larger cross-sectional studies using surveys and land cover maps in Oceania, both rated Good. One study, of 4,557 adolescents in New Zealand, did not report statistically significant associations between vegetation diversity and wellbeing (measured as WHO-5) (Mavoa et al., 2019a). The second, which included 4,912 residents of Australia, included wellbeing and neighbourhood species richness (Mavoa et al., 2019b). Both flora and fauna species richness were negatively associated with depressive symptoms, but not positive wellbeing indicators, when considering neighbourhoods at a range of scales from 400 m to 1600 m.

Also in Australia, another Good cross-sectional study of 840 residents used in-situ park surveys and asked respondents to rate the perceived benefits of those parks local to them, across a number of wellbeing dimensions (Schebella et al., 2019); vegetation cover was the strongest predictor of psychological wellbeing. Biodiversity attributes significantly predicted self-reported improvements to stress, mood, and concentration (stress: $F = 10.443$, $p < 0.01$; mood: $F = 6.953$, $p < 0.01$; concentration: $F = 2.551$, $p < 0.05$), but not self-esteem, all on a scale of 0–10. Increases in each biodiversity attribute significantly affected wellbeing at different thresholds, suggesting the relationship between biodiversity and wellbeing may be non-linear.

The final cross-sectional study, a Fair quality analysis of avian species in the neighbourhoods of 1,819 residents across four cities in Australia and New Zealand, used the WHO-5 wellbeing scale (Taylor et al., 2018). Surprisingly, wellbeing was not found to be correlated with bird species richness (results were not reported), which the authors suggest may be due to low response rates in some areas, and consideration of coastal cities, where a predominance of seabirds may be less related to vegetation and interactions with humans. However, the amount of greenery was positively related to wellbeing in the two Australian, but not New Zealand, cities ($R^2 = 0.01$, $p = 0.014$ and $R^2 = 0.02$, $p < 0.001$). In general, the evidence is mixed but supportive of an association between biodiversity and wellbeing, mostly in terms of vegetation. This broadly agrees with the findings of previous reviews, for a relationship between biodiversity and self-reported health and wellbeing (Dean et al., 2011; Aerts et al., 2018; Lovell et al., 2014).

3.2.2.4. Depressive symptoms. The Good cross-sectional study by Mavoa et al. reports the only analysis of depressive symptoms, measured using the Reynolds Adolescent Depression Scale, with 4,557 participants in a survey of New Zealand residents (Mavoa et al., 2019b). Using buffers around individuals, several indicators of biodiversity were included (variation in greenness, vegetation diversity, presence of native vegetation). Presence of native vegetation, and nature availability index within 1600 m of homes were all significantly associated with reduced symptoms of depression, on a scale of 10–40 ($B = -0.84$, $p < 0.05$). However, as only one study was detected, evidence is limited. Similar conclusions were drawn by both Aerts et al. (2018) and Dean et al. (2018), who only detected one study on depression, which was related to higher levels of vegetation and bird species richness, although Lovell et al. (2014) report mixed results across mental health measures.

4. Discussion

Research into biodiversity and health has expanded exponentially over recent decades. Having conducted a bibliometric analysis, evaluated five existing literature reviews into biodiversity and health, and considered recent original research on this topic, we find a mixed amount of evidence for a positive relationship. Generally, there is a lack of evidence specifically for biodiversity, with many papers excluded from our selection due to a broad comparison of 'natural' and 'non-natural' environments; this was also reported by previous literature reviews (Lovell et al., 2014; Lai et al., 2019; Fuller et al., 2007).

While many studies have focused specifically on the relationship between nature and health (Hartig et al., 2014; Public Health England, 2020), much less scholarly attention has so far been paid to the mechanisms for urban greenspace. This review provides further evidence that biodiversity is a potentially important factor in how humans obtain health benefits from urban greenspaces. Therefore, improving the biodiversity of such spaces, by supporting a diverse range of flora and fauna, could have positive implications for human health. Our bibliometric analysis emphasises this as a growing, yet still relatively small field. Further support from funding and research bodies would thus be required to conduct more rigorous studies, given the potential for benefits to human health and the relative lack of research funding in this area, as evidenced by the absolute number of publications we observe.

Of the included original studies here, most consider floral biodiversity, while some capture avian species diversity, a pattern noted in several previous reviews (Lai et al., 2019; Jorgensen and Gobster, 2010; Lovell et al., 2014), while others note a dominance of avian studies (Aerts et al., 2018). More evidence supports associations between health and floral biodiversity. The strongest results were observed for outcomes of subjective wellbeing, followed by self-rated general health, as others have also reported (Dean et al., 2011; Aerts et al., 2018; Lovell et al., 2014). There was much less evidence for specific physical and mental health outcomes, and only two studies took physical (pulse) measures as an indicator of stress (Lindemann-Matthies and Matthies, 2018; Hussain et al., 2019), revealing mixed evidence for an association with biodiversity, while just one considered mental ill health (Mavoa et al., 2019b). One study also reported preferences for biodiverse environments (Hussain et al., 2019, Taylor et al., 2018), although evidence for whether perceptions of diversity were accurate was contradictory (Hussain et al., 2019; Meyer-Grandbastien et al., 2020; Cameron et al., 2020; Taylor et al., 2018; Schebella et al., 2019). Schebella et al. (2019) suggest this may provide justification for improved ecological literacy among the general population, to potentially improve pro-environmental behaviours, although caveating that understanding and derived benefit may not always correlate. Other reviews have also highlighted the difficulties in synthesising findings from studies with disparate, or absent, definitions of greenspace and biodiversity (Lai et al., 2019).

Our review also highlights this issue of diverse definitions, covering aspects of 'heterogeneity', 'richness' and 'abundance', emphasising the commonalities of such issues across the field and thus the importance of clearly qualifying such terms to enable interpretation across multiple contexts. Greater understanding and agreement upon standardised approaches to biodiversity indicators in future research would allow for deeper comparisons across studies and health outcomes. Previous reviews have revealed mixed, or weak evidence for a relationship between biodiversity and various aspects of physical and mental health, as well as healthy behaviours (Aerts et al., 2018; Lai et al., 2019), identifying few studies which focus directly upon biodiversity. While most studies in the present review revealed a positive association between their chosen biodiversity indicators and health (Mavoa et al., 2019b; Lindemann-Matthies and Matthies, 2018; Hoyle et al., 2019; Meyer-Grandbastien et al., 2020; Cameron et al., 2020; Hussain et al., 2019; Schebella et al., 2019; Mavoa et al., 2019a), two authors suggested this may not be linear, with 'moderate' biodiversity displaying the strongest outcomes in two studies (Lindemann-Matthies and Matthies, 2018; Schebella et al., 2019), while some suggest that subtle differences in biodiversity may not be observable to laypersons, whereas more extreme variation is easier to identify and thus could yield greater benefit, although environments with too many diverse elements may be overwhelming (Schebella et al., 2019). Other researchers have postulated that individuals do not necessarily prefer the highest levels of biodiversity for environmental enjoyment, but rather 'semi-open' spaces with a mix of pasture and wilder habitats (Qiu et al., 2013). Building on the Biophilia hypothesis, broader theories draw on the Savannah landscapes where the human species evolved, to propose that a balance of wider planes, which provide prospect, and clusters of trees, to afford refuge, may be optimal for survival and thus influence modern preferences (Appleton, 1996, 1984). However, other studies have concluded that, overall, biodiversity relates to aesthetic preference (Gunnarsson et al., 2017), alongside several confirming the association with improved health outcomes (Mavoa et al., 2019b; Lindemann-Matthies and Matthies, 2018; Hoyle et al., 2019; Meyer-Grandbastien et al., 2020; Cameron et al., 2020; Hussain et al., 2019; Schebella et al., 2019; Mavoa et al., 2019a), implying a more complex relationship between these factors which could lend consideration to individual preference and non-linearity in future studies. Lovell et al. (2014) speculate that variation in measures, study design and scale across disciplines may further contribute to potentially contradictory findings.

All but one study included controls for demographic variables (Hussain et al., 2019), meaning that, for the majority, at least some individual characteristics were accounted for, which strengthens the quality of research, validity of findings, and transferability of outcomes. No studies examined differences across social groups; future studies could build on this through interactions between socio-economic or other personal factors, such as changes across the life course, influence of childhood experiences, in areas of greater deprivation, or through cultural factors which might make biodiversity more important for different communities. This has been demonstrated in the topic of heath and greenspace more broadly, although the study did not include measures of biodiversity (Lachowycz and Jones, 2013).

Most (six) of the studies were rated as Good quality, while others had a higher risk of bias introduced by sampling and intervention strategies, which was particularly notable among case studies. Several studies were also limited by overall low sample sizes; although four were larger and contained over 1000 subjects, (Hoyle et al., 2019; Mavoa et al., 2019a, b; Taylor et al., 2018), some recruited fewer than 200 participants (Cameron et al., 2020; Lindemann-Matthies and Matthies, 2018), with one having just 22 (Hussain et al., 2019), which may reduce statistical power. We also observe a dominance of cross-sectional analyses, which combine surveys with local-area greenspace indicators, with only four of ten using case studies (Cameron et al., 2020; Hoyle et al., 2019; Hussain et al., 2019; Lindemann-Matthies and Matthies, 2018), two of which were controlled (Hoyle et al., 2019; Lindemann-Matthies and Matthies, 2018).

4.1. Strengths and weaknesses

As far as the authors are aware, this is the first study to conduct a review of reviews and analyse research trends in published research on the relationship between greenspace biodiversity and health. Using a range of search terms and greater number of databases than most previous reviews, we were able to conduct thematic and temporal investigations, as well as aggregating evidence on recent (since 2018) original research related to these keywords. Thus, we provide an updated perspective on the current state of the field and interpret our findings in a broadened context, benefiting from inclusion of both self-reported and clinical outcomes. We conducted a comprehensive database search, thorough screening of articles, quality assessment, and detailed narrative synthesis of the five reviews and ten recent studies which met our inclusion criteria.

However, the relatively small number of studies, methodological heterogeneity and wide diversity in measurement of both biodiversity and health meant that it was not possible to undertake a meta-analysis. In particular, the range of biodiversity measures made aggregating the results more challenging and leaves many questions to be addressed in future studies. We also note that studies on the preference for, and perceptions of, biodiversity, may not always directly relate to more objective measures, though they do provide an insight into individual experiences. The small number of papers discussed may also limit coverage of the topic and the conclusions we are able to draw, and generalisability of findings. We attempted to mitigate these risks somewhat by including the review of reviews.

The general lack of controlled case studies or longitudinal analysis also leaves a gap in knowledge surrounding causality or long-term consequences of exposure to biodiverse environments. While we searched four large, diverse databases, there is a possibility that other sources may contain additional records. We considered only published, peer-reviewed studies, and did not include unpublished or grey literature, in order to maintain quality standards, although this may additionally limit our sample. We also focussed specifically on health and wellbeing outcomes, rather than more niche sub-domains such as allergies; our search terms were designed to be as inclusive and strategic as possible, although the minor element of subjectivity in selecting terms and inclusion criteria means that there is a small likelihood that other researchers may have concluded slightly different results. We also acknowledge that database searches which provide narrower terms of definitions of 'biodiversity' and 'health' may yield varying findings.

5. Conclusion

The ecosystem services provided by urban greenspaces are vital in the functioning of a healthy environment. In particular, biodiversity is theorised to provide physical, cultural, microbiome and emotional benefits to humans and society. However, while some previous reviews have suggested a relationship between biodiversity and aspects of human health, our bibliometric and narrative analyses highlight a growing, yet still relatively small, field of research attention, where most evidence suggests a weak association between floral biodiversity of greenspace and subjective wellbeing, as well as self-rated health, and mixed evidence for other health outcomes. This potentially limits the generalisability of findings. Fewer studies have focussed on broader aspects biodiversity, including avian and fauna, where consistent and detailed future analyses of a range of biodiversity indicators should accurately quantify these dimensions. Larger-scale and longitudinal studies would enable greater statistical power in future studies and provide further insight into causality and potential mechanisms. Additional exploration of the possible non-linear, geospatial, and demographic variation would also deepen understanding of the complexities of these relationships. In order to promote and preserve urban greenspaces, robust evidence regarding the features of these spaces, including quality and quantity of diversity, is required to demonstrate how and why health benefits may be obtained through nature-based solutions.

Author statement

Victoria Houlden: conceptualization, methodology, software, investigation, writing- original draft, visualization. **Anant Jani**: conceptualization, investigation, writing- original draft, project administration, funding acquisition. **Andy Hong**: conceptualisation, software, validation, writing-original draft, funding acquisition.

Data availability

Data are available from the corresponding author upon request.

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. Supplementary data

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References

Aerts, R., Honnay, O., Van Nieuwenhuyse, A., 2018. Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. Br. Med. Bull. 127, 5–22.
Appleton, J., 1984. Prospects and refuges re-visited. Landsc. J. 3, 91–103.
Appleton, J., 1996. The Experience of Landscape. Wiley, Chichester.
Assembly, G., 2015. 70/1. Transforming Our World: the 2030 Agenda for Sustainable Development. Retrieved from. United Nations, New York. http://www.un.org/ga/search.
Assessment, M.E., 2005. Ecosystems and Human Well-being. Island press, Washington, DC.
Cameron, R.W.F., Brindley, P., Mears, M., Mcewan, K., Ferguson, F., Sheffield, D., Jorgensen, A., Riley, J., Goodrick, J., Ballard, L., Richardson, M., 2020. Where the wild things are! Do urban green spaces with greater avian biodiversity promote more positive emotions in humans? Urban Ecosyst. 23, 301–317.
Dean, J., Van Dooren, K., Weinstein, P., 2011. Does biodiversity improve mental health in urban settings? Med. Hypotheses 76, 877–880.
Farrell, M.J., Govender, D., Hajibabaei, M., Van Der Bank, M., Davies, T.J., 2019. Bacterial diversity in the waterholes of the Kruger National Park: an eDNA metabarcoding approach. Genome 62, 229–242.
Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H., Gaston, K.J., 2007. Psychological benefits of greenspace increase with biodiversity. Biol. Lett. 3, 390–394.
Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A., Nieuwenhuijsen, M.J., 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int. J. Environ. Res. Public Health 12, 4354–4379.
Gatersleben, B., Andrews, M., 2013. When walking in nature is not restorative—the role of prospect and refuge. Health Place 20, 91–101.
Gruebner, O., Rapp, M.A., Adli, M., Kluge, U., Galea, S., Heinz, A., 2017. Cities and mental health. Deutsches Ärzteblatt Int. 114, 121.
Gunnarsson, B., Knez, I., Hedblom, M., Sang, Å.O., 2017. Effects of biodiversity and environment-related attitude on perception of urban green space. Urban Ecosyst. 20, 37–49.
Haahtela, T., Holgate, S., Pawankar, R., Akdis, C.A., Benjaponpitak, S., Caraballo, L., Demain, J., Portnoy, J., Von Hertzen, L., 2013. The biodiversity hypothesis and allergic disease: world allergy organization position statement. World Allergy Organ. J. 6, 1–18.
Hartig, T., Mitchell, R., De Vries, S., Frumkin, H., 2014. Nature and health. Annu. Rev. Public Health 35, 207–228.
Higgins, J.P., Altman, D.G., Gøtzsche, P.C., Jüni, P., Moher, D., Oxman, A.D., Savović, J., Schulz, K.F., Weeks, L., Sterne, J.A., 2011. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 343.
Higgins, J.P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M.J., Welch, V.A., 2019. Cochrane Handbook for Systematic Reviews of Interventions. John Wiley & Sons.
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 One 13.
Hoyle, H., Jorgensen, A., Hitchmough, J.D., 2019. What determines how we see nature? Perceptions of naturalness in designed urban green spaces. People Nat. 1, 167–180.
Hussain, R.I., Walcher, R., Eder, R., Allex, B., Wallner, P., Hutter, H.P., Bauer, N., Arnberger, A., Zaller, J.G., Frank, T., 2019. Management of mountainous meadows associated with biodiversity attributes, perceived health benefits and cultural ecosystem services. Sci. Rep. 9.
Jacobs, J., 2016. The Death and Life of Great American Cities. Vintage.

Jorgensen, A., Gobster, P.H., 2010. Shades of green: measuring the ecology of urban green space in the context of human health and weil-being. Nat. Cult. 5, 338–363.
Kaesler, S., Skabytska, Y., Volz, T., Biedermann, T., 2018. The biodiversity hypothesis and immunotolerance in allergy. Allergo J. Int. 27, 140–146.
Lachowycz, K., Jones, A.P., 2013. Towards a better understanding of the relationship between greenspace and health: development of a theoretical framework. Landsc. Urban Plan. 118, 62–69.
Lai, H., Flies, E.J., Weinstein, P., Woodward, A., 2019. The impact of green space and biodiversity on health. Front. Ecol. Environ. 17, 383–389.
Lindemann-Matthies, P., Matthies, D., 2018. The influence of plant species richness on stress recovery of humans. Web Ecol. 18, 121–128.
Lovell, R., Wheeler, B.W., Higgins, S.L., Irvine, K.N., Depledge, M.H., 2014. A systematic review of the health and well-being benefits of biodiverse environments. J. Toxicol. Environ. Health-Part B-Crit. Rev. 17, 1–20.
Lovell, R., Depledge, M., Maxwell, S., 2018. Health and the Natural Environment: a Review of Evidence, Policy, Practice and Opportunities for the Future.
Mavoa, S., Davern, M., Breed, M., Hahs, A., 2019a. Higher levels of greenness and biodiversity associate with greater subjective wellbeing in adults living in Melbourne, Australia. Health Place 57, 321–329.
Mavoa, S., Lucassen, M., Denny, S., Utter, J., Clark, T., Smith, M., 2019b. Natural neighbourhood environments and the emotional health of urban New Zealand adolescents. Landsc. Urban Plan. 191.
Maxwell, S., Lovell, R., 2017. Evidence Statement on the Links Between Natural Environments and Human Health. Department for Environment, London. Food and Rural Affairs.
Mclennan, D., Noble, S., Noble, M., Plunkett, E., Wright, G., Gutacker, N., 2019. The English Indices of Deprivation 2019: Technical Report.
Meyer-Grandbastien, A., Burel, F., Hellier, E., Bergerot, B., 2020. A step towards understanding the relationship between species diversity and psychological restoration of visitors in urban green spaces using landscape heterogeneity. Landsc. Urban Plan. 195.
Montgomery, C., 2013. Happy City: Transforming Our Lives Through Urban Design. Macmillan.
Nath, T.K., Han, S.S.Z., Lechner, A.M., 2018. Urban green space and well-being in Kuala Lumpur, Malaysia. Urban For. Urban Green. 36, 34–41.
Ofori, B.Y., Garshong, R.A., Gbogbo, F., Owusu, E.H., Attuquayefio, D.K., 2018. Urban green area provides refuge for native small mammal biodiversity in a rapidly expanding city in Ghana. Environ. Monit. Assess. 190.
Oosterbroek, B., De Kraker, J., Huynen, M.M., Martens, P., 2016. Assessing ecosystem impacts on health: a tool review. Ecosyst. Serv. 17, 237–254.
Peterson, J., Welch, V., Losos, M., Tugwell, P., 2011. The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomised Studies in Meta-analyses. Ottawa Hospital Research Institute, Ottawa.
Public Health England, 2020. Improving Access to Greenspace: a New Review for 2020.
Qiu, L., Lindberg, S., Nielsen, A.B., 2013. Is biodiversity attractive?—on-site perception of recreational and biodiversity values in urban green space. Landsc. Urban Plan. 119, 136–146.
Ritchie, H., Roser, M., 2019. Urbanization. Our World in Data.
Rook, G.A., 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. Proc. Natl. Acad. Sci. 110, 18360–18367.
Schebella, M.F., Weber, D., Schultz, L., Weinstein, P., 2019. The wellbeing benefits associated with perceived and measured biodiversity in Australian urban green spaces. Sustainability 11.
Schmidt, K.A., Ostfeld, R.S., 2001. Biodiversity and the dilution effect in disease ecology. Ecology 82, 609–619.
Soga, M., Yamanoi, T., Tsuchiya, K., Koyanagi, T.F., Kanai, T., 2018. What are the drivers of and barriers to children's direct experiences of nature? Landsc. Urban Plan. 180, 114–120.
Taylor, L., Hahs, A.K., Hochuli, D.F., 2018. Wellbeing and urban living: nurtured by nature. Urban Ecosyst. 21, 197–208.
The Endnote Team, 2013. EndNote. EndNote X9 Ed. Clarivate., Philadelphia, PA.
The R Foundation For Statistical Computing, 2014. The R Foundation For Statistical Computing. R Version 3.5.2.
Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landsc. Urban Plan. 81, 167–178.
Wilson, E.O., 1984. Biophilia. Harvard, MA.
Wilson, E.O., 2017. Biophilia and the conservation ethic. Evolutionary Perspectives on Environmental Problems. Routledge.
World Health Organization, 2017. Urban Green Space Interventions and Health: a Review of Impacts and Effectiveness. World Health Organization.
Young, C., Hofmann, M., Frey, D., Moretti, M., Bauer, N., 2020. Psychological restoration in urban gardens related to garden type, biodiversity and garden-related stress. Landsc. Urban Plan. 198.