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A systematic map of research exploring the effect of greenspace on mental health

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A B S T R A C T

The past 35 years has seen an accumulation of empirical evidence suggesting a positive association between greenspace and mental health. Existing reviews of evidence are narrow in scope, and do not adequately represent the broad range of disciplines working in this field. This study is the first systematic map of studies investigating greenspace effects on mental health. A total of 6059 papers were screened for their relevance, 276 of which met inclusion criteria for the systematic map.

The map revealed several methodological limitations hindering the practical applications of research findings to public health. Critically, the majority of studies used cross-sectional mental health data which makes causal inference about greenspace effects challenging. There are also few studies on the micro-features that make up greenspaces (i.e., their "quality"), with most focussing only on "quantity" effects on mental health. Moreover, few studies adopted a multi-scale approach, meaning there is little evidence about at which spatial scale(s) the relationship exists. A geographic gap in study location was also identified, with the majority of studies clustered in European countries and the USA.

Future research should account for both human and ecological perspectives of "quality" using objective and repeatable measures, and consider the potential of scale-dependent greenspace effects to ensure that management of greenspace is compatible with wider scale biodiversity targets. To establish the greenspace and metal health relationship across a life course, studies should make better use of longitudinal data, as this enables stronger inferences to be made than more commonly used cross-sectional data.

1. Introduction

Unprecedented rates of urbanisation (United Nations, 2018), have been identified as an important threat to biodiversity conservation at a global scale (Grimm et al., 2008; Güneralp & Seto, 2013; Seto, Güneralp, & Hutyra, 2012). But as the view that nature improves mental health becomes more commonplace (Hartig & Kahn, 2016; Hartig, Mitchell, de Vries, & Frumkin, 2014; Keniger, Gaston, Irvine, & Fuller, 2013), the loss of natural ecosystems and biodiversity also represents a major challenge to human mental health and wellbeing (Dean, van Dooren, & Weinstein, 2011; Sandifer, Sutton-Grier, & Ward, 2015; Wood et al., 2018). This is particularly the case in urban areas where nature is predominantly accessed through a fragmented network of multi-functional green and blue spaces, such as parks, public and private gardens, street trees, lakes, ponds and community gardens. The role of greenspace in delivering mental health benefits in addition to other ecosystem services (ES) such as air quality regulation (Escobedo, Kroeger, & Wagner, 2011), biodiversity maintenance (Beninde, Veith, & Hochkirch, 2015; Goddard, Dougill, & Benton, 2010), and recreation (Kaczynski & Henderson, 2007; O'Brien et al., 2017) has been widely studied. As increased rates of urbanisation further restricts the urban greenspace network (Fuller & Gaston, 2009), billions of people may lose the opportunity to interact with, benefit from, or develop an appreciation of nature (Fuller & Gaston, 2009; Miller, 2005; Pyle, 1978; Turner, Nakamura, & Dinetti, 2006). This 'extinction of experience' (Pyle, 1978; Soga & Gaston, 2016) comes at a critical point: globally depression is the leading cause of ill health and disability (World Health Organisation, 2017). The associated economic and social costs of mental health are significant. For example, for the 28 European Union countries approximately 84 million people had a mental health problem in 2016, the annual cost of which is estimated to be in excess of 600 billion euros (approximately 4% of GDP) (OECD/EU, 2018). What is needed is a sound understanding of how greenspace (broadly defined to be inclusive of blue space) can be effectively exploited or designed to enhance mental health. Such evidence not only helps mitigates the current mental health crisis, but also presents one of the many arguments for biodiversity conservation (Sandifer et al., 2015; Wood et al., 2018) and supports the improvement, integration and expansion of greenspace in urban environments (Dean et al., 2011; Hartig & Kahn, 2016).

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The past three decades have seen an accumulation of theoretical and empirical evidence on the association between greenspace (and to a lesser extent, blue space) and mental health. This has coincided with the popularisation of Wilson's biophilia hypothesis that humanity has an innate affinity for the natural environment, evolved through natural selection (Wilson, 1984). Theoretical research has largely been concentrated within the discipline of environmental psychology with the development of two prominent mechanistic pathways (Box 1). By contrast, empirical evidence for the relationship between greenspace and mental health from experimental and observational studies are published across multiple disciplines. In an attempt to offer generalisations concerning greenspace-mental health relationships, a growing number of systematic reviews have been published. However, systematic reviews are characterised by their specific scope, as they focus on either narrowly-defined questions or methodological approaches (Nakagawa et al., 2019). Therefore, systematic reviews may not adequately characterise the diverse methodological approaches that exist across multiple disciplines (Miake-Lye, Hempel, Shanman, & Shekelle, 2016). For example, Tillmann, Tobin, Avison, and Gilliland (2018) and Vanaken and Danckaerts (2018) synthesised studies measuring greenspace exposure effects on children and adolescents; with findings limited to these age groups. Gascon et al. (2015) reviewed studies that used objective greenspace measures (i.e., repeatable measures derived from remotely sensed data, Normalized Difference Vegetation Index (NDVI)) that were assigned to a person's location of residence. Consequently, the included studies were predominantly from disciplines that typically adopt this methodological approach, such as in public health and epidemiology, and disciplines such as psychology and social sciences were comparatively underrepresented. The scope of included literature within existing systematic reviews is further limited by the adopted definitions of nature or greenspace. Many studies outside of ecology use the terms 'nature', 'biodiversity', or 'green' and 'blue' synonymously (Botzat, Fischer, & Kowarik, 2016; Keniger et al., 2013). For example, Gascon et al. (2015) used a broad definition of greenspace that included blue space, whereas Houlden, Weich, de Albuquerque, Jarvis, and Rees (2018) and Lee and Maheswaran (2011) defined it more narrowly to include only urban parks and open spaces. Variation in definitions of greenspace among disciplines (Taylor & Hochuli, 2017) is problematic for reviews, as syntheses that adopt a narrow definition may omit entire disciplines and methodological approaches. The narrow scopes of previous reviews means that a broad synthesis of the greenspace (inclusive of blue space) and mental health literature is lacking, and urgently required to direct future interdisciplinary research efforts.

Box 1: Mechanistic Pathways

Attention Restoration Theory (ART) proposes that vegetation and other natural features attract and hold a person's attention without effort, enabling the rest of the neurocognitive mechanism on which effortful attention depends (Kaplan & Kaplan, 1989; Kaplan, 1995; Kaplan & Talbot, 1983).

Stress Reduction Theory (SRT) proposes that contact or viewing vegetation and other natural features can rapidly result in a positive effect within a person experiencing acute stress, which in turn can block negative thoughts and feelings (Ulrich, 1983; Ulrich, Simons, Losito, Fiorito, & Miles, 1991)

Achieving such a broad synthesis requires a systematic mapping methodology. Systematic mapping uses established searching protocols and a rigorous inclusion criteria to identify, categorise, and synthesise the available literature on a particular topic (James, Randall, & Haddaway, 2016). Systematic mapping is a recognised robust, repeatable, and transparent scientific method that is commonly used in social sciences (Haddaway, Bernes, Jonsson, & Hedlund, 2016; James et al., 2016), and is now increasingly adopted in environmental management and conservation (e.g. Randall, Donnison, Lewis, & James, 2015). Unlike a systematic review, systematic maps are not used to address a specific question but facilitate a broad synthesis of a research field (Nakagawa et al., 2019), by identifying and describing the nature, volume and characteristics of the evidence base (James et al., 2016). Results can highlight knowledge gaps and direct future research priorities, including primary and secondary research, synopses of evidence, systematics reviews, and meta-analyses (Haddaway et al., 2016; James et al., 2016).

In this study, we provide a broad synthesis of the literature evaluating the relationship between mental health and greenspace (inclusive of blue space) using a systematic mapping methodology. To our knowledge, this paper will be the first within the greenspace and mental health review literature to adopt a systematic mapping methodology to describe and catalogue studies of greenspace effects on mental health. Specifically, we characterise the range of methodological approaches adopted, identify trade-offs across disciplines and identify knowledge gaps that present opportunities for future research.

2. Methods

Standard systematic mapping methods (Collaboration for Environmental Evidence, 2013; James et al., 2016) were followed to collate empirical studies that aimed to identify the effects of greenspace in a person's environment on mental health. Definitions of greenspace are context-dependent and the term can be synonymous with 'nature' (Taylor & Hochuli, 2017), may describe specific natural settings (e.g., parks, gardens or forests), or natural elements (e.g., street trees), or can extend to include 'blue space' (e.g., lakes, ponds and coastal zones). As such, we used multiple terms: (green* or blue* or "natural space" or "natural area" or "natural environment" or land* or ecosystem or "open-space" or "open space" or garden* or wilderness or outdoor or wood* or park or forest* or countryside or allotment or biod*) and mental health ((mental or psycholog* or emotion*) AND (health or wellbeing or "well-being" or "well being")).

The literature search was completed using the ISI Web of Science in August 2018. Retrieved articles were exported from Web of Science into R version 3.4.2 as a single library (R Core Team, 2017). Using the R package metagear (Lajeunesse, 2016), articles identified through the search process were 'blinded' and their title and abstract screened for their potential relevance against the following criteria:

a) Studies that evaluated a quantitative measure of mental health outcome(s) in relation to a quantitative measure of the natural environment were included. Studies that evaluated the effects of natural or environmental hazards, such as air pollution, were excluded due to their potentially confounding effects of health hazards on the relationship between greenspace and mental health.
b) Mental health outcomes only included those associated with mood and anxiety disorders, due to stronger links with the theorised ART and SRT pathways (Box 1). Mental health outcomes relating to psychotic, eating disorders, dementias and other neurodevelopment disorders were excluded.
c) Only studies published in English within peer-reviewed journals were included. Purely descriptive or opinion pieces in addition to editorials, conference abstracts, methodological papers, book chapters and reviews were excluded.
d) Studies that solely assessed mental health outcomes relating to indoor "greening", or greening of the work or educational environments were excluded.
e) The study population were non-institutionalised people (i.e., those who are exposed or have the opportunity to be exposed to greenspace in their home/daily living). On this basis, studies in prisons, nursing homes or in hospitals were excluded.
f) Studies on all age groups were included.
g) No date restrictions were applied, but the search was limited to the scope of the Web of Science database.

The inclusion criteria were applied by the lead author (RMC) at the title and abstract level to ensure consistent understanding of the inclusion criteria.

2.1. Coding studies into a systematic map database

For the articles that met the review criteria, key variables were used to describe, categorise and code the studies, including: publication year, country, web of science research discipline, data source, study population, study population age, sample size, and study design. Study designs were defined as either 'experimental' or 'observational'. Experimental studies were those carried out in a controlled or manipulated environment to determine the causal effect of a certain condition. Observational studies used data reported by, or about, the individual and the researcher made no change to the environment. For observational studies, measures of environmental exposure were classified into one of four categories; 'proximity' to greenspace, 'quality' of greenspace, 'quantity' of greenspace, or a 'visit or activity' to or in greenspace. Greenspace "quality" is arguably the most subjective measure, since definitions can relate to one or multiple greenspace characteristics such as aesthetics, safety, walkability, biodiversity, or the availability of social activities (Gascon et al., 2015). For this assessment, we have adopted a broad definition of quality (Table 2) to ensure that the multiple methods used to measure greenspace quality are represented within the systematic map's findings. Additional variables and their definitions coded for experiments and observational studies are outlined in Tables 1 and 2, respectively. The categorised variables were used to create a searchable map or database to identify key trends in the research, knowledge clusters and knowledge gaps. The database enables analysis by allowing simple numerical frequencies of each category, in addition to more complex cross-tabulations.

2.2. Visualising the systematic map with correspondence analysis

We use correspondence analysis (CA), an indirect gradient analysis ordination technique, to objectively visualise multiple study-wise variables within one figure (Hill, 1974). The exploratory nature of indirect gradient analysis makes methods such as CA suitable for the application to systematic maps. The graphical outputs, such as correspondence plots, enables the visualisation of multiple study characterises simultaneously. Similar row (study) and column (characteristics) are distributed in two-dimensional space enabling category level comparison of their association. For this application, CA was used in favour of DCA as there was no observable "horseshoe effect" (Hill & Gauch, 1980). The R package 'FactoMineR' (Lê, Josse, & Husson, 2015) was used to perform all ordination analysis. Two additional visualisation packages 'ggplot2' (Wickham, 2016) and 'ggrepel' (Slowikowski, 2017) were used to develop the correspondence plots.

3. Results

The search terms returned a total of 6,059 articles, 543 of which met the inclusion criteria from their title and abstract, and were explored in full. A total of 271 papers met the inclusion criteria following a full text review and were included in the final systematic map (Fig. 1). Of the 271 papers, four papers had multiple studies which were included in the map as separate records. There were a total of five additional studies from these four papers, as a result the total number of studies within the map was 276, of which 124 were experimental studies and 152 were observational studies (Fig. 1).

The 276 studies came from 104 different journals and from 36 different Web of Science defined disciplines. A total of 205 studies were distributed across 37 journals, with the greatest number of studies published in the International Journal of Environmental Research and Public Health (18%), followed by Landscape and Urban Planning (10%), Journal of Environmental Psychology (9%), Urban Forestry & Urban Greening (9%), and Health and Place (9%). The remaining 67 journals published a single paper each.

If we do not consider 2018 (due to only 8 months' worth of data), the number of published articles assessing the association between greenspace and mental health increased exponentially between 1995 and 2017 (Fig. 2), with a substantial increase occurring from 2013 onwards (Fig. 2). Accounting for 24% of all studies, 2017 was the peak year for publications, of which 52% were observational (Fig. 2).

3.1. Observational studies

Observational studies were published across 62 journals. The greatest number of which were published in the International Journal of Environmental Research and Public Health (12%), followed by Health and Place (10%), Landscape and Urban Planning (8%), and Urban Forestry and Greening (6%). A total of 41 journals published only one paper.

The correspondence plot (Fig. 3) shows the diversity of approaches employed in the observational studies (green dots). The plot displays the first two dimensions, which together explained 35% of the total variability in study characteristics (Table 2). Dimension 1 explained 19.5% of the variation, and represented studies that included interaction effects, sensitivity tests, and measures of greenspace "quantity" in the positive quadrant, and a tendency of studies to measure exposure to greenspace as a "visit or activity" in the negative quadrant. Dimension 2 explained 15.4% of the variation, and was most closely related to studies that used longitudinal analysis, assessment made at multiple spatial scales, and exposure measures of "proximity" on the positive quadrant, and blue space assessment on the negative quadrant.

The global pattern and distribution of the greenspace exposure measures showed that greenspace "quantity" was negatively correlated with greenspace "quality" or "proximity" along Dimension 2 and a greenspace "visit or activity" along Dimension 1 (Fig. 3). Greenspace "quantity" is the predominant measure of greenspace exposure (61% of observational studies). By year, from 2013 onwards, greenspace "quantity" has remained the most commonly adopted exposure measure followed by a measure of greenspace "visit or activity" (Fig. 4). The frequency of studies using measures of greenspace "quality" peaked in 2017 (Fig. 4). The number of observational studies peaked in 2017, which included those that assessed blue space (Fig. 5). Investigations that focused on blue space accounted for 25% of all observational studies. However, unlike the general exponential increase in observational studies (Fig. 4), the publication of blue space studies has varied over time (Fig. 5). Studies that included a measure of blue space were negatively correlated with measures of "proximity" and "quality", and positively associated with studies that assessed the "quantity" of greenspace (Fig. 3).

A total of 26 studies used longitudinal analysis to explore the effect of greenspace on mental health. The majority of longitudinal studies (n = 20) assessed exposure as "quantity" of greenspace (Table S1-2). As

Table 1
Definition of coded variables for experimental studies.

Coding Variable	Categories	Definition
Intervention	Activity	Experimental studies that evaluated the effect of a prescribed activity in greenspace, including walking, gardening and 'green exercise'.
	Passive	Experimental studies that assessed the impact of the participant observing greenspace in person (with no other form of interaction).
	Pictorial	Experimental studies that assessed the impact of images and videos of the greenspace.
	Sensory	Experimental studies that assessed the impact of sound, audio clips, or smells of the greenspace.
	Mixed	Experiments that adopted more than two intervention methods.

Table 2
Definitions of coded variables for observational studies.

Coding Variable	Categories	Definition
Environmental exposure	Proximity	A measure of distance to greenspace.
	Quality	A multi-dimensional measure of the greenspace's "micro" features or characteristics (e.g., biodiversity or self-reported quality).
	Quantity	A measure of the total amount of greenspace within a given area (e.g., percentage of land cover that is greenspace).
	Visit or activity	A measure of the number of visits to, or activities in, greenspace.
	Multiple	When two or more of the above exposures were adopted.
Blue space	Yes/No	Studies defined as 'Yes' included a measure of blue space within their exposure variable.
Measures of mental health	Single	Only one measure of mental health was used.
	Multiple	Two or more measures of mental health were used.
Data source	Primary	Data collected for the purpose of the study.
	Secondary	Data collected independently from the study but being utilised by the study for another purpose.
Analysis temporal scale	Cross-sectional	Data are from participants at a single point in time.
	Longitudinal	Data are obtained from the same sample at different points in time.
Analysis spatial scale	Single scale	The analysis used only one scale for exposure variable (exposure to greenspace).
	Multiple scales	The analysis used two or more scales for the exposure variable (exposure to greenspace).
Analysis of interactions	Yes/No	Studies defined as 'Yes' included interaction terms between independent variables i.e., an interaction between independent variables X and Y, means the value of the dependent variable Z is determined jointly by X and Y.Interaction variables included the use of mediation analysis, where the interaction is dependent on the sequence of variables i.e., X to M to Y, whereby the independent variable (X) causes the mediator (M) and the mediator causes the dependent variable (Z).
Sensitivity analysis	Yes/No	Studies defined as 'Yes' explicitly stated that sensitivity analysis was performed. Sensitivity analysis included: (i) an evaluation of the influence of parameters; (ii) the ranking of significant factors in accordance with their influence; and (iii) quantifying the uncertainty of the model.

such, the variable "longitudinal analysis" was most closely related to the "quantity" exposure measure and negatively correlated the exposure variables "quality" and "proximity" (Fig. 3), as well as studies that considered exposure to blue space.

All analytical variables ("analysis at multiple spatial scales", "analysis of interactions", "sensitivity analysis", and longitudinal analysis") were positively dispersed along Dimension 1 (Fig. 3). Analysis conducted at multiple scales tended to use the greenspace variables "quantity" and "proximity", a total of 23 and 12 studies, respectively (Table S1-3). The majority of observational studies included an interaction term within their analysis (n = 97) and did not carry out sensitivity analysis (n = 132). The variable "analysis of interactions" and the exposure measure "quantity" display a similar trajectory in the correspondence plot (Fig. 3), suggesting a high level of similarity. Of

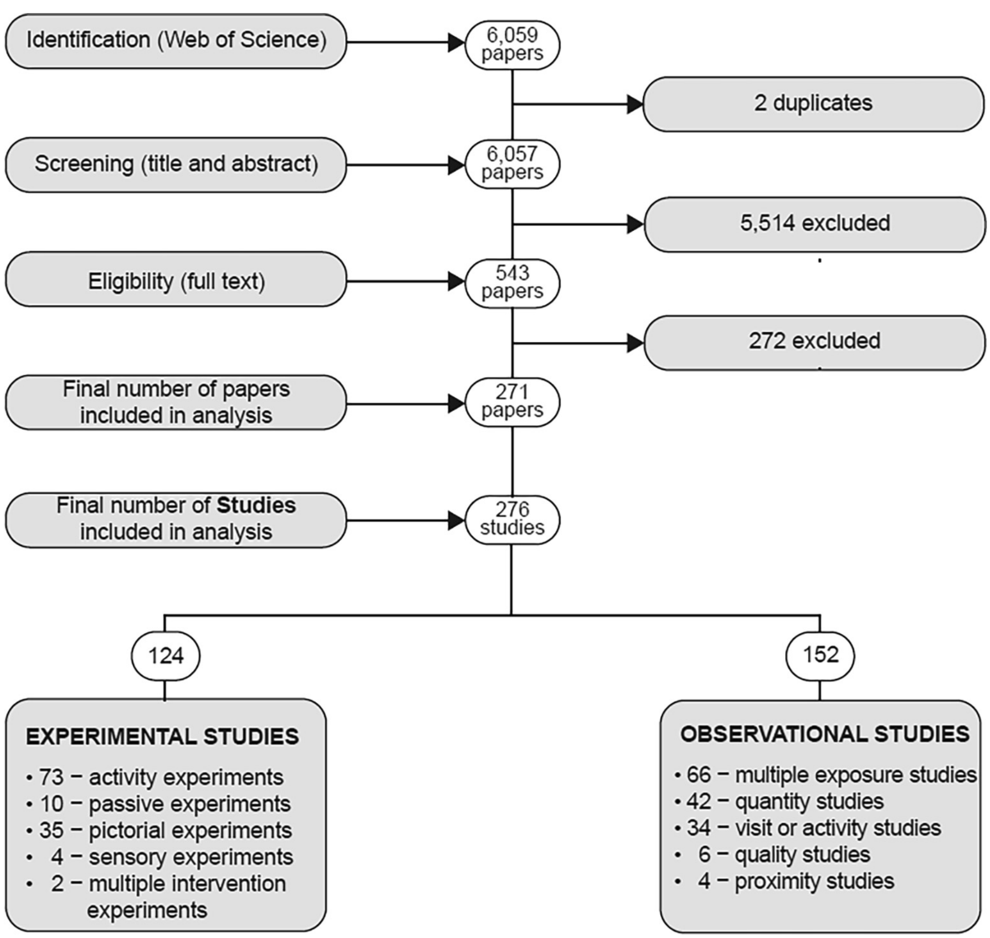

Fig. 1. A conceptual diagram showing the selection process for the papers and the respective number of studies (within papers) included in the systematic map.

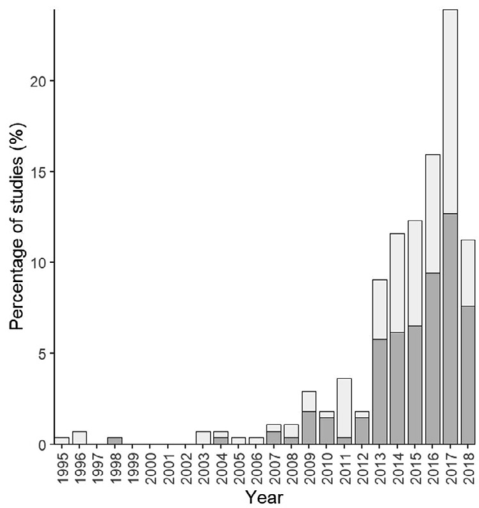

Fig. 2. Percentage of published studies by year (to August 2018) and study design.

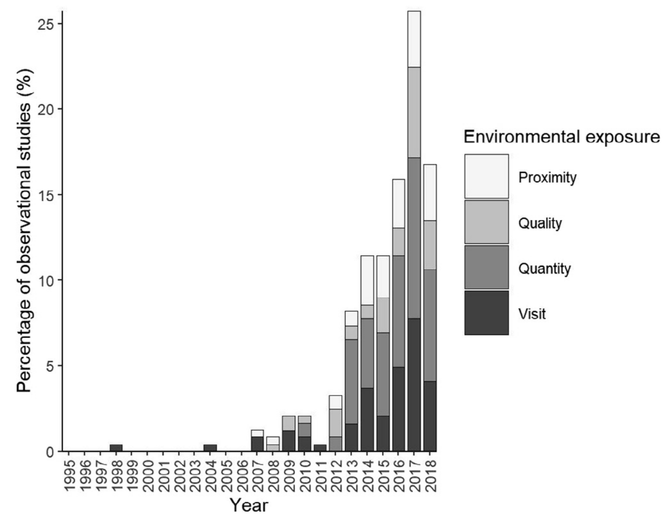

Fig. 4. Percentage of observational studies by year (to August 2018) and measure of greenspace exposure.

the 55 studies that included an interaction term, 21 assessed exposure to greenspace as "quantity", and 23 as "quantity" in addition to another exposure measure (Table S1-4). The variable "sensitivity analysis", showed strong similarity to studies that included interaction terms; 15 of the 20 studies that included sensitivity analysis also included interaction terms. As such, the variable sensitivity analysis was most similar to the exposure measure "quantity" (Fig. 3), 14 studies that performed sensitivity analysis used the exposure measure "quantity" of greenspace (Table S1-5).

A total of 55 studies used only one measure of mental health. The variable "single measure of mental health" is negatively correlated (along Dimension 1) with the variable blue space and greenspace measure of "quantity" (Fig. 3). Greenspace measures of "quality", "proximity" and "visit or activity" were more closely related to single measures of mental health (Fig. 3).

3.2. Experimental studies

The coded variables for experimental studies differ from observational due to fundamental differences in their design. The variety of different experimental designs used for the studies included in this analysis made it difficult to create multiple and comparable categories without a high number of missing or not applicable cases. Therefore, fewer categories for experimental studies were used to ensure categories were common and therefore comparable across all studies. The 124 experimental studies were published across 58 different journals with 38 journals having published one study only. The greatest number of experimental studies were published in the International Journal of Environmental Research and Public Health (15%), followed by the Journal of Environmental Psychology (10%), the Journal of Environmental Psychology (10%), Urban Forestry and Greening (7%)

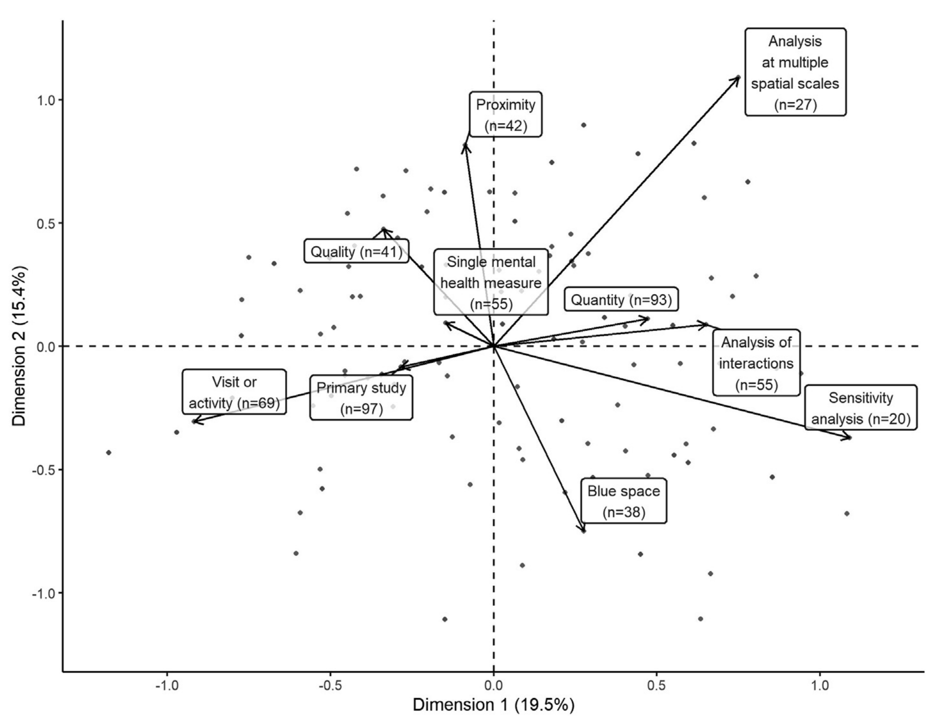

Fig. 3. Biplot of the first two dimensions of a correspondence analysis of the study characteristics (red vectors) of the 152 observational studies retrieved (blue dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

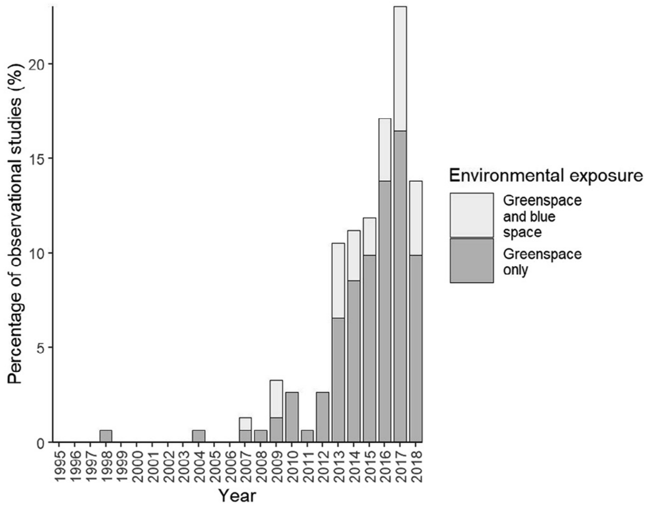

Fig. 5. Number of observational studies measuring greenspace and blue space by year (to August 2018). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and Landscape and Urban Planning (6%).

The number of experimental studies has increased over time (Fig. 6). The majority of studies, approximately 80%, were published during or after 2013, with the greatest number published in 2017. The majority of experimental studies (59%) assessed the impact of a prescribed activity on the participants' mental health. The average sample size of activity-based experiments was 75 participants, with maximum and minimum sample sizes of 498 and six participants, respectively. On average, pictorial experiments had the largest sample size with approximately 129 participants and a maximum and minimum sample size of 1,478 and 12 participants, respectively. On average, passive experiments where participants were exposed to greenspace, as opposed to imagery, had comparatively smaller sample sizes (e.g., approximately 50 participants).

Of the experimental intervention methods, pictorial experiments had the longest history, the first was published in 1995 (Fig. 6). By 2017, greater volumes of experimental studies were employing a greater variety of interventions (Fig. 6). The first sensory experiment was published in 2008 (Fig. 6). The maximum, minimum and average sample size for a sensory experiment was 90, 30 and 57 participants, respectively. More recent still were experiments that adopted multiple

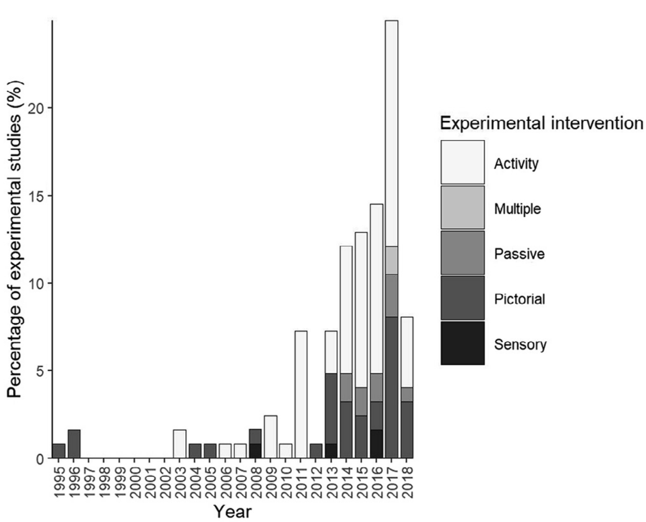

Fig. 6. Percentage of published experiments studies by year (to August 2018) and experiment intervention.

intervention methods, all of which were published in 2017. A total of two studies used multiple intervention methods with sample sizes of 47 and 43 respectively. The majority of experimental studies recruited participants from specific sub-populations. For example, a total of 45 studies used convenience sampling to recruit from students or university staff to participate in their experiments, and a further 24 experiments sampled from only one gender (male = 14).

3.3. Study location

Geographically, the majority of studies were from Europe (57%), North America (18%), Asia (15%), Australia and New Zealand (8%) and South America (1%). In terms of individual countries, the UK is overall the biggest contributor to this field accounting for 24% of all studies. Similar trends were observed for experimental and observational studies (Fig. 7), though Japan was particularly well represented for experimental work (15% of experimental compared to 6% of total studies), the majority of which used activities as an intervention. Sweden was the only country that performed all four experiment types; activity (n = 11), passive (n = 1), pictorial (n = 3), sensory (n = 2). Sweden therefore accounted for half of all sensory studies; the remaining two sensory experiments were from Austria and Italy.

4. Discussion

Since 1984, there has been an exponential increase in the number of quantitative studies that describe the relationship between nature and mental health. While there have been numerous reviews of different aspects of this very broad question, this systematic map is the first to broadly collate studies across the breadth of disciplines this research covers. Results show that the majority of studies identified in this systematic map were observational studies, which assess exposure to the natural environment as a measure of greenspace "quantity" against standardised measures of mental health, followed by experimental studies that assess the effect of a prescribed activity on mental health. These both represent knowledge clusters (i.e., the majority of studies) and are areas of research that are suitable for further knowledge synthesis, such as a systematic review or meta-analysis (Nakagawa et al., 2019). Although insight has and could be gained through exploring knowledge clusters (for examples see existing systematic reviews and meta-analysis), our discussion focuses on knowledge gaps identified from a broad synthesis of this field.

Although most commonly adopted for observational studies, the exposure measure "quantity" reflects the total amount of greenspace within a given area. As such, greenspace is either present or absent. What is not known from measures of "quantity" are the micro-features or multi-dimensional characteristics (i.e., "quality") or types of greenspace that are beneficial for mental health. Existing reviews have presented evidence that mental health benefits are likely to vary according to characteristics such as vegetation type (Markevych et al., 2017) and inclusion of blue space (Gascon, Zijlema, Vert, White, & Nieuwenhuijsen, 2017). These 'micro' features of greenspace can be classified as measures of greenspace "quality", and it is measures of greenspace "quality", rather than "quantity", that are recognised as a priority for future research (Hartig et al., 2014). Furthermore, measures of "quality" present the opportunity to assess whether attributes of greenspace are beneficial to both ecological and psychological well-being. Of the existing "quality" studies, the majority are cross-sectional and are limited in that they can only identify association and not causation. Experimental studies can identify causation, however, they are characterised by small sample sizes and a narrow geographic range that limits the conditions in which results can be applied. The use of secondary longitudinal data is recognised as a tool for identifying causal greenspace and mental health relationships for free-living populations (Hartig et al., 2014; Pearce, 2018) as compared to cross-sectional designs (McIntosh et al., 2016). Despite the acknowledged benefits of

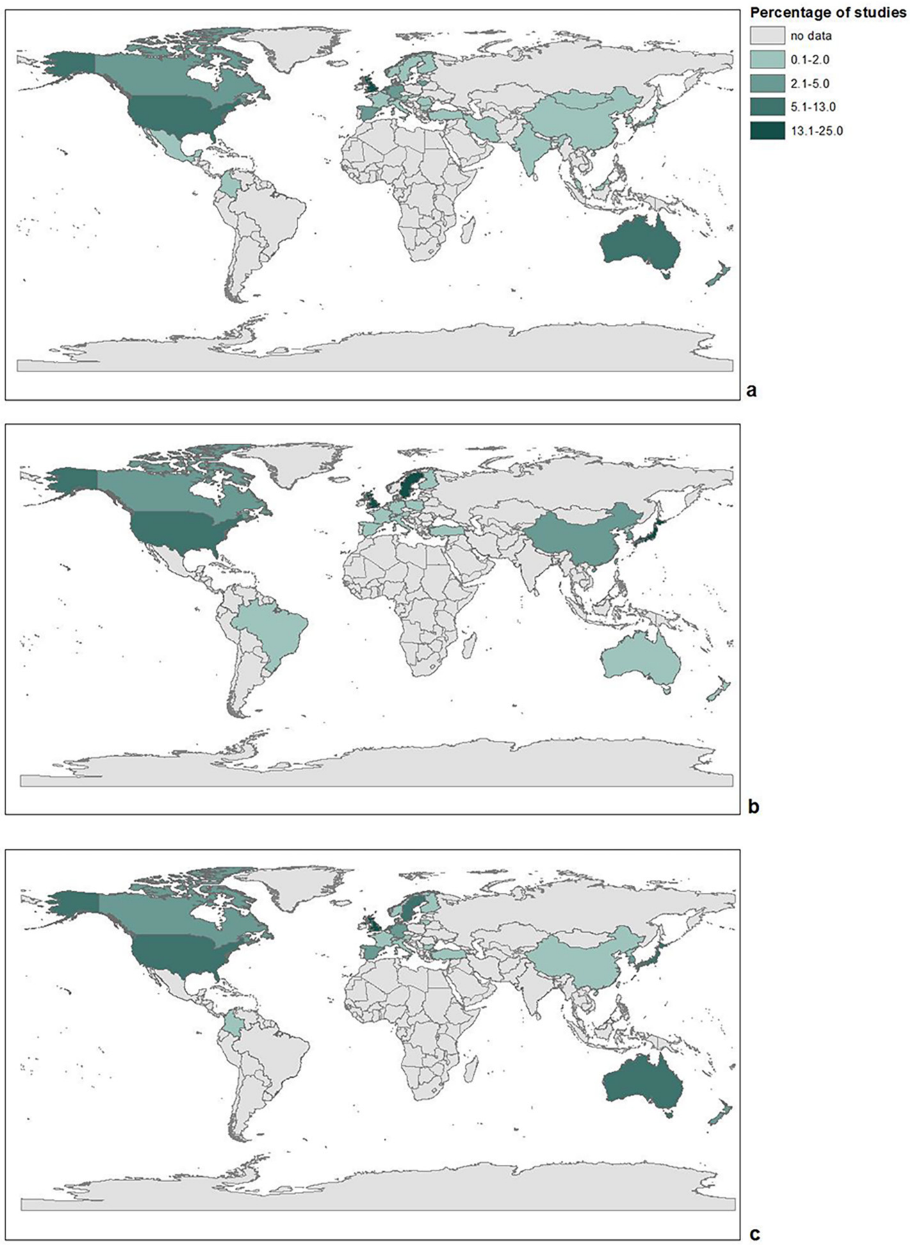

Fig. 7. Global distribution of the retrieved studies. In this figure (a) is observational studies, (b) is experimental studies, and (c) is total of all studies.

longitudinal assessments few have been undertaken for greenspace "quantity" (i.e., the majority of studies). Fewer still focus on greenspace "quality" (i.e., the priority for future studies), and none have assessed "quality" of greenspace longitudinally at multiple spatial scales. This is an important consideration, as the critical scale at which people interact with nature is not known and any observed changes in effect size may be the true effect of the relationship or a statistical artefact. As there is no single scale to study and manage biodiversity and ES (Spake et al., 2019), the scale of effect should be considered alongside the scale of management interventions to ensure the management of urban greenspace is compatible with wider scale biodiversity targets.

4.1. Observational studies

Observational studies offer the opportunity to study 'realistic' environmental exposures in 'realistic' settings, and therefore better indicate the long-term impacts compared to experimental study findings (Frumkin et al., 2017). The correspondence plot revealed several clusters of observational studies adopting similar research methods. Trade-offs among research methods are apparent and represent future avenues of research.

The majority of studies use a measure of greenspace "quantity" as a way to evaluate an individual's exposure to greenspace. Measures of "quantity" treat all greenspaces as homogenous and are too coarse to account for detailed, small-scale environmental changes that could influence mental health (James, Banay, Hart, & Laden, 2015). Also, using "quantity" as the sole exposure measure does not explicitly describe the biodiversity being considered with terms such as urban greenspace, forest or parks being adopted without detailed explanation of ecological features they contain (Bratman, Hamilton, & Daily, 2012; Clark et al., 2014). Consequently, research using only measures of "quantity" is not sufficient to inform either conservation efforts or public health policies (Dean et al., 2011; Francis, Wood, Knuiman, & Giles-Corti, 2012; Taylor & Hochuli, 2017). As previously mentioned, it is the consideration of the micro-features (or "quality") of greenspace that is an important for future studies (Francis et al., 2012; Hartig et al., 2014; Jorgensen &

Gobster, 2010), as benefits are likely to vary according vegetation types, as well as spatial and temporal characteristics (Markevych et al., 2017). Greenspace "quality" can be quantified from two perspectives: human and ecological (Gaston et al., 2018; Wood et al., 2018). From a human perspective, the micro-features considered are factors that make greenspace feel safe and accessible, such as greenspace cleanliness, lighting, and availability of amenities (for examples see de Gelder et al., 2017; Parra et al., 2010; Pope et al., 2018). Alternatively, an ecological perspective would result in the quantification of factors such as habitat diversity, species diversity, or ecological functions (for examples see Cox, Shanahan, et al., 2017; Dallimer et al., 2012; Taylor & Hochuli, 2017). Although a human perspective of "quality" is needed to ensure that people will interact with greenspaces (and therefore nature), designing and managing greenspace purely from a human perspective might exclude species perceived as undesirable or threaten the ecological integrity of urban greenspaces (Stanley et al., 2015; van Heezik & Brymer, 2018). The reverse is true from an ecological perspective whereby species considered important for conservation my not reflect the type needed for psychological benefits (Gaston et al., 2018). Critically, without an ecological perspective, urban greenspaces will become increasingly biodiversity-poor and lead to compromised ES (van Heezik & Brymer, 2018). As few studies consider greenspace "quality", and fewer still both human and ecological perspectives of "quality", there is limited evidence whether a trade-off between the two perspectives exists. Therefore, future studies need to consider both perspectives to ensure both psychological and ecosystem wellbeing.

It is important to consider the comparability and repeatability of future studies and use approaches that obtain measures of "quality" without resorting to costly and difficult to scale methods such as site surveys. The use of remotely sensed data is one solution for future measures of greenspace "quality". Presently, remotely sensed data are more commonly used in the greenspace and mental health studies as a measure of greenspace "quantity" rather than "quality", because specialist technical skills and training are required for further processing (Markevych et al., 2017; Shoshany, 2012). Furthermore, studies may be restricted in their use of remotely sensed data by the spatial and temporal availability of satellite images (Markevych et al., 2017). However, eight studies use secondary data sources to create quantitative and repeatable measures of "quality". Tsai et al. (2018) used the US' 2011 National Land Cover Database to generate seven landscape metrics, such as patch density and edge density to characterise landscape patterns. Results showed that these characteristics had a stronger association with mental health than a presence-absence (or "quantity") approach. Similarly, Annerstedt et al. (2012) used the National Land Survey of Sweden to map five predefined green qualities ("serene", "wild", "lush", "spacious", and "culture"). Interestingly, results for this study showed that mental health was not affected by access to, or the amount of, the chosen green qualities. These studies demonstrate that objective and repeatable measures of greenspace "quality" are possible, and an increase in the number of studies measuring greenspace "quality" in this way will enable the comparison between studies, and the identification of greenspace qualities that promote better mental health.

The approach for measuring mental health is as important a consideration as the exposure measure. This systematic mapping approach showed that studies measuring "quality" are closely related to studies measuring only one measure of mental health, which supports findings from existing reviews whereby "sophisticated" measures of greenspace has focussed on a relatively narrow range of human health and wellbeing measures (Jorgensen & Gobster, 2010). Mental health and wellbeing are comprised of both happiness and life satisfaction, and not just the absence of mental distress (World Health Organisation, 2016). As identified by previous reviews (e.g., Houlden, Weich, & Jarvis, 2017), multidimensional measures of mental health are required (Tennant et al., 2007). Therefore, there is a requirement for future research to explore in more detail the effect of different outcome measures used when looking at the effect of greenspace "quality" has on mental health.

Relative to greenspace, blue space research is in its infancy and the blue space concept is not common (Gascon et al., 2017). Understanding of whether greenspace includes blue space differs in the literature (Taylor & Hochuli, 2017). We recognise that the relative absence of blue space studies in this map may be a result of not using multiple blue space search terms such as lakes, ponds and ocean. Even so, the results agree with the existing literature and reviews increasingly acknowledge the relative absence of blue space research. One review has called for the increase in the number of longitudinal assessments and natural experiments to better understand the causal associations between blue spaces, health and wellbeing as well as the influence of change in circumstances and exposure over a life course (Gascon et al., 2017). However, the correspondence plot indicates that there is a level of similarity between studies adopting longitudinal assessments and measure of blue space. Nine of the 26 longitudinal studies assess blue space. The priority areas for future research would be the variables negatively correlated with blue space, such as using exposure measures of "quality" and "proximity". Only two studies identified within the map assess greenspace "quality" whilst considering blue space (i.e., Bakolis et al., 2018; Beute & de Kort, 2018). In both studies, participants used the smartphone applications (apps) to report the presence or absence of water, in combination with other natural features, to indicate exposure to "quality" of greenspace. Although the presence of blue space has been considered as a component of environmental "quality", the "quality" of blue space has itself not been taken into account. Subsequently, these two studies do not consider a life course perspective as they only follow participants for one week taking multiple measures of mood and natural environment exposure per day. Therefore, "quality" assessments of exposure to blue space (in addition to greenspace) remains a gap in the literature.

Existing reviews, both systematic and narrative, have identified longitudinal assessment of the relationship between greenspace and mental health as a research priority (e.g., Hartig et al., 2014; Houlden et al., 2018). Generally, longitudinal studies benefit from large sample sizes across a wider geographic space, for example the UK's British Household Panel Survey (BHPS) (University of Essex, 2018a), Understanding Society (University of Essex, 2018b), and Berlin Aging Study (Baltes, Mayer, Helmchen, & Steinhagen-Thiessen, 1993). Unlike cross-sectional studies, longitudinal studies track habits over time (often a life-course), and can provide stronger evidence of causality, at a broad geographic extent (Pearce, 2018). Although there is considerable debate about the circumstances under which causal inference can be tested and assumed (Lawlor, Tilling, & Smith, 2016; Munafò & Davey Smith, 2018; Pearce & Lawlor, 2016), the temporal perspective of longitudinal studies might enable researchers to identify points in time when exposure to the greenspace can generate the greatest benefit (Astell-Burt, Mitchell, & Hartig, 2014; Pearce, 2018). The map identifies a total of 26 longitudinal studies, and this low representation suggests that studies on greenspace and health have primarily relied on cross-sectional designs to establish association (Craig & Prescott, 2017; Hartig et al., 2014; Markevych et al., 2017). Results from both cross-sectional and longitudinal studies are complementary to understanding greenspace-mental health relationships. The integration of these different approaches, each with different types of biases, will allow for improved understanding of greenspace-mental health relationships (i.e., 'triangulation', Lawlor et al., 2016).

The majority of longitudinal studies use "quantity" of the greenspace as the exposure variable, hence the comparatively closer proximity of these variables within the correspondence plot. However, cross-sectional studies have identified that "quality" of the greenspace such as amenities or species composition, have the potential to change interaction and therefore influence mental health benefits (e.g., Francis et al., 2012). Despite cross-sectional evidence, the correspondence plot illustrates that "quality" of greenspace in combination with longitudinal assessment remains underrepresented with only seven studies addressing this gap. This being said, the number of assessments of "quality" are increasing over time, as are the number of assessments considering "quality" alongside other exposure measures. Assessment of multiple exposure measures are an important consideration, as evidence shows that different types of exposure are associated with different aspects of wellbeing (White, Pahl, Wheeler, Depledge, & Fleming, 2017). To establish what types and characteristics of greenspace affect mental health at different points of a life-course, future research should increase their use of "quality" measurements combined with longer term longitudinal health data (Hartig et al., 2014).

Studies within the systematic map adopt different exposure measures, at differing spatial scales and few studies have identified what the most appropriate geographical scale is for defining exposure to the greenspace. As a result, not enough is known about the critical scales at which people interact and experience the greenspace (Astell-Burt et al., 2014; Jorgensen & Gobster, 2010), or whether the scale at which the interaction occurs aligns with suitable scales for biodiversity conservation. Existing studies have highlighted the possibility that different effect sizes may occur as a result of neighbourhood level exposures being measured at different scales (e.g., Astell-Burt et al., 2014). This may be the 'real' effect of scale and the effect of greenspace may affect people's mental health at different scales (Openshaw, 1984), or alternatively, it may be an artefact of the modifiable areal unit problem (MAUP), whereby analytical results for the same data in the same study area differ depending on the scale adopted (Openshaw, 1984). Attention should be paid to the MAUP, and as there is no available information of how to optimally define exposure for different health outcomes, pathways and population groups, several scales, buffer sizes and shapes should be tested. Adopting methods commonly used in landscape ecology presents an opportunity to do so. For example by using a 'scale of effect' approach that examines explanatory variables characterised within the same focal areas but at varying grain sizes (Jackson & Fahrig, 2012). This allows identification of the scale at which a relationship exist; i.e., the scale at which a given variable has the strongest statistical relationship (Holland, Bert, & Fahrig, 2004). Tools developed within landscape ecology have been developed to automate and simplify multi-scale analysis. For example, the R function *multifit* (Huais, 2018) has been developed to simultaneously run multiple statistical models for a response variable at multiple spatial scales and visualise model outputs in a simple way, allowing users to select to compare and select the most appropriate scale.

In many cases the scale at which the analysis is performed is dependent on the grain at which health data can be obtained (Pearce, 2018). Thus, analysis is often limited to administrative geographic units. Administrative geographic units have been determined for purposes other than the study's aims and may be awkwardly shaped, create edge effects, or impose an inappropriate neighbourhood scale (Branas et al., 2011). There is limited evidence that administrative boundaries are an appropriate scale to assess exposure to greenspace, nor is there evidence that management at these boundary levels is suitable for biodiversity conservation. There is no single natural scale at which biodiversity should be studied (Levin, 1992). Ecological systems demonstrate variability at a range of spatial scales, and as management boundaries are not based on these ecological considerations, but instead based on socio-economic factors such as administrative boundaries and ownership, spatial mismatches occur (Borgström, Elmqvist, Angelstam, & Alfsen-Norodom, 2006; Cumming, Cumming, & Redman, 2006; Cumming, Olsson, Chapin, & Holling, 2013). Spatial mismatches are an important cause of failure in natural resource management and are often more pronounced in urban landscapes, where nature is scattered in small and dissimilar patches (Borgström et al., 2006). This makes it difficult to target and coordinate appropriate management (Cumming et al., 2006). Until an understanding of scale-dependent management effects is achieved (Spake et al., 2019), biodiversity within urban greenspace must be managed at multiple scales whilst also considering the scale at which the nature and mental health relationship exists. Without the co-ordination of management resources at multiple scales, management practices used at smaller scales can be incompatible with wider scale biodiversity targets (Aronson et al., 2017).

Moreover, administrative boundaries may not be the appropriate unit of measurement to aggregate area level confounding factors (Markevych et al., 2017). All assumptions about individuals based on aggregate data are vulnerable to ecological fallacy, as the relationship may be a result of data aggregation effects rather than any real association (Openshaw, 1984). This can become more pronounced when a series of confounding factors are unaccounted for, as confounding factors can result in bias and a change in effect size. Sensitivity analysis offers one solution to assess the impact of unmeasured confounding factors (Markevych et al., 2017). Yet very few studies within the map have conducted sensitivity analysis and the correspondence plot shows that these two characteristics ("sensitivity analysis" and "analysis at multiple spatial scales") are negatively correlated along Dimension 2. As previously mentioned, one of the benefits of longitudinal analysis is addressing confounding factors. However, the correspondence plot shows that the variables of analysis at multiple scales and longitudinal analysis are also negatively correlated on Dimension 2. Of the 27 studies assessing multiple scales, only two longitudinal perform analysis at multiple scales and both assess "quantity" using repeatable exposure measures such as NDVI and land use cover. The first, Gariepy, Blair, Kestens, and Schmitz (2014) was used in a sensitivity model to determine which area was most relevant for analysis, a buffer of 500 m was determined to have the best fit in the model. The second, Picavet et al. (2016), found a significant association between greenspace and depressive complaints within a 1 km radius and not a 125 m. It is plausible that no single scale is relevant across all stages of the life-course (Astell-Burt et al., 2014) and there is a need for more longitudinal assessments measuring exposure at multiple scales to consider establishing this. In addition, further consideration needs to be given as to whether the scale at which the greenspace mental health relationship exists aligns with the scale at which greenspace should be managed to ensure longevity of benefits, and by using methods and tools commonly adopted in landscape ecology (e.g., scale of effect, Jackson & Fahrig, 2012 and R function *multifit*, Huais, 2018) it is easier to link these to the ecological benefits of greenspace.

4.2. Experimental studies

Experiments are typically carried out in the earlier stages of research to establish associations that then inform the wider-scale survey and observational studies (Hartig et al., 2014). The proportion of experimental studies and the dominance of activity based experiments has remained consistent through time. Activity based experiments assume that participants interact intentionally (or actively) with greenspace. Intentional interaction means a physical engagement with greenspace as a primary activity (Keniger et al., 2013). However, the interactions with greenspace can also be passive (i.e., visual engagement with greenspace). With the 'extinction of experience' paradigm, active interaction with nature is becoming the exception as opposed to the norm (Cox, Hudson, Shanahan, Fuller, & Gaston, 2017). As a result, a person's connection to nature is now more positively associated with passive and incidental experiences (Cox & Gaston, 2016; Cox, Hudson, et al., 2017). More recent experimental studies have adopted alternative interventions to activities, including sensory and passive experiments that assess these incidental interactions. The overall number of these types of intervention are low ($n = 4$ and $n = 10$, respectively) and there is a need to for future studies to expand the evidence base for experiments assessing the incidental experiences of nature.

One of the notable feature of the experimental studies retrieved by this map are the small sample sizes and narrow study site or extent. This limits the conditions in which associations can be applied (Magliocca et al., 2018). Many experiments identified in the systematic map failed to obtain a representative sample, with a large number of experiments focusing on sub-populations, such as males only (n = 11), and university or college students (n = 25). This dominance of experimental studies using university students of the same gender has been noted by an existing review (Kondo, Fluehr, McKeon, & Branas, 2018). Other reviews have established that contact with nature is strongly patterned by socio-economic characteristics, which are themselves, linked to a person's health (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Hartig et al., 2014). Therefore, caution should be taken when generalizing these results, as they may be biased by experiences specific to these sub-populations. Despite potential limitations with generalization, 'true' experiments are still considered to be the 'gold' standard in science, as their controlled nature enables the identification of causal affect mechanisms (Magliocca et al., 2018). This is particularly beneficial when considering the use of new and innovative measures of mental health such as stress indicators cortisol, amylase, skin conductance (Beil & Hanes, 2013; Jiang, Chang, & Sullivan, 2014; Roe & Aspinall, 2011), and measures of brain activity including novel electroencephalogram (EEG) methods (Bratman, Daily, Levy, & Gross, 2015). Therefore, in order to account for the small samples sizes and to infer broader patterns it is necessary for future studies to repeat these small-scale experiments in different places and with different sub-populations.

4.3. Study location

The scope of countries carrying out research is limited, with the majority of studies concentrated within the UK and other North-West European countries. Many countries, particularly African and South American, are completely absent from the systematic map. This international bias may be a result of included publications only being written in English. However, it is a finding that is supported by results from previous reviews of the literature (e.g., van den Berg et al., 2015). The concentration of studies within cool temperate climates in countries with high income means there is low social and spatial variation in current findings (Frumkin et al., 2017). Cultural and environmental differences between countries may modify the greenspace and mental health relationship (Frumkin et al., 2017; Markevych et al., 2017). Therefore, the extent to which current knowledge can be generalised to countries absent from the systematic map in unknown. Future studies in under-represented low and middle-income countries are required. International collaborations, that enable inter-country comparisons, are also needed to improve understanding of how greenspace and culture influence reporting of mental health.

5. Conclusions and future research opportunities

To our knowledge, this is the first systematic map to explore research on the effect of greenspace on mental health. As a systematic map, this study presents evidence of knowledge clusters and gaps from trade-offs between research methods within the broader literature. Knowledge clusters (e.g., observational studies that used measures of greenspace "quantity" and experimental studies that assessed the impact of an activity in greenspace on mental health) present the opportunity for a more detailed data synthesis method (e.g., a systematic review or meta-analysis). Such approaches make a logical follow-on from this study, but require a narrower inclusion criteria to enable the comparison of results, and given the existing numbers of such reviews, we believe that greater attention and research investment should be directed towards the map's identified knowledge gaps.

This map identified a knowledge gaps within in the methodological approaches adopted. The majority of observational studies used cross-sectional data to evaluate the relationship between greenspace and mental health. From these studies, it is not known whether there is a causal relationship between greenspace and mental health, nor the strength of such a relationship. Future research needs to assess the causality of the greenspace and mental health relationship and to do so experimental or longitudinal observational studies are preferred. As a result of small and unrepresentative samples, the experimental studies identified in this map are limited in their ability to make knowledge generalisations. Rather than prioritising research efforts to obtain representative samples for experimental studies we believe that longitudinal assessments, which also provide information across a life-course in addition to providing stronger causal inferences than standard observational approaches, should be the priority for future research and ultimately should become the methodological standard for evaluating greenspace and mental health relationships. Longitudinal assessments have been used to establish life course relationships for measures of greenspace "quantity" (e.g., Astell-Burt et al., 2014), but what is not known are what types and characteristics of greenspace, or greenspace "quality", effect mental health and whether this relationship extends to blue space "quality", or the critical scale at which this relationship occurs. For future studies, greenspace "quality" needs to be considered from both a human and ecological perspectives. The former to ensure that people will continue to interact with urban greenspaces, and the latter to maintain the ecological integrity of urban greenspaces and the provision of ES. Little is also known about whether management of greenspace for mental health has wider biodiversity or ES impacts. As there is no single scale to manage biodiversity and ES, the scale of the "quality" effect should be considered alongside the scale of management interventions to ensure that the management of urban greenspace is compatible with wider scale biodiversity targets.

Taking the above recommendations, a future study looking into the greenspace and mental health relationship might use a country wide longitudinal survey that consistently collects data on mental health, and create a composite measure of greenspace "quality" through identifying existing spatial data that have theoretical links with human and ecological perspectives of quality. One starting point for measuring "quality" would be identifying a high-resolution baseline level of "greenness" such as NDVI data at 30 m resolution from LandSat 8 (United Stated Geological Survey, 2017). This enables the identification of small areas of greenspace that may be missed by lower resolution land cover metrics commonly used in greenspace "quantity" measures. This being said, as discussed, it is not just the spatial resolution of data that indicates ecological "quality", this measure of greenness should be combined with additional sources of data to create a composite measure of "quality". For example, when using the UK as a case study, a baseline measure of NDVI could be combined with additional sources such as the Land Cover Map 2015 (Rowlands et al., 2015) that classifies land cover based on the UK Biodiversity Action Plan Broad Habitats classes, and the Ordinance Survey's Open Greenspace (Ordnance Survey, 2020) can be used to indicate more human aspects of "quality" within the UK such as allotments, sport facilities and play spaces. Such measures of quality could then be linked to longitudinal studies with consistent measures of mental health available to researchers. In the UK these include, the BHPS (University of Essex, 2018a) and Understanding Society (University of Essex, 2018b). Both of which provide annual data on participants' mental health. The statistical analysis of these data should include not only the multi-scale approach outlined earlier (Holland et al., 2004), but also careful consideration of the covariance structure and range of variance of the key predictors of both greenspace and mental health. The latter is important to insure robust statistical inference is possible from the study (Eigenbrod, Hecnar, & Fahrig, 2011); subsampling approaches can aid in achieving this (Fahrig et al., 2011). Although this example is UK centric, it shows how spatial data can be identified and their links between human and ecological perspectives of quality can be made. Adopting such an approach is beneficial for creating reproducible and objective measures of greenspace "quality".

Finally, knowledge gaps exist in the global distribution of research efforts, with the majority of studies concentrated within European countries and the USA. Future research is needed across a broader range of countries, particularly in those where it is currently absent, to better understand any cultural differences in the mental health benefits provided by nature.

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Appendix A. Supplementary data

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