VALUING NATURE PROGRAMME

VNP27

ENVIRONMENTAL SCIENCE AND MENTAL HEALTH REVIEW

Final Report to NERC Valuing Nature Programme
March 2021

Authors: Katherine N. Irvine, Michaela Roberts, Antonia Eastwood, Kathryn Colley, Mags Currie, and Zulin Zhang
The James Hutton Institute, Aberdeen, UK

valuing-nature.net/environmental-science-and-mental-health-review

Executive summary

This project considers the potential contribution that environmental science can make to mental health research and innovation, and interrogates exisiting research to identify evidence gaps and opportunities.

Approach

The research consisted of a systematic scoping review and three expert workshops. Mental health was interpreted broadly to include psychiatric illness, mental wellbeing, cognitive development and cognitive decline. A scoping review was used to identify knowledge gaps and provide an overview of approaches and evidence within the identified body of literature. The participatory workshops identified case study examples and informed findings and recommendations. Workshop participants comprised a mixture of environmental and mental health researchers.

Literature Synthesis

We synthesised global literature (202 final papers) from 2010 to 2020 that included environmental science and mental health. Several robust systematic reviews undertaken on climate change, flooding, air pollution and urban greenspace were identified, warranting exclusion from the scoping review. From these previous reviews, climate change, flooding and air pollution were predominantly associated with poor mental health whilst urban greenspace (proximity to, use of) was often associated with improved mental health.

The synthesis of scoping review papers related to clear thematic groupings, from which we identified the following broad conclusions:

- **Meteorological Conditions (general):** Studies used only secondary spatial data for environmental science but incorporated a wide range of mental health conditions. Generally, good weather was associated with improving mental health, and vice versa.

- **Meteorological Conditions (temperature):** Secondary spatial data or self-reported heat stress were predominantly used in studies. High temperatures were found to have a negative relationship to mental health. Temperature was generally considered independently of other weather variables.

- **Noise:** Studies included environmental data collection which modelled or measured noise. Almost all studies focused on negative sounds.

- **Natural Disasters (general):** The environmental science component was typically the presence of a disaster, with the exception of drought. Studies usually reported that natural disasters had a negative impact on mental health.

- **Natural Disasters (wildfire):** Studies were limited in their environmental science contribution to the presence of wildfire. Wildfires were linked to poor mental health.

- **Natural Environments (excluding greenspace):** Studies focused on forest and land-use. Forest activities were associated with good mental health, but environmental science contributions were limited. Diverse land use and types were found to impact mental health.

- **Pollution (general, excluding air pollution):** Industrial, agricultural and domestic pollutants were studied. Direct measures of exposure were examined. The effect on mental health varied by contaminant and exposure.

- **Pollution (oil spill):** Studies were primarily concerned with the US-based BP Horizon oil spill. Exposure assessment had limited contribution from environmental science. Mental health was commonly self-reported. Impact of spills on mental health varied with exposure.

The geographic bias within the literature highlights opportunity for research in other environmental settings, climatic conditions and socio-cultural contexts to enhance scientific understanding and development of relevant innovations. Research designs were largely cross-sectional, and methodological approaches largely quantitative.

Mental health outcomes have minimally considered cognitive development and decline, substance abuse disorders, delusional disorders, behavioural syndromes, and suicide and self-harm. There has been limited attention to the ways in which environments can support maintenance of 'good' mental health or promote wellbeing. There remains a knowledge gap in understanding what natural environment attributes related to observed changes in mental health and wellbeing. Overall, more substantive involvement of environmental science would strengthen measurement and facilitate deeper understanding of causal relationships.

Case Studies

Workshop participants identified 16 case studies illustrating advances in academic understanding of the nexus between environmental science and mental health. The eight case studies included in this report collectively demonstrated the importance of: interdisciplinary and transdisciplinary studies; international replication and collaboration; proof of concept; and novel methodological approaches (e.g. life course analysis, randomised control trials, longitudinal). Participants observed that successful larger, collaborative projects were often based on smaller scoping projects. Interdisciplinary science was considered key for their success and transdisciplinary approaches were found to increase impact of the work.

Opportunities and Recommendations

Six areas of opportunity were identified which consider both the research approach and topics warranting further investigation. From these derive the following five recommendations:

- **Exploit large-scale datasets:** including composite and longitudinal studies. This necessitates more open-access availability, training, novel data linkage methodologies, and assessment of cohort configuration and representativeness for research questions of relevance. Appropriate investment, resources and guidance is critical.

- **Longitudinal approaches:** specific opportunities include, capturing impact of environmental change over time, understanding exposure throughout the life course and how different disorders and vulnerabilities manifest at different life stages. Strategic exploitation of natural experiments offers a valuable route through which to develop longitudinal studies that integrate the environmental sciences.

- **Integrative complex systems research:** holistic complex system frames from the environmental sciences can help understand origin and progression of good and poor mental health. Methods can account for intersecting factors, multiple levels and the non-linearity of the system to offer understanding of how socio-ecological systems iteratively interact and impact on individual and community mental health.

- **Mixed methods approach:** invest in opportunities that incorporate qualitative and quantitative approaches to generate rich understanding. Qualitative approaches build depth and breadth of understanding, generate holistic insight of individual experience, and uncover potential directions for quantitative research. Structured mixed methods approaches can help address challenges of bringing different research traditions together.

- **Community of practice:** foster novel and established interdisciplinary and transdisciplinary collaborations through cross-council and aligned individual funding calls that facilitate communication and idea development across disciplines. Develop appropriate mechanisms that foster a community of practice around the intersectionality of environmental sciences and mental health.

ENVIRONMENTAL SCIENCE AND MENTAL HEALTH REVIEW

Report to NERC Valuing Nature Programme March 2021

Suggested citation: Irvine, K.N., Roberts, M., Eastwood, A., Colley, K., Currie, M. and Zhang, Z. (2021) *Environmental Science and Mental Health Review.* Valuing Nature Programme, UKCEH, Wallingford.

Contents

Executive summary 2

1. Introduction 8

1.1 Aim and research questions 9

1.2 Conceptual framework 10

1.3 Methods 12

1.3.1 Scoping review 12

1.3.2 Expert workshops 13

2. What is the state of the art? 14

2.1 Synthesis of literature 14

2.1.1 Summary of published systematic review papers. 14

2.1.2 Characterisation of scoping review literature 15

2.1.3 Themes within the scoping review literature 20

Natural Disasters *General* 20

Natural Disasters *Wildfire* 22

Noise 24

Pollution *General* 26

Pollution *Oil Spill* 28

Natural Environments 30

Meteorological Conditions *General* 32

Meteorological Conditions *Temperature* 34

2.2 Case studies of research at the nexus between environmental science and mental health 36

Workshop Case Study 1 37

Workshop Case Study 2 39

Workshop Case Study 3 41

Workshop Case Study 4 43

Workshop Case Study 5 44

Workshop Case Study 6 46

Workshop Case Study 7 47

Workshop Case Study 8 48

3. Gaps and opportunities 49

3.1 The geography of environmental science and mental health research 49

3.2 Interdisciplinary research – an opportunity to understand complexity 49

Cover image credits
(left to right — top row):

NASA *on Unsplash*
Markus Spiske *on Unsplash*
Paul Brennan *from Pixabay*
Macau Photo Agency *on Unsplash*

(left to right — bottom row):

sippakorn yamkasikorn *from Pixabay*
Markus Spiske *on Unsplash*
Piyush Priyank *on Unsplash*

3.3 Improving awareness, data sharing and linkages across large data sets 52

3.4 Engaging with natural experiments 54

3.5 Draw on complex system approaches from environmental sciences 56

3.6 Key areas to target environmental science research 58

3.7 A word of caution from environmental science researchers 60

4. Conclusions and recommendations 61

4.1 What is the current contribution of environmental science to mental health research? 61

4.2 How does research on environmental science and mental health relate to other determinants of mental health? . . 61

4.3 What are the current research designs and methodological approaches being used in environmental science-mental health research? 62

4.4 What are the evidence gaps and opportunities for the contributions of environmental science to mental health research? 63

5. References 64

Appendix A:
Scoping review search strings 76

Appendix B:
List of participants per participatory workshop 78

Appendix C:
Example workshop agenda 79

Appendix D:
Other suggested case studies 80

Appendix E:
Overview of review papers 81

1. Introduction

This report summarises findings from a project focused on the intersection between the environmental sciences and mental health. The project was commissioned by the UK's Natural Environment Research Council (NERC) and managed under the **Valuing Nature Programme** (VNP). It included a literature review and participatory workshops with experts drawn from a wide range of environmental science and mental health disciplines who, alongside the project team, brought a variety of perspectives to the issue. The focus was to understand the potential contribution that environmental science can make to mental health research and innovation, and to identify evidence gaps and opportunities.

1.1 Aim and research questions

Mental health is governed by complex, interacting factors including social, economic, demographic, genetic, experiential and environmental. Due to this complex intersectionality, there is a general move to developing a more holistic approach to managing mental health. This project sought to examine where and how the environmental sciences might contribute to the mental health domain, and to identify exemplar case studies, highlight gaps and outline areas for potential future investment.

More specifically, we addressed the following questions:

- What is the current contribution of environmental science to mental health research?
    - Including consideration of the pathways by which the environment impacts on mental health; and how environmental science has been leveraged to understand these pathways or impacts.
- How does the relationship between environmental science and mental health research relate to existing evidence linking mental health to social, economic, demographic and genetic determinants?
- What are the current research designs and methodological approaches being used in environmental science-mental health research?
- What are the evidence gaps and opportunities for the contributions of environmental science to mental health research?

1.2 Conceptual framework

The initial scoping of the research was framed with reference to Barton and Grant's (2006) model of the socio-ecological systems influencing human health and wellbeing. The model frames health determinants within a number of spheres ranging from individual-centred socio-demographic and genetic factors, through lifestyle, community, local economy and activities, to physical environmental factors relating to the built environment, natural environment, and global ecosystem.

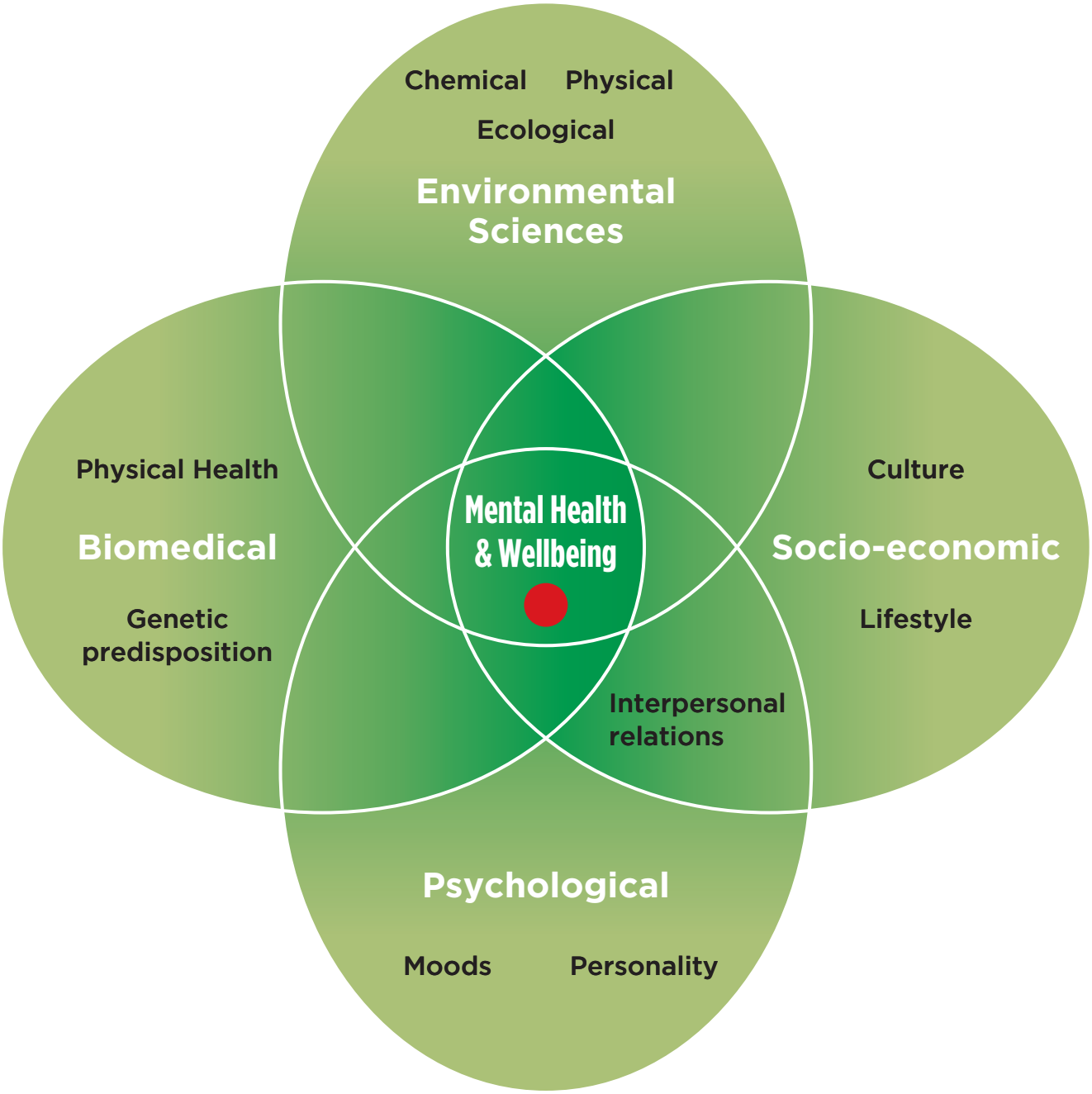
In framing the intersection between mental health and environmental science, we were particularly interested in the state of the art in the domains of natural environment and global ecosystem. Health determinants mentioned within these domains included natural habitats, air, water, land, biodiversity and climate change. These informed the process of developing search terms and boundary setting for the review component of the research. We also drew on knowledge of more specific frameworks elucidating mechanisms by which the natural environment influences health (e.g. Hartig *et al.* 2014).

The environmental sciences were considered in terms of ecological, chemical and physical to align with the scope of the Natural Environment Research Council as detailed in the UKRI/NERC delivery plan. These domains of environmental science guided the structure of the expert workshop component of the research.

The funding call specified consideration of mental health 'including cognitive development and decline, not just psychiatric/wellbeing definitions of mental health'. We thus adopted a broad interpretation of mental health. We employed the World Health Organisation's (WHO) definition of mental health to ensure capture of not only the negative aspects (mental ill health, mental health disorders) but also the positive (good mental health, mental wellbeing). Disorders were defined according to the WHO's International Statistical Classification of Diseases and Related Health Problems, tenth revision (WHO 2015; ICD-10). Mental wellbeing was defined as subjectively experienced (as opposed to objective indicators such as socio-economic factors) and non-momentary, i.e. wellbeing as a more global state that persists over a period of time (e.g. the last two weeks). Conditions relating to cognitive development and cognitive decline were also incorporated.

We visualised this socio-ecological system of multiple, and often interacting, factors that might influence mental health and wellbeing of an individual as illustrated in **Figure 1**. This diagram was used within the workshops to facilitate discussion and exploration of existing areas of research.

Figure 1: Domains of multiple and often interacting factors which might influence mental health and wellbeing of an individual (centre overlap) and relate to potential areas of research. The red dot symbolises an example of one researcher's overlapping areas of research which included using self-report questionnaires, qualitative interviews, ecological surveys and secondary data sources to explore associations between biodiversity and mental wellbeing.



1.3 Methods

The research consisted of two components: a scoping review, and a series of expert workshops.

1.3.1 Scoping review

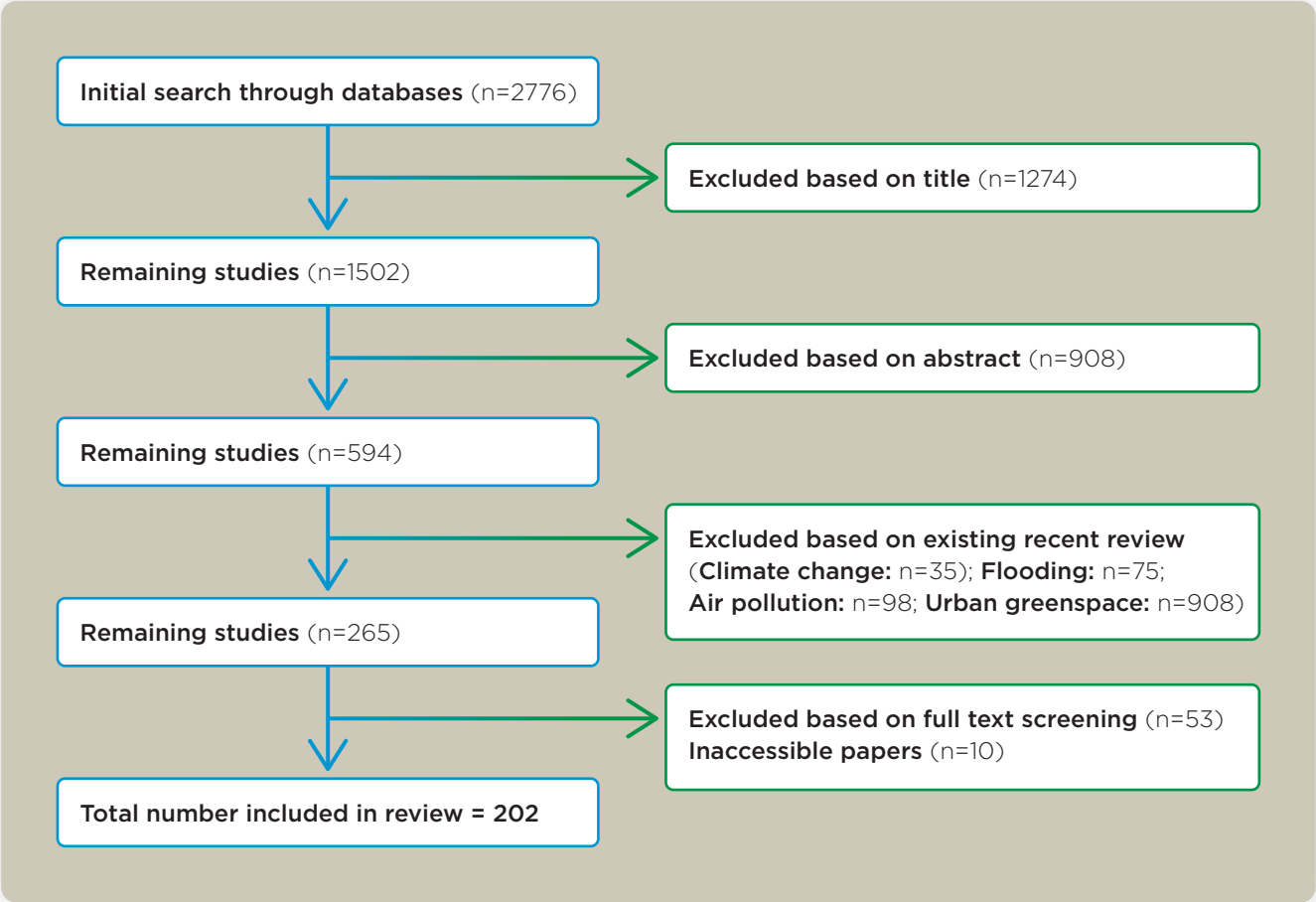
For the purposes of this project a scoping review was conducted. Scoping reviews are regarded as preferential to systematic reviews when the purpose of the review is to scope a body of literature, identify knowledge gaps, clarify concepts or investigate how research has been conducted (Munn *et al.* 2018). The structured approach incorporates rigorous and transparent methods to ensure robust insight (Munn *et al.* 2018; Tricco *et al.* 2018). Due to their aim of providing an 'overview or map of the evidence', scoping reviews do not typically include a quality assessment (e.g. risk of bias, methodological limitations) (Munn *et al.* 2018, p. 3).

Search strings were developed to identify literature concerned with mental health and environmental science, excluding those using animal models (e.g. Alzheimer research on rats) and reviews or opinion articles. These were generated in consultation with experts in environmental science and mental health research as part of three project workshops. (More details on the workshops in **section 1.3.2**; full search strings in **Appendix A**.) Language was restricted to English; the publication timeframe covered from January 2010 to August 2020 to encompass the breadth of recent research. Web of Science, PubMed, the British Library, UK and devolved governments and EU research portals were searched, returning 2776 papers. After screening, the final review included 202 papers **(Fig. 2)**.

Data were extracted into a spreadsheet capturing methods (e.g. rainfall records, presence/absence) and measures (e.g. mean temperature, presence of oil spill), study characteristics (population, study size, location), study design, analysis, main results and future research suggested by the authors. Once the full dataset was collated further grouping was carried out by one of the members of the project team (MR) to link studies with similar methods (e.g. rainfall records and air pollution records both become secondary spatial data, direct measurement of ozone and noise become environmental measurement), and group mental health outcomes into classifications of the ICD-10 (WHO 2015). In addition, the project team made a judgement on the main approach of the paper as being either mental health, environmental science, or both, and on the interaction of the two disciplines in the paper, following the categories presented in Huutoniemi *et al.* (2010). Finally, papers were categorised by themes emerging from the identified literature.

For full details of the search methods used in this report see **Appendix A**; for the scoping review protocol contact authors for separate document.

Figure 2: Scoping review screening record



1.3.2 Expert workshops

During July and August 2020, three interactive workshops were conducted (each three-hours in length) by the project team to further elucidate the role of the environmental sciences in mental health research. The virtual, online workshops were organised to focus on different aspects of the environment, specifically, the physical, chemical and ecological aspects. Workshop participants comprised a mixture of environmental and mental health researchers. We recruited the participants through the network of known centres of expertise, universities, organisations (public and NGO) and institutions in mental health and environmental research in the UK. In total, 22 disciplinary and interdisciplinary scientists participated in the workshops focusing on the role of physical, chemical and ecological environment sciences in mental health research.[1]

The three workshops (with 8, 8 and 6 participants, respectively) incorporated time and space for all the experts to engage in both the interactive activities and discussions that were developed by the project team. A list of workshop participants is provided in **Appendix B**. An example workshop agenda is provided in **Appendix C**. **Appendix D** lists the additional environmental science-mental health research examples that were suggested alongside those described in this report.

[1] The project was approved by the Research Ethics Committee at the James Hutton Institute, Scotland, UK. All participants provided written and verbal informed consent including agreement to include their name and affiliation on the list of workshop contributors that might be provided in project outputs.

2. What is the state of the art?

Here we provide an overview synthesis of identified literature followed by eight illustrative case studies identified by workshop participants.

2.1 Synthesis of literature

The literature synthesis first briefly summarises recently published systematic reviews on climate change, flooding, air pollution and urban greenspace that were identified through the literature search. This is followed by a characterisation of the research included in the scoping review, initially at study level then by themes used to organise the literature.

2.1.1 Summary of published systematic review papers

Thirty-four review papers were found through our search process for the scoping review. From these we identified several recent systematic reviews on climate change, flooding, air pollution and urban greenspace as robust enough to consider these topics already reviewed. Papers focusing on these four topics were removed from the scoping review (for full details and reference list for systematic reviews see **Appendix E**).

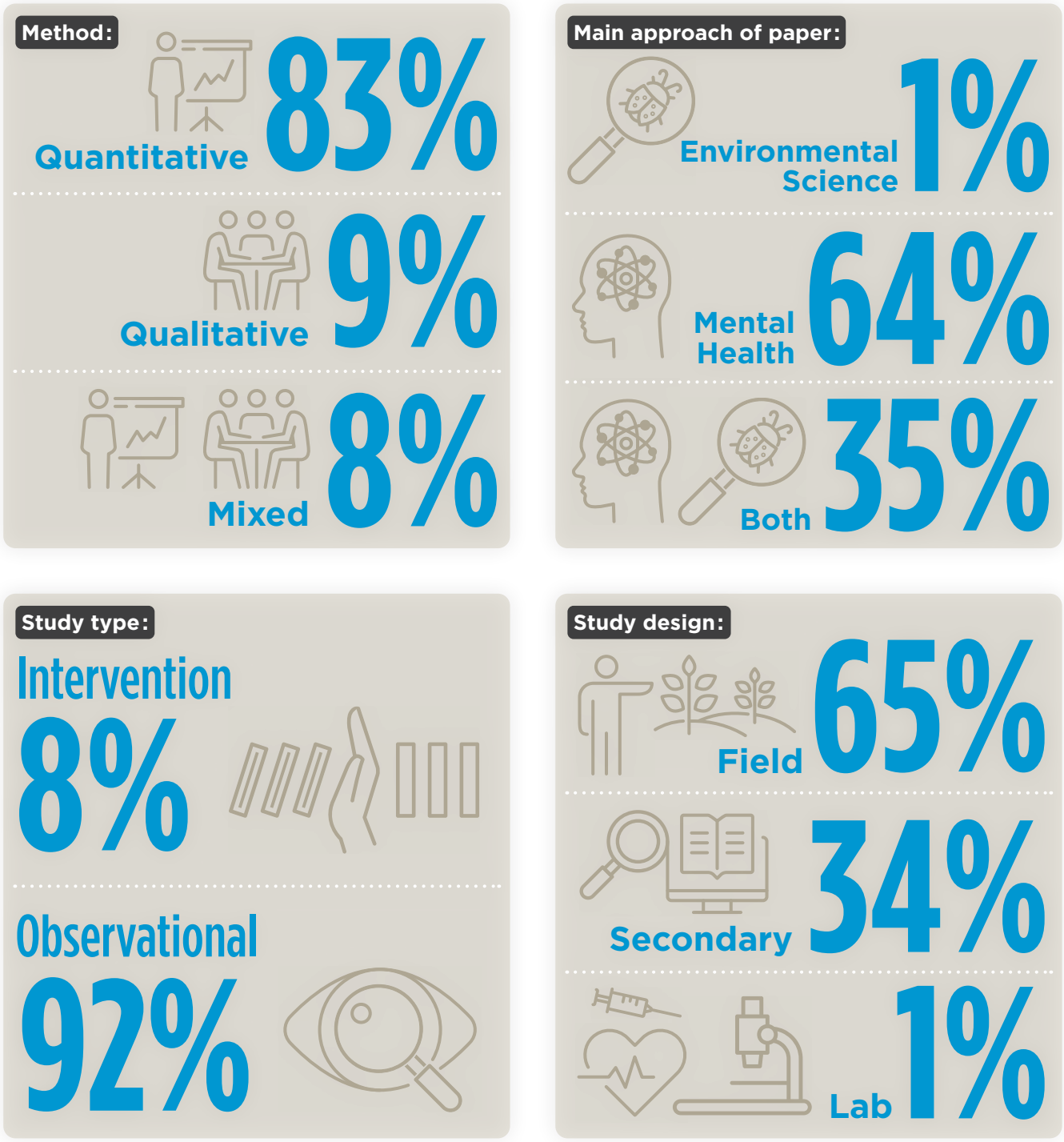
The systematic reviews provide the following insight on evidence and knowledge gaps:

- Climate change systematic reviews overall find a negative relationship between climate change and mental health, with trauma, migration, and despair at lost environments[2] most often implicated. Substantial gaps in the literature are identified, particularly with regards to pathways of impact, potential modifiers, and vulnerable populations.
- Flooding is linked to poor mental health, although mental health is less researched than physical impacts, and much of the evidence is descriptive.
- Air pollution has direct physical impacts on neurology and development, and is associated with poor mental health, delayed cognitive development, and cognitive decline. Further research is needed on causal pathways and potential confounders.
- Urban greenspace is often related to improved mental health, frequently via promotion of healthy behaviours. Marginal groups, such as refugees, are often overlooked, and more research is needed on pathways in particular.

2 Literature discusses this in terms of eco-anxiety (e.g. Clayton *et al.* 2017), ecological grief (e.g. Cunsolo and Ellis 2018) and solastalgia (e.g. Albrecht, Sartore and Connor 2007).

2.1.2 Characterisation of scoping review literature

Figure 3: Characteristics of scoping review literature



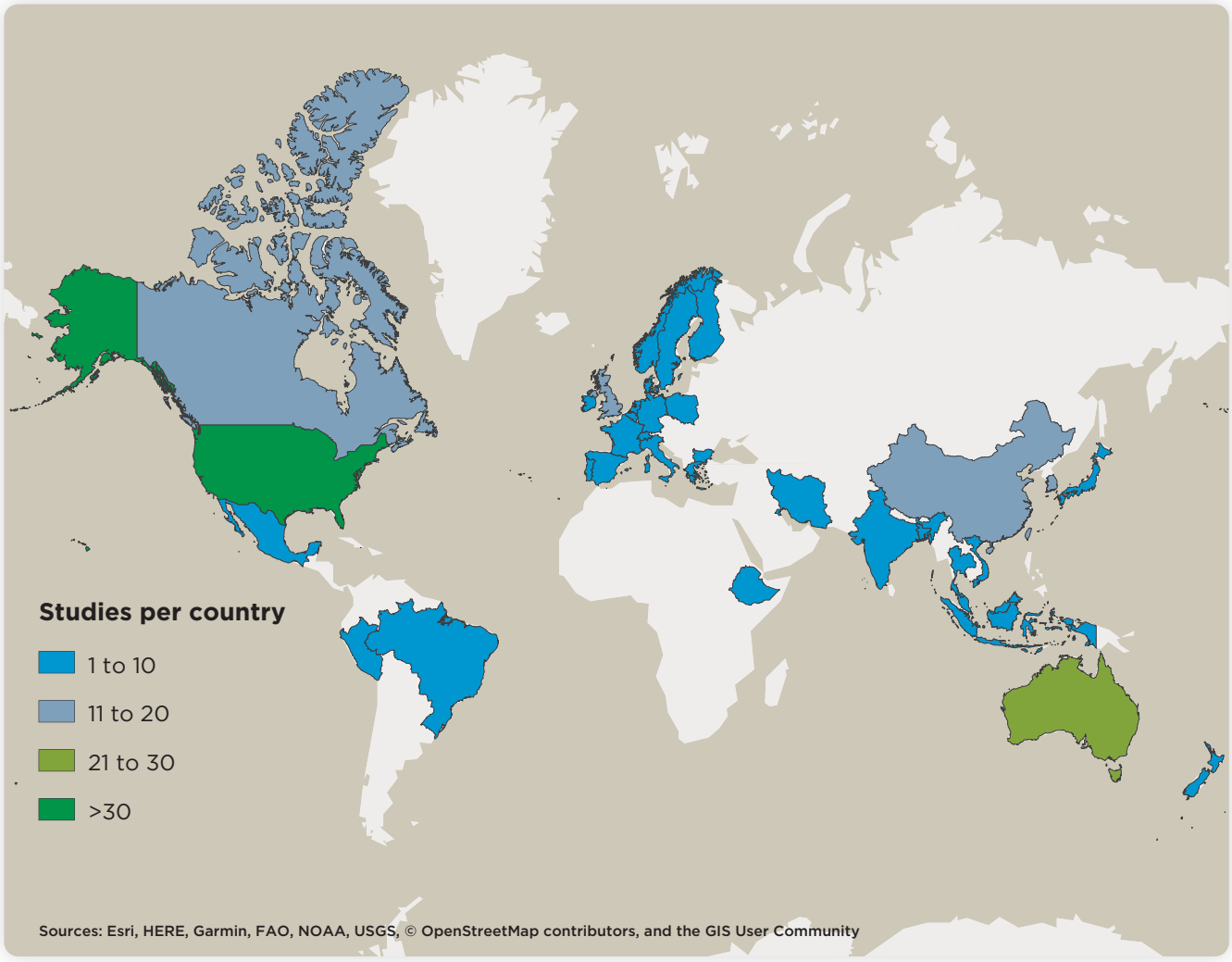
Data were extracted from 202 papers (for methods see **section 1.3**). **Figure 3** provides a summative overview. These were predominantly quantitative papers (83%).

Interaction between environmental science and mental health was largely empirical (89%), whereby environmental science data were incorporated alongside mental health data but methods were not further integrated.

Studies primarily used field data (65%), followed by secondary data (35%). Sample recruitment varied, including random (12%), convenience (13%), and central records (12%) being the most often used. Samples were only explicitly stated to be representative in 29% of papers.

Study sites were mainly in North America (31%, predominantly USA), Asia (24%, predominantly China) or Europe (21%, not limited to EU) **(Fig. 4)**.

Figure 4: Locations of study populations featuring in reviewed papers, by country



Broadly, five discernible themes, of which three have additional sub-themes, arose from classification of papers with the majority concerned with natural disasters **(Fig. 5)**.

With regard to mental health, general mental health is the most common metric described, with mood disorders (as defined in the ICD-10 (WHO 2015) the most common **(Fig. 6)**. Where multiple aspects of mental health were covered in a single paper all aspects were considered separately.

Figure 5: Percentage of studies by theme.
Note: *one paper may include more than one theme.*

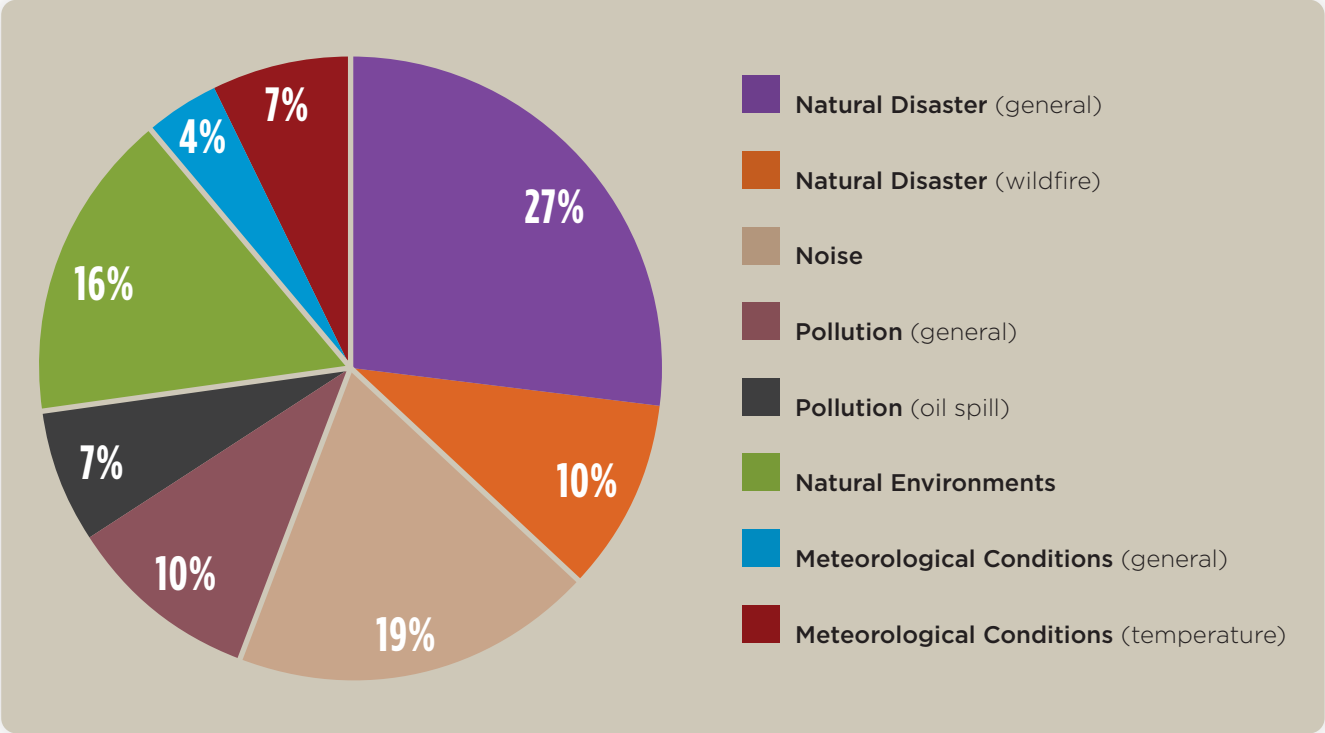


Figure 6: Percentage of studies by mental health area as defined for this research.
Note: *one paper may focus on more than one aspect of mental health.*

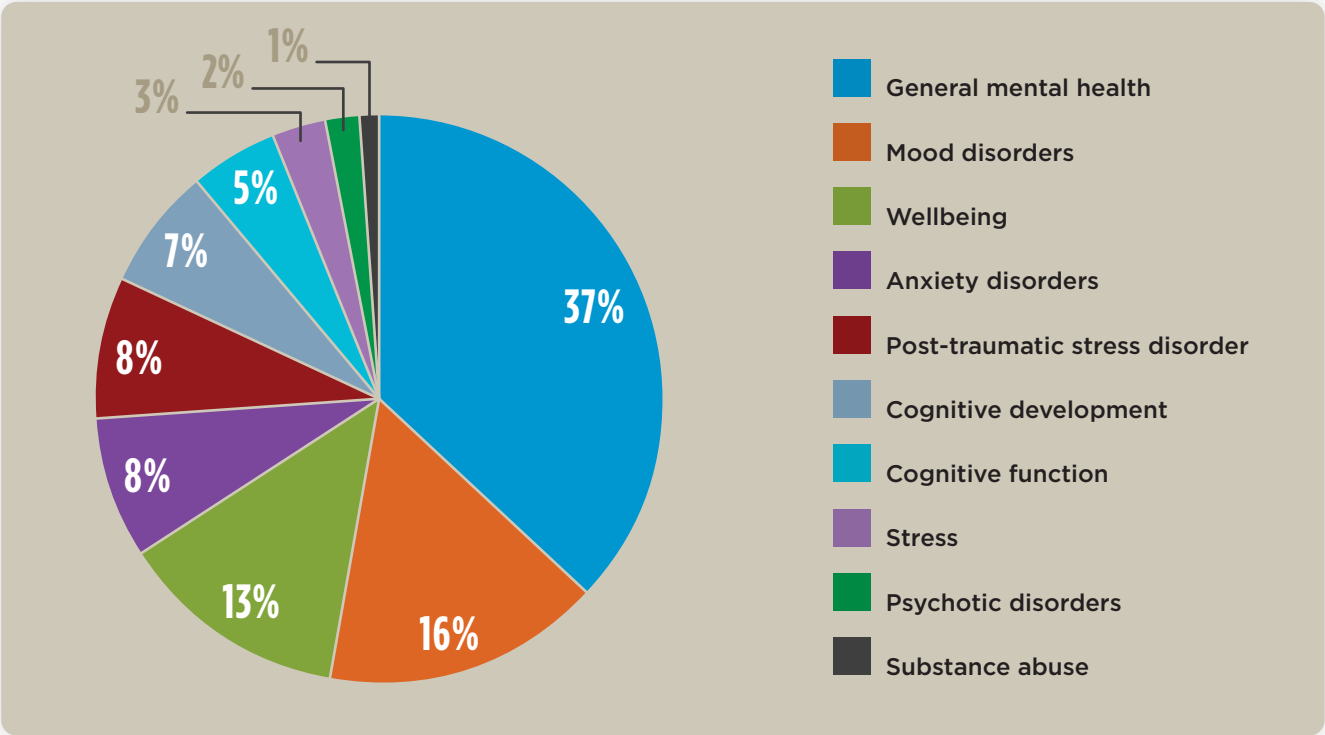
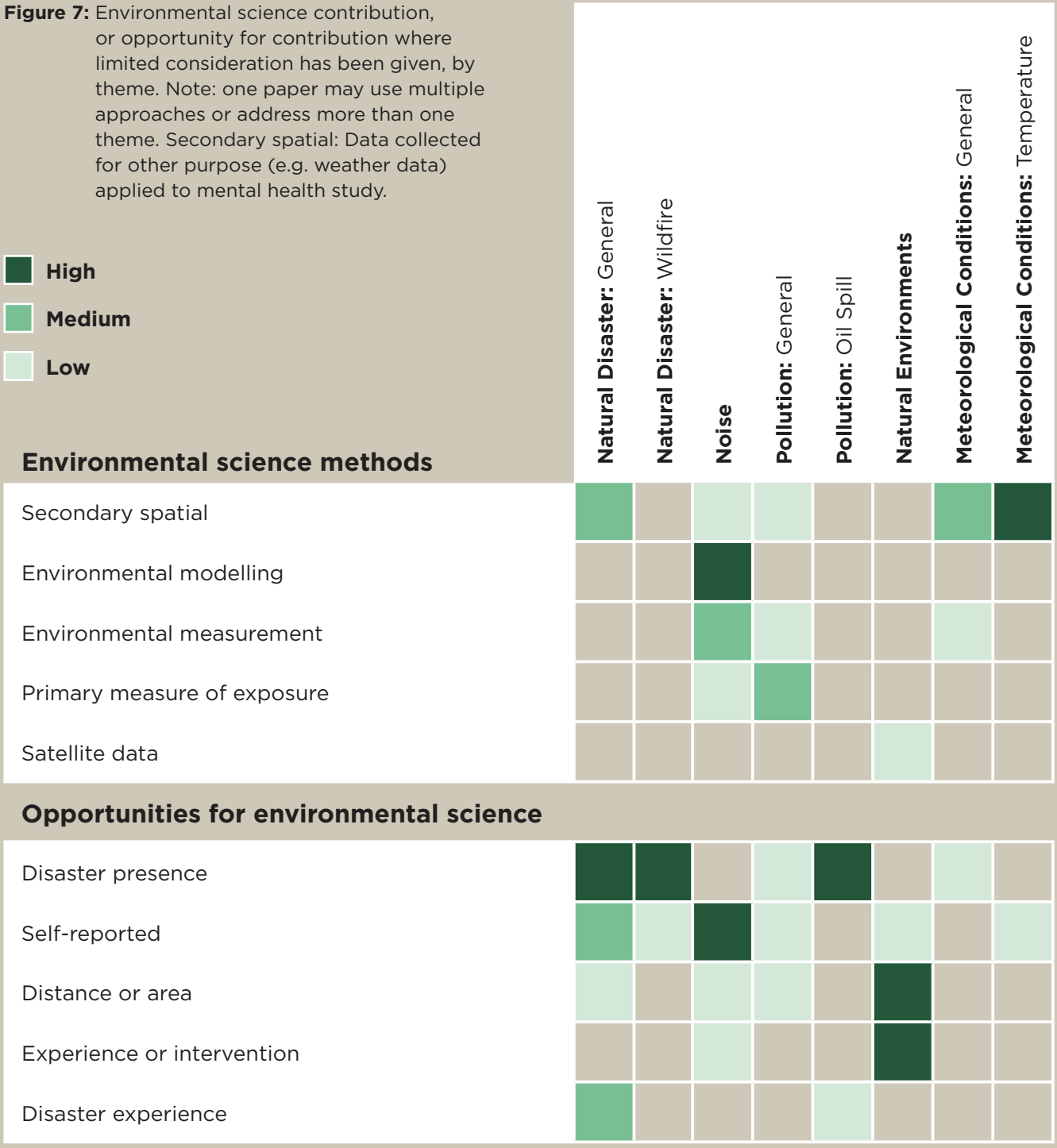
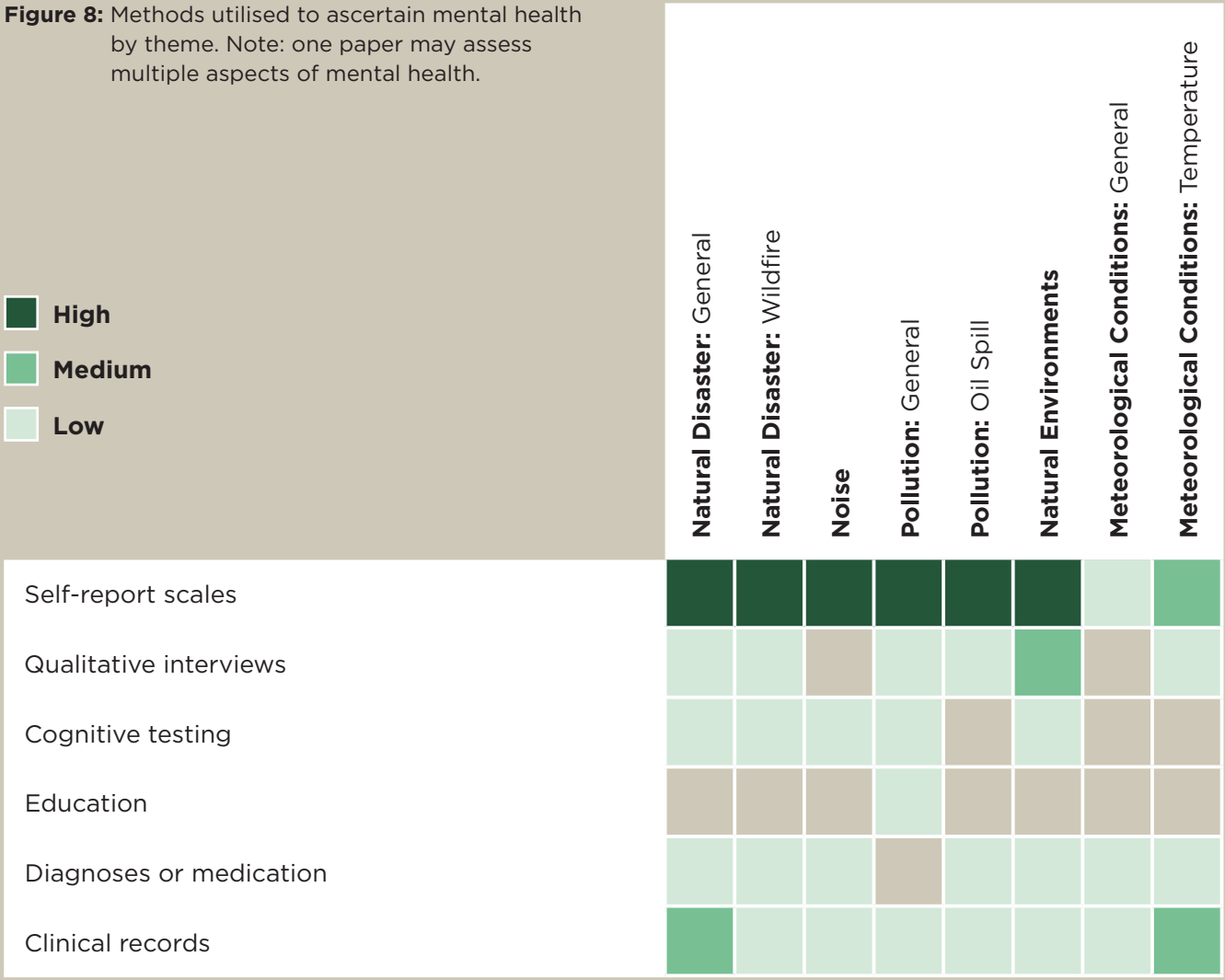


Figure 7: Environmental science contribution, or opportunity for contribution where limited consideration has been given, by theme. Note: one paper may use multiple approaches or address more than one theme. Secondary spatial: Data collected for other purpose (e.g. weather data) applied to mental health study.



A range of environmental science methods were used. The most predominant – the presence or occurrence of an event (34%), such as an oil spill or natural disaster – can only loosely be considered 'environmental science'. Additional metrics included secondary spatial data (16%), self-reported experience (15%) and distance to or area of natural environment type (11%). These methods varied by theme **(Fig. 7)**.

Figure 8: Methods utilised to ascertain mental health by theme. Note: one paper may assess multiple aspects of mental health.



Mental health methods were dominated by the use of self-report scales (78%), both self-administered and researcher-administered (e.g. structured interview) **(Fig. 8)**. Regression analyses were the most common form of analysis overall (67%), with thematic analysis the most common qualitative analysis technique used (6% total papers) **(Fig. 8)**.

2.1.3 Themes within the scoping review literature

This section presents the results of the scoping review structured by eight themes (five overarching and three sub-themes) within the literature. Within each theme, we provide a summary overview of the theme, draw out how environmental science and mental health were considered and offer an overview of findings.

Natural Disasters
General

Summary: The environmental science component was typically the presence of a disaster with the exception of drought. Studies usually reported that natural disasters had a negative impact on mental health.

Number of papers: 50				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	84%	0%	16%	8%	82%	10%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	20%	30%	2%	36%	8%	4%
Study type				**Study design**		
Intervention		Observation		Lab	Field	Secondary
2%		98%		0%	68%	32%

Population: Predominantly adults, including older adults aged 65+, and middle age (45—61), or specific focus on women. Children and adolescents were also studied.

Environmental science. The natural disaster theme had very little contribution from environmental science. Natural disasters were most commonly extreme weather events such as hurricanes, cyclones, typhoons and related flooding impacts. Papers also addressed drought, tsunami, earthquakes and landslide events. Environmental measures were most often considered in terms of a dichotomy of exposed vs. not exposed, often assumed based on residency, with very little actual environmental science considered. Few papers quantified the extent of exposure, and these were largely self-reported. Drought studies did incorporate objective measures, including use of rainfall data (Friel *et al*. 2014; Hanigan *et al*. 2018; O'Brien *et al*. 2014; Daghagh Yazd *et al*. 2020), drought period (Daghagh Yazd *et al*. 2020), soil moisture (Daghagh Yazd *et al*. 2020), Hutchinson's Drought index (Friel *et al*. 2014; Powers *et al*. 2015; Daghagh Yazd *et al*. 2019), and water allocations (Daghagh Yazd *et al*. 2020). Measures of exposure to storm events such as hurricanes/typhoon/cyclone included area of flooding in a buffer around the home, from GIS flood maps (Flores *et al*. 2020), and recorded typhoon intensity and duration (Han *et al*. 2018).

Mental health. Mental health outcomes included general mental health/stress, mood disorders, and anxiety disorders (including post-traumatic stress disorder). Other papers investigated sleep disorder/problems (Ryan *et al*. 2019; Ishiki *et al*. 2016; Shih *et al*. 2020; Motreff *et al*. 2013), suicide or self-harm (Lee *et al*. 2019; Powers *et al*. 2012; Hanigan *et al*. 2012; Shih *et al*. 2020), substance abuse (Stough and North 2018; Maclean *et al*. 2016; Bevilacqua *et al*. 2020) and cognitive decline (Ishiki *et al*. 2016).

Self-report scales were commonly used to assess both general mental health/psychological distress and mental disorders. Whilst the use of established psychometric scales was widespread, there was much variation in self-report measures within mental health outcome categories. A number of studies used diagnostic data on mental health disorders, either through health or insurance records (Shih *et al*. 2020, Motreff *et al*. 2013), or diagnostic tools (Maclean *et al*. 2016; Stough and North 2018; King *et al*. 2016).

Findings. Although negative relationships between mental health and natural disasters were most common, results were mixed, with studies also finding no associations, or associations for some measures of exposure and not others. Due to the breadth of environmental exposure measures and mental health outcomes studied it is difficult to present a concise synthesis of the results in this theme.

Natural Disasters
Wildfire

Summary: Studies were limited in their environmental science contribution to the presence of wildfire. Wildfires were linked to poor mental health.

Number of papers: 20				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	80%	0%	20%	10%	80%	10%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	5%	20%	15%	60%	0%	0%

Study type		**Study design**		
Intervention	Observation	Lab	Field	Secondary
20%	100%	0%	80%	15%

Population: Studies included both adults and children, and were largely concerned with wildfire affected areas or individuals only.

Environmental science. Presence or occurrence of wildfires was the only consideration. The contribution of environmental science was therefore highly limited.

Mental health. Studies included neurotic and mood disorders (Belleville *et al*. 2019; Cherry *et al*. 2017; Dodd *et al*. 2018; Hayward *et al*. 2020; Ritchie *et al*. 2020; Agyapong *et al*. 2020; Brown *et al*. 2019; Lewis *et al*. 2015; Papanikolaou *et al*. 2011; Psarros *et al*. 2018; Block *et al*. 2019), substance abuse disorders (Belleville *et al*. 2019; Agyapong *et al*. 2020; Ritchie *et al*. 2020), suicide or self-harm (Brown *et al*. 2019; Stanley 2018), behavioural syndromes (Belleville *et al*. 2019) and schizophrenia and delusional disorders (Papanikolaou *et al*. 2011), along with general mental health (Dodd *et al*. 2018; Hayward *et al*. 2020; Felix and Afifi 2015; Lin *et al* 2016; Brown *et al*. 2019; Papanikolaou *et al*. 2011; Shrestha *et al*. 2019; Block *et al*. 2019) and wellbeing (Block *et al*. 2019; Dodd *et al*. 2018; Brown *et al*. 2019). Mental health was measured via self-assessed scales or diagnostic tools (e.g. HADS).

Findings. Self-esteem (Brown *et al*. 2019), paranoia (Papanikolaou *et al*. 2011), suicide ideation and risk (Brown *et al*. 2019; Stanley *et al*. 2018); excessive drinking and drug use (Ritchie *et al*. 2020; Belleville *et al*. 2019; Agyapong *et al*. 2020); anxiety and depression (Agyapong *et al*. 2020; Belleville *et al*. 2019; Lewis *et al*. 2015), and post-traumatic stress disorder (Belleville *et al*. 2019; Block *et al*. 2019; Psarros *et al*. 2018; Ritchie *et al*. 2020; Agyapong *et al*. 2020) were all negatively impacted by wildfire presence. Presence of smoke (Dodd *et al*. 2018; Felix and Afifi 2015) or air pollution (Shrestha *et al*. 2019) was implicated in some studies.

Some factors appeared to affect the extent of mental health decline, including: a weak attachment to the environment (Block *et al*. 2019); future wildfire risk (Agyapong *et al*. 2020; Dodd *et al*. 2018); fearing for their own or others' lives (Agyapong *et al*. 2020); witnessing a wildfire (Brown *et al*. 2019); being evacuated (Brown *et al*. 2019); assisting with wildfire recovery (Stanley *et al*. 2018); severity of damage (Papanikolaou *et al*. 2011) including injury (Wasiak *et al*. 2013). There was some conflicting evidence about whether evacuation increased or decreased mental health.

Noise

Summary: Studies included environmental data collection which modelled or measured noise. Almost all studies focused on negative sounds.

Number of papers: 36				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	39%	6%	56%	0%	97%	3%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	25%	6%	61%	8%	0%	0%
Study type				**Study design**		
Intervention		Observation		Lab	Field	Secondary
3%		97%		3%	69%	33%

Population: Predominantly adults in the general population, although students, infants and children aged 9 and 10 were also considered.

Environmental science. Noise was modelled based on physical forms of the environment and noise sources (Eze *et al.* 2020; Generaal *et al.* 2019; He *et al.* 2019; Hill *et al.* 2014; Okokon *et al.* 2018) or measured and analysed at a coarse (e.g. neighbourhood, Al-Mutairi *et al.* 2011; Kageyama *et al.* 2016; Dzhambov *et al.* 2017, 2018b & c; He *et al.* 2019; Roswall *et al.* 2015; Schreckenberg *et al.* 2010; Sygna *et al.* 2014; Wright *et al.* 2018;) or fine (Wass *et al.* 2019; Ma *et al.* 2019) scale. Self-reported noise (Ma *et al.* 2018; Dreger *et al.* 2015) or noise annoyance (Hammersen *et al.* 2016; Jensen *et al.* 2018; Nitschke *et al.* 2014; Beutel *et al.* 2016 & 2020; Yoon *et al.* 2014) was also used, either alone or in combination with other measures. Some studies considered additional stressors (air pollution, Generaal *et al.* 2019 & 2019a; Dzhambov *et al.* 2018b) and potential moderators such as green (Dzhambov *et al.* 2018c; Putrik *et al.* 2015) or blue (Dzhambov *et al.* 2018d; Generaal *et al.* 2019 & 2019a) space.

Mental health. General mental health was measured through self-report scales, including: short-form health status questionnaire (Al-Mutairi *et al*. 2011; Hammersen *et al*. 2016; Jensen *et al*. 2018; Ma *et al*. 2018; Nitschke *et al*. 2014; Roswall *et al*. 2015; Schreckenberg *et al*. 2010), or the Strengths and Difficulties Questionnaire (Crombie *et al*. 2011; Dreger *et al*. 2015). Hospital diagnoses (He *et al*. 2019) or structured interviews (Kageyama *et al*. 2016; Staudt *et al*. 2016) were also used. Depression and anxiety were the only named disorders considered, measured via self-report scales (Beutel *et al*. 2016 & 2020; Eze *et al*. 2020; Generaal *et al*. 2019; Hill *et al*. 2014; Park *et al*. 2017; Pun *et al*. 2019; Putrik *et al*. 2015; Dzhambov 2018d) or diagnoses (Eze *et al*. 2020; Okokon *et al*. 2018), or hospital admission (Díaz *et al*. 2020; He *et al*. 2019). Suicide was considered via death records (Díaz *et al*. 2020; Min and Min 2018), or self-reported suicide ideation (Yoon *et al*. 2014). Children's behavioural disorders were measured via parental reports (Dreger *et al*. 2015) or the Child Behaviour Checklist (Lim *et al*. 2018). Cognitive development was measured using electrocardiogram (ECG) monitoring to measure arousal in infants (Wass *et al*. 2019). Wellbeing was measured via the Perceived Restorativeness Scale (Zhu *et al*. 2020).

Findings. Noise showed varied impacts on general mental health. Although both measured noise (Al-Mutairi *et al*. 2011; Roswall *et al*. 2015; Crombie *et al*. 2011; Dreger *et al*. 2015; Ma *et al*. 2020; He *et al*. 2019) and noise annoyance (Hammersen *et al*. 2016; Nitschke *et al*. 2014; Dzhambov *et al*. 2017 & 2018a; Jensene *et al*. 2018; Ma *et al*. 2018; Staudt *et al*. 2016) often had a negative impact on mental health. Many studies found no relationship (Al-Mutairi *et al*. 2011; Sygna *et al*. 2014; Schreckenberg *et al*. 2010; Wright *et al*. 2018; Crombie *et al*. 2011; Dreger *et al*. 2015; Kageyama *et al*. 2016; Ma *et al*. 2020; Park *et al*. 2017; Hammersen *et al*. 2016).

Similar patterns were observed for depression and anxiety, whether measured via diagnoses or self-report scales. Although higher noise was often associated with higher depression and anxiety rates (Díaz *et al*. 2020; Generaal *et al*. 2019; Okokon *et al*. 2018; He *et al*. 2019; Eze *et al*. 2020; Poulsen *et al*. 2019; Pun *et al*. 2019; Beutel *et al*. 2016 & 2020; Park *et al*. 2017), this was not always the case (Putrik *et al*. 2015; Generaal *et al*. 2019a; Park *et al*. 2017; Poulsen *et al*. 2019). Noise annoyance was more consistently associated with both depression and anxiety (Beutel *et al*. 2016; Park *et al*. 2017; Okokon *et al*. 2018; Yoon *et al*. 2014) although the timing of noise was important (Beutel *et al*. 2020). Impacts of noise annoyance are suggested to be related to stress (Okokon *et al*. 2018; Hill *et al*. 2014). Suicide also showed an increase in noisier neighbourhoods (Díaz *et al*. 2020; Min and Min 2018), and noise annoyance was associated with increased suicide ideation (Yoon *et al*. 2014).

Conduct problems in children were related to some sources of noise (Dreger *et al*. 2015; Lim *et al*. 2018). Noise had negative impacts on cognitive development in infants, reducing attention span and increasing recovery time after mild stress (Wass *et al*. 2019).

Pollution
General

Summary: Pollutants studied include industrial, agricultural and domestic. Direct measures of exposure were examined. Relationship to mental health varied by contaminant and exposure.

Number of papers: 19				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	58%	0%	42%	5%	90%	5%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	42%	0%	11%	47%	0%	0%
Study type				**Study design**		
Intervention		Observation		Lab	Field	Secondary
0%		100%		0%	68%	32%

Population: Predominantly adults in pollution affected areas, but children at specific development stages considered.

Air pollution articles are not considered here as they have been the subject of recent systematic review **(see section 2.2.2; Appendix E)**.

Environmental science. Pollution-focused papers consider the effect of industrial contaminants (Aschengrau *et al.* 2016; Staudt *et al.* 2016; Seyedin *et al.* 2017; Stough and North 2018; Berk *et al.* 2014), agricultural chemicals (Kannuri and Jadhav 2018) or poor water (Stough and North 2018; Norra *et al.* 2012; Kruger *et al.* 2017a; Kruger *et al.* 2017) or air (Seyedin *et al.* 2017; Lu *et al.* 2018; Chen *et al.* 2013; Song *et al.* 2019) quality, including pollen concentration (Stickley *et al.* 2017).

Exposure was primarily quantified through hair and urine (Norra *et al.* 2012; Berk *et al.* 2014; Forns *et al.* 2012; Gaspar *et al.* 2015; Kyriklaki *et al.* 2016; Liu *et al.* 2014) or water (Norra *et al.* 2012; Manczak *et al.* 2020; Akter *et al.* 2019) samples, pollen (Stickley *et al.* 2017) or particulate matter (Song *et al.* 2019) concentration. Other measures included self-report (Stough and North 2018; Chen *et al.* 2013; Kruger *et al.* 2017; Gaspar *et al.* 2015), presumed exposure based on residency (Seyedin *et al.* 2017; Kruger *et al.* 2017a; Staudt *et al.* 2016) or occupation (Kannuri and Jadhav 2018; Lu *et al.* 2018), or estimated exposure using historical maps and modelling (Aschengrau *et al.* 2016).

Mental health. Outcomes and measures varied. Cognitive development in children was investigated using clinical assessment of cognitive functioning, mental and motor development (Aschengrau *et al*. 2016; Norra *et al*. 2012; Akter *et al*. 2019; Liu *et al*. 2014; Forns *et al*. 2012; Gaspar *et al*. 2015; Kyriklaki *et al*. 2016) or grade advancement (Akter *et al*. 2019). General mental health was assessed using self-report scales, including short-form health status questionnaire (Stough and North 2018; Seyedin *et al*. 2017; Norra *et al*. 2012), perceived mental health (Lu *et al*. 2018) or ethnographic interviews (Kannuri and Jadhav 2018). Mental health disorders included: mood, specifically depression (Chen *et al*. 2013; Berk *et al*. 2014; Manczak *et al*. 2020; Aschengrau *et al*. 2016; Staudt *et al*. 2016) and bipolar (Aschengrau *et al*. 2016); neurotic, specifically post-traumatic stress disorder (Aschengrau *et al*. 2016; Kruger *et al*. 2017a; Stough and North 2018) and anxiety (Staudt *et al*. 2016); substance abuse, specifically alcohol (Stough and North 2018); schizophrenia (Aschengrau *et al*. 2016); behavioural syndromes, specifically sleep disorder (Kruger *et al*. 2017); and suicide rates (Stickley *et al*. 2017). These were largely measured through standardised self-report scales; suicide was assessed via death records. Wellbeing was also considered (Song *et al*. 2019).

Findings. Early-life exposure to high levels of lead negatively affected mental and motor development (Liu *et al*. 2014). Mixed results were found for early-life exposure to different persistent organic pollutants for mental and motor development at different life stages. Adverse effects of salinity on grade advancement were found among children age 7–12 (Akter *et al*. 2019) and high arsenic levels had a negative effect on mental health and neurological performance among adults (Norra *et al*. 2012). Residency length in a neighbourhood with known environmental risks did not significantly predict mental health (Seyedin *et al*. 2017) but was related to depression and anxiety (Staudt *et al*. 2016). Perceived mental health risks were greater among skilled workers in high smog areas (Lu *et al*. 2020).

For specific disorders, early-life exposure to tetrachloroethylene (PCE) was associated with risk of post-traumatic stress disorder and bipolar disorder but not depression in young adulthood (Aschengrau *et al*. 2016). Post-traumatic stress disorder was not found to increase with repeated exposures to pollution (Stough and North 2018), nor with perceptions of water quality (Kruger *et al*. 2017a). Among adolescents, exposure to high levels of arsenic, lead or nitrates predicted changes in depressive symptoms over time; the effect of lead and nitrates was stronger in families with higher parental control (Manczak *et al*. 2020). In adults, higher cadmium levels were associated with higher prevalence of depression, high levels of mercury – and some polyfluorinated compounds and phenols – were associated with lower prevalence of depression although evidence is mixed (Berk *et al*. 2014). Depression was not associated with perceived air or water quality but was related to perceived danger of toxic industrial waste (Chen *et al*. 2013). Higher pollen concentrations were associated with suicide mortality in women (Stickley *et al*. 2017). Pollution exposure was not found to impact on substance abuse (Stough and North 2018), or happiness (Song *et al*. 2019); perceived water quality was associated with sleep disorders (Kruger *et al*. 2017).

Pollution
Oil Spill

Summary: Studies were primarily concerned with the US-based BP Horizon oil spill. Mental health was commonly self-reported. Impact of spills on mental health varied with exposure.

Number of papers: 14				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	100%	0%	0%	14%	86%	0%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	14%	0%	0%	79%	7%	0%

Study type		**Study design**		
Intervention	Observation	Lab	Field	Secondary
0%	100%	0%	79%	21%

Population: Predominantly adults in oil spill affected areas or seeking mental health support, including specific focus on women, individuals employed in fishing or related occupations, or healthcare providers.

Environmental science. Studies of a single oil spill (BP Deep Horizon in the United States) dominated this literature; others were conducted in Asia and South America. The effect of oil spills was examined at different temporal (immediately following, 1 year later) and spatial (proximity to spill) scales incorporating different comparisons (regional, national, occupation, gender). Exposure was often assumed based on residency within (Buttke *et al.* 2012; Kim *et al.* 2013; Cherry *et al.* 2015; Morris *et al.* 2013; Nugent *et al.* 2019) or distance to (Choi *et al.* 2016; Kim *et al.* 2013) an oil spill affected area. Where the extent of exposure was quantified this was done via self-report (Ayer *et al.* 2019; Rung *et al.* 2016; Johnson and Boodram 2017; Aiena *et al.* 2016), health/economic claims to assess impact (Gould *et al.* 2015) or oil spill characteristics including hazardous material, volume, surface area of spill, magnitude, dispersant volume (Shultz *et al.* 2015).

Mental health. Largely investigated with self-report questionnaires. Neurotic and mood disorders commonly used standardised measures for anxiety (Cherry *et al*. 2015; Ayer *et al*. 2019; Choi *et al*. 2016; Gould *et al*. 2015), post-traumatic stress disorder (Cherry *et al*. 2015; Aiena *et al*. 2016; Choi *et al*. 2016; Nugent *et al*. 2019; Kim *et al*. 2013; Shenesey and Langhinrichsen-Rohling 2015) and depression (Cherry *et al*. 2015; Ayer *et al*. 2019; Choi *et al*. 2016; Gould *et al*. 2015; Kim *et al*. 2013; Morris *et al*. 2013; Rung *et al*. 2016; Shenesey and Langhinrichsen-Rohling 2015). Additional mental health disorders included substance abuse (Ayer *et al*. 2019; Gould *et al*. 2015) and suicide ideation (Gould *et al*. 2015; Choi *et al*. 2016) or plans (Gould *et al*. 2015).

General mental health was measured with standard scales for mental health status (Buttke *et al*. 2012), mental distress (Rung *et al*. 2016), worry over money for rent or food (Gould *et al*. 2015), treatment for mental health (Gould *et al*. 2015) or a mental health index (Cope *et al*. 2013). Other than self-report, in-depth qualitative interviews (Johnson and Boodram 2017) and expert opinion were employed (Shultz *et al*. 2015).

For specific disorders, early-life exposure to tetrachloroethylene (PCE) was associated with risk of post-traumatic stress disorder and bipolar disorder but not depression in young adulthood (Aschengrau *et al*. 2016). Post-traumatic stress disorder was not found to increase with repeated exposures to pollution (Stough and North 2018), nor with perceptions of water quality (Kruger *et al*. 2017a). Among adolescents, exposure to high levels of arsenic, lead or nitrates predicted changes in depressive symptoms over time; the effect of lead and nitrates was stronger in families with higher parental control (Manczak *et al*. 2020). In adults, higher cadmium levels were associated with higher prevalence of depression, high levels of mercury – and some polyfluorinated compounds and phenols – were associated with lower prevalence of depression although evidence is mixed (Berk *et al*. 2014). Depression was not associated with perceived air or water quality but was related to perceived danger of toxic industrial waste (Chen *et al*. 2013). Higher pollen concentrations were associated with suicide mortality in women (Stickley *et al*. 2017). Pollution exposure was not found to impact on substance abuse (Stough and North 2018), or happiness (Song *et al*. 2019); perceived water quality was associated with sleep disorders (Kruger *et al*. 2017).

Findings. The effect of oil spills on mental health varied by measure of exposure (geographical, self-report), mental health outcome and time since exposure. Proximity increased incidences of post-traumatic stress disorder, depression (Choi *et al*. 2016, Kim *et al*. 2013), anxiety and suicide ideation (Choi *et al*. 2016), particularly among those in fishing related occupations (Choi *et al*. 2016). In studies comparing residents of affected and unaffected areas, no association was found for anxiety (Gould *et al*. 2015; Cherry *et al*. 2015), money worries or mental health service utilisation (Gould *et al*. 2015). Substance abuse and suicide plans were associated with living in an affected area (Gould *et al*. 2015); results were mixed for post-traumatic stress disorder (Cherry *et al*. 2015; Kim *et al*. 2013) and depression (Kim *et al*. 2013; Gould *et al*. 2015).

When assessed using self-report, high exposure is associated with increased mental distress (Rung *et al*. 2016), anxiety (Ayer *et al*. 2019), and post-traumatic stress disorder (Nugent *et al*. 2019; Aiena *et al*. 2016) with mixed results for depression (Ayer *et al*. 2019, Rung *et al*. 2016). Immediately following an oil spill, quality of life (Johnson and Boodram 2017) was impacted, and the number of mentally unhealthy days increased (Buttke *et al*. 2012). Over time, the proportion of individuals reporting mentally unhealthy days (Buttke *et al*. 2012) or poor mental health (Cope *et al*. 2013) decreased although anxiety and depression increased after a year particularly among individuals who lost income (Morris *et al*. 2013).

Natural Environments

Summary: Studies focused on forest and land-use. Forest activities were associated with good mental health, but environmental science contributions were limited. Diverse land use and types were found to impact mental health.

Number of papers: 32				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	56%	0%	44%	12%	72%	16%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	25%	3%	66%	6%	0%	0%
Study type				**Study design**		
Intervention		Observation		Lab	Field	Secondary
0%		100%		0%	66%	34%

Population: Predominantly adults, though several studies included children.

Urban greenspace articles are not considered here as they have been the subject of recent systematic review **(see section 2.2.2; Appendix E)**.

Environmental science. Natural environment papers focused on two natural environments: forests (Hassan *et al*. 2018; Sonntag *et al*. 2015; O'Brien 2019; Lee *et al*. 2019a; Choi *et al*. 2018; von Linden *et al*. 2013; Song *et al*. 2020; Ward Thompson *et al*. 2019; Furuyashiki *et al*. 2019) and land use including types (Zock *et al*. 2018; Sarkar *et al*. 2013), access and use of green and blue spaces (Dzhambov 2018d; Alcock *et al*. 2015; Hsieh *et al*. 2015; Chen *et al*. 2020; Garrett *et al*. 2019; White *et al*. 2013; Generaal *et al*. 2019a; Bezold *et al*. 2018; Pasanen *et al*. 2019), indoor versus outdoor settings (Dolling *et al*. 2017), and nature versus built environments (Hassan *et al*. 2018). Methods used were classified into three main approaches: (i) participation in an activity in a natural environment; (ii) access to natural spaces measured by the proximity of their location to that natural environment; and (iii) access to natural spaces measured by mapping tools including proximity of the natural environment and overall proportion of the land use where the environment could be classified as natural in some way.

Mental health. General mental health was measured with self-report scales such as General Health Questionnaire-12 (GHQ-12) (Alcock *et al*. 2015; Dzhambov *et al*. 2018c; Garrett *et al*. 2019; Pasanen *et al*. 2019) and the 36-item Short Form Health Survey (SF-36) (Dolling *et al*. 2017) as well as other author-developed questionnaires (Dolling *et al*. 2017; Sonntag *et al*. 2015) and physical measures (Hassan *et al*. 2018). Mental health disorders were limited to mood (Song *et al*. 2020; O'Brien 2019; Furuyashiki *et al*. 2019; Hsieh *et al*. 2015), neurotic (Song *et al*. 2020; Ward Thompson *et al*. 2019; Furuyashiki *et al*. 2019; Costello *et al*. 2019; Chen *et al*. 2020; Garrett *et al*. 2019; Sarkar *et al*. 2013; Pasanen *et al*. 2019; Gascon *et al*. 2018), and behavioural (Song *et al*. 2020). Wellbeing was also considered (Roberts 2017; von Linden *et al*. 2013; Kibria *et al*. 2019; Pasanen *et al*. 2019; Dolling *et al*. 2017).

Findings. Participants in forest activities reported improvements in attentiveness (Hassan *et al*. 2018; Sonntag *et al*. 2015), relaxation (Hassan *et al*. 2018) and decreased use of anti-depressants (O'Brien 2019). Presence of forests was associated with higher levels of happiness, wellbeing and restoration (Lee *et al*. 2019a; Choi *et al*. 2018; von Linden *et al*. 2013; Song *et al*. 2020), decreased negative emotions, reduced stress, decreased anxiety and improved moods (Dolling *et al*. 2017; Song *et al*. 2020; Hassan *et al*. 2018; Ward Thompson *et al*. 2019; Furuyashiki *et al*. 2019). No difference was found for children for self-reported behavioural problems after spending time in a forest programme (Song *et al*. 2020).

Decreased diagnoses of all conditions (Zock *et al*. 2018) and reductions in distress (Sarkar *et al*. 2013) were found where there was more diverse land use. Increased proportions of fresh water and woodland land use (Alcock *et al*. 2015) and mangroves (Hsieh *et al*. 2015) improved mental health, although the presence of marine and coastal land use decreased it (Alcock *et al*. 2015). Living close to blue space was related to improved mental health (White *et al*. 2013; Garrett *et al*. 2019) – particularly for low income groups (Pasanen *et al*. 2019) – and reduced depression (Generaal *et al*. 2019a; Garrett *et al*. 2019; Bezold *et al*. 2018; Pearson *et al*. 2019) and anxiety (Dzhambov 2018d, Chen *et al*. 2020) although not in all cases (Alcock *et al*. 2015; Chen *et al*. 2020; Generaal *et al*. 2019a).

Meteorological conditions
General

Summary: Studies used only secondary spatial data for environmental science but incorporated a wide range of mental health conditions. Generally, good weather was associated with improving mental health, and vice versa.

Number of papers: 7				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	29%	0%	71%	0%	100%	0%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	28%	0%	14%	57%	0%	0%
Study type				**Study design**		
Intervention		Observation		Lab	Field	Secondary
0%		100%		0%	0%	100%

Population: Users of (mental) health services or general population.

Environmental science. Quantitative (largely regression) analyses of secondary meteorological data, including: precipitation (Han *et al*. 2018; Obradovich *et al*. 2018; Settineri *et al*. 2016; Tapak *et al*. 2018), sunshine/sunlight exposure (Ha and Shao 2019; Beecher *et al*. 2016), cloudiness (Tapak *et al*. 2018), humidity, wind speed and direction (Settineri *et al*. 2016), visibility, (Tapak *et al*. 2018), dust (Tapak *et al*. 2018), fog (Tapak *et al*. 2018), air pressure (Tapak *et al*. 2018) and seasonality (Settineri *et al*. 2016).

Mental health. Measures of mental health varied, including burden of disease, assessed as economic estimations of disease burden at aggregate levels (Ha and Shao 2019; Han *et al*. 2018) and hospital/emergency department visits related to psychiatric disorders generally (Vida *et al*. 2012), or specific disorders/disorder classifications (Settineri *et al*. 2016; Tapak *et al*. 2018). Other papers used self-reported measures of mental health (Beecher *et al*. 2016; Obradovich *et al*. 2018; Ha and Shao 2019), administrative hospital records or medical insurance claim records (Han *et al*. 2018; Vida *et al*. 2012; Settineri *et al*. 2016; Tapak *et al*. 2018). Additional variables were only included in relation to general mental health outcomes, not specific mental health disorders, and these were limited.

Findings. Greater sunshine exposure was associated with better mental health (Beecher *et al*. 2016; Ha and Shao 2019), though not suicide ideation (Beecher *et al*. 2016). Relationships to precipitation were mixed, with some studies linking higher precipitation to poorer mental health (Obradovich *et al*. 2018) and greater incidence of psychosis (Tapak *et al*. 2018), mood disorders (Settineri *et al*. 2016), and depressive disorder (Tapak *et al*. 2018) but lower incidence of bipolar disorder (Tapak *et al*. 2018) and no linear relationship between rainfall intensity and economic estimations of burden of disease (Han *et al*. 2018). Low humidity (Vida *et al*. 2012; Settineri *et al*. 2016), cloudiness, dust and wind speeds (Tapak *et al*. 2018; Settineri *et al*. 2016) were associated with better mental health outcomes, while findings on fog, visibility and air pressure were mixed (Tapak *et al*. 2018).

Meteorological conditions
Temperature

Summary: Secondary spatial data or self-reported heat stress were predominantly used in studies. High temperatures were found to have a negative relationship to mental health. Temperature was generally considered independently of other weather variables.

Number of papers: 16				**Analysis type**		
Main approach	MH	Env	Both	Qualitative	Quantitative	Mixed
	31%	0%	69%	0%	100%	0%
Location of population studied	Asia	Australasia	Europe	North America	South America	Africa
	31%	19%	19%	31%	0%	0%

Study type		**Study design**		
Intervention	Observation	Lab	Field	Secondary
0%	100%	0%	6%	94%

Population: Predominantly adults, with some limitation on age, over 45 and over 65 and one study on children.

Environmental science. Temperature was generally measured via meteorological records (Ding *et al*. 2016; Almendra *et al*. 2019; Mullins *et al*. 2019; Min *et al*. 2019; Obradovich *et al*. 2018; Page *et al*. 2012; Vida *et al*. 2012; Xue *et al*. 2019; Chen *et al*. 2018; Díaz *et al*. 2020), with self-reported heat stress also considered (Tawatsupa *et al*. 2012).

Mental health. General mental health was considered, either via self-report scales (Ding *et al*. 2016; Xu *et al*. 2018), mentally unhealthy days (Ha and Shao 2019; Mullins *et al*. 2019, Obradovich *et al*. 2018) or by use of hospital admissions (Almendra *et al*. 2019, Guirguis *et al*. 2014; Liu *et al*. 2018; Mayner *et al*. 2010; Min *et al*. 2019; Mullins *et al*. 2019; Vida *et al*. 2012) or death (Page *et al*. 2012) records. Specific mental health disorders included dementia (Chan *et al*. 2018), alcohol and drug abuse (Chen *et al*. 2018), schizophrenia (Chen *et al*. 2018), depression (Chen *et al*. 2018; Ding *et al*. 2016; Xue *et al*. 2019), anxiety (Chen *et al*. 2018; Díaz *et al*. 2020; Ding *et al*. 2016), dissociative disorder (Chen *et al*. 2018), and suicide rates (Mullins *et al*. 2019). These were largely measured through clinical records (Chen *et al*. 2018; Díaz *et al*. 2020; Mullins *et al*. 2019) or self-report (Ding *et al*. 2016; Xue *et al*. 2019). Wellbeing was measured using a self-report scale (Tawatsupa *et al*. 2012).

Findings. Overall temperature varied in its relationship to mental health. Higher temperatures were associated with poorer mental health (Chan *et al*. 2018; Guirguis *et al*. 2014; Min *et al*. 2019; Mullins *et al*. 2019; Vida *et al*. 2012; Ding *et al*. 2016; Obradovich *et al*. 2018) although this was not seen in all heatwaves (Mayner *et al*. 2010) or locations (Vida *et al*. 2012). Some individual disorders did not show a relationship (dementia, alcohol related disorders, anxiety, dissociative disorders, Chan *et al*. 2018).

The impacts of temperature were largely considered independently of other determinants of mental health or weather, although socio-demographic characteristics were included in most papers. Other variables considered include humidity (Ding *et al*. 2016), existing health conditions (Ha and Shao 2019, Almendra *et al*. 2019; Min *et al*. 2019; Mullins *et al*. 2019; Xue *et al*. 2019) and physical activity (Ha and Shao 2019; Xu *et al*. 2018).

2.2 Case studies of research at the nexus between environmental science and mental health

Workshop participants were asked to identify exemplar or innovative case studies, which, in their opinion, have led to substantial advances in understanding linkages between environmental science and mental health. Seven case studies were selected to illustrate the diversity of research where the environmental sciences have contributed to mental health research. These case studies demonstrate innovation in research methods by either developing and testing new approaches and methods, linking very large or comprehensive sets of environmental and health data, or in their choice of sampling units, resolution, or degrees of replication. Successful larger, collaborative projects were often based on smaller proof-of-concept or feasibility projects. An eighth case study illustrates an opportunity for environmental science contribution. Other suggested case studies can be found in **Appendix D**.

One of the success factors highlighted for these case studies was the interdisciplinary team of scientists (sometimes quite broad) for the project. One researcher described this as, *"An important factor [for its success] was the willingness of those from different disciplines to patiently work together to navigate this interdisciplinary space"*. Another value of the interdisciplinary mix mentioned by workshop participants was being able to develop research designs grounded in medical studies (randomised trials) – which facilitated transferability – but also to integrate nature-based environmental and social science theory (e.g. attention restoration theory, Kaplan and Kaplan 1989). Many noted that the interdisciplinary research was often made possible through collaborative grants from different UK research councils. Alongside the emphasis on interdisciplinarity, cross-sector partnership (transdisciplinarity) was also mentioned as an important factor. One researcher felt that the significant impact of their research was due to strong partner collaborations with local councils and government agencies and delivering communication outputs for both academic and non-academic audiences.

Workshop Case Study 1 —

Beyond greenspace: linking ecological, socio-economic and health data to deepen our understanding of relationships between nature, health and wellbeing [3]

This case study highlights the importance of engaging with practitioners and partner organisations, and the need for detailed ecological/environmental data to extend scientific investigation of linkages between nature and wellbeing.

Researchers: Interdisciplinary team of geographers, epidemiologists, psychologists, social scientists and environmentalists.

Research Question: Do different types and qualities of natural environments have varying relationships with human health and wellbeing, and how do these relationships differ according to rural/urban context and socio-economic status?

The research involved standard GIS approaches, for example allocating UK CEH Land Cover Map data to census small areas in order to match to health data. It showed that people moving to a greener urban area report better mental health, which stays improved for at least three years. Another study showed that people living nearer the coast in England, UK are more likely to meet physical activity guidelines than those living further inland. Using the British Household Panel Survey (BHPS) for longitudinal analysis of rural residents, the researchers showed that while 'greenspace' generically was not a very useful environmental exposure to consider in terms of mental health, certain land cover types were associated with better mental health. Lastly, a cross-sectional ecological analysis using census data also demonstrated that a range of more nuanced environmental measures were associated with better population health (for example, broadleaf woodland, land cover diversity, density of protected/designated areas and bird species richness).

3 Numerous publications have been generated from this project including: Wheeler, B.W. *et al*. 2015. Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. *International Journal of Health Geographies* 14, 17. doi:10.1186/s12942-015-0009-5. See also https://beyondgreenspace.net/

The ***broad interdisciplinary team*** contributed to the success of the research. ***Extensive interactions with partner organisations*** supported both relevance and robustness of the research and subsequent impact development. ***Environmental science approaches underpinned the development of novel small-area environmental indices,*** beyond the typical green/built environment dichotomy, that were nationally applicable, meaningful and robust. Ecologists and environmental scientists substantively contributed to the conceptualisation of what metrics might be relevant in representing diverse natural environment conditions, and how they might influence human health and wellbeing, for example, considering how landscape diversity indices or the relative spatial density of protected and designated areas might relate to human health.

The project and related research led to working extensively with the World Health Organisation (WHO) to inform development of suggested urban greenspace indicators for the European Region, and ultimately to our research centre being designated WHO Collaborating Centre for Natural Environments and Health in 2019. It also led to making significant contributions to health aspects of the UK government 25-year plan for the environment.

Case study suggested by Ben Wheeler, a researcher on the case study project.

Air Pollution and Mental Health Case Studies. Case studies 2–4 illustrate the progression of an area of research and how targeted and aligned funding (by NERC, cross council joint grants, and as part of UKRI newly established cross council priority funding) has opened up and established a field of interdisciplinary enquiry. These studies contribute to an increasing body of literature documenting associations between air pollution and brain health.[4]

4 Alzheimer Research UK added air pollution as one new key modifiable risk to their list of factors in 2020. See: https://www.alzheimersresearchuk.org/blog/can-we-really-reduce-the-number-of-people-living-with-dementia-by-40/

Workshop Case Study 2 —

The Environmental Risk study: exploring associations between ambient air pollution and adolescent psychotic experiences in a longitudinal cohort study [5]

This case study illustrates integration of a cohort sample with environmental science modelling techniques drawing from a road traffic emissions inventory.

Researchers: An interdisciplinary team of psychologists, atmospheric modellers, epidemiologists and psychiatrists.

Research Question: Is ambient air pollution exposure associated with psychotic experiences in adolescence?

The research linked modelled annualized estimates of exposure to four air pollutants in high spatial resolution—nitrogen dioxide (NO_2), nitrogen oxides (NO_x), and particulate matter with aerodynamic diameters of less than 2.5 μm ($PM_{2.5}$) and less than 10 μm (PM_{10}) for 2012 to the home addresses plus two commonly visited locations of 2066 participants from the Environmental Risk (E-Risk) longitudinal twin study when the participants were 18 years old. The E-Risk Study is a population-based cohort study of 2232 children born during the period from January 1, 1994 through December 4, 1995 in England and Wales and followed up from birth through 18 years of age (with 93% retention). At 18 years of age, participants were privately interviewed regarding adolescent psychotic experiences (e.g. hearing voices, being extremely paranoid). Urbanicity was estimated using 2011 census data. Pollution exposure estimates were modelled using the local-scale Community Multiscale Air Quality (CMAQ-urban) Modelling System, which is a coupled regional chemical transport model and street-scale dispersion model. [6] CMAQ-urban uses a new generation of road traffic emissions inventory to model air quality down to individual streets, providing hourly estimates of pollutants at 20 × 20-m grid points throughout the UK (i.e. address level).

5 Newbury, J.B. *et al.* 2019. Association of air pollution exposure with psychotic experiences during adolescence. *JAMA Psychiatry.* 76(6):614–623. doi:10.1001/jamapsychiatry.2019.0056. Available from: https://jamanetwork.com/journals/jamapsychiatry/fullarticle/2729441

6 http://erg.ic.ac.uk/Research/home/modelling-no2-pollution-in-the-uk.html

Psychotic experiences were significantly more common among adolescents with the highest (top quartile) level of annual exposure to NO_2, NO_X, and $PM_{2.5}$. Together NO_2 and NO_X statistically explained 60% of the association between urbanicity and adolescent psychotic experiences. No evidence of confounding by family socio-economic status, family psychiatric history, maternal psychosis, childhood psychotic symptoms, adolescent smoking and substance dependence, or neighbourhood socio-economic status, crime, and social conditions was found.

This project ***innovatively*** brought together ***high-resolution ambient air pollution modelling*** with comprehensively ***phenotyped longitudinal cohort data*** thus leading to successful outputs.

The research attracted considerable media attention thus highlighting the potential links between air pollution and adolescent mental health issues in the UK context. Together with a paper from a previous collaboration between members of this group, which explored associations between air pollution at age 10 and common mental health outcomes (ADHD, anxiety, depression, conduct disorder),[7] it was also mentioned during a debate in the House of Lords on accelerating reductions in traffic-related air pollution in the UK.

Case study suggested by Helen Fisher, a researcher on the case study project which was funded by a joint grant from NERC-MRC-CSO [NE/P010687/1].

7 Roberts, S. *et al.* 2019. Exploration of NO_2 and $PM_{2.5}$ air pollution and mental health problems using high-resolution data in London-based children from a UK longitudinal cohort study. *Psychiatry Research*. 272:8–17. Available from: https://www.sciencedirect.com/science/article/pii/S016517811830800X?via%3Dihub

Workshop Case Study 3 —

Consequences of long-term air pollution exposure for mental health in an adult cohort[8]

This case study extends observations made within the E-Risk study to consider the impact of long-term exposures to air pollution on mental health and wellbeing of an urban adult population over time. Noise was integrated as an additional significant urban stressor.

Researchers: A research team drawing on expertise across epidemiology, atmospheric modelling, geography, sociology, psychiatry and public health disciplines.

Research Question: Is long-term residential exposure to air pollution associated with early-indicators of poor mental health?

This study incorporated questionnaire data assessing common mental disorders (anxiety and depression), perceptions of physical health and wellbeing, plus an evaluation of sub-clinical psychotic symptoms. The population of 1698 adults were randomly selected from 1057 households within two inner-city boroughs in London, UK with assessments performed over two periods (2008–10, 2011–13, drawn from the South East London Community Health [SELCoH] study). Annual and quarterly air pollution exposures to NO_2, NO_X, $PM_{2.5}$ and PM_{10} were estimated based on the individual's home address using high resolution pollutant models. Estimates of noise, using modelled road traffic noise, were also included as a potential alternative explanation (confounder) for poor mental health, alongside other individual- and neighbourhood-level indicators of socio-economic status and urbanisation.

8 Bakolis, I. *et al.* 2020. Mental health consequences of urban air pollution: prospective population-based longitudinal survey. *Social Psychiatry and Psychiatric Epidemiology.* Available from: https://doi.org/10.1007/s00127-020-01966-x

There was a consistent longitudinal association of long-term exposure to air pollutants (NO_2, NO_X, $PM_{2.5}$) with symptoms indicative of common mental disorders. Associations were more pronounced for NO_2, NO_X in individuals who had not moved over the period of the study. There was a greater likelihood of psychotic experiences associated with PM_{10} though this observation was limited to only the first assessment period. Effects remained following adjustment for negative aspects of the urban environment, individual-level factors and urban noise. The signal for subclinical psychosis was found to be surprisingly robust to adjustment by confounders.

The research ***overcame limitations of previous studies*** through integration of the effect of road traffic noise and detailed consideration of a range of individual-level confounders, not normally available in population-based research. It contributes to methodological advancement of linking cohort samples and environmental science demonstrating that mental health impacts of air pollution track into adulthood.

Case study suggested by Ian Mudway, a researcher on the project. The study was part funded by the Economic and Social Research Council [RES-177-25-0015], an internal award made within King's College London (under their Kings Together award scheme to stimulate interdisciplinary research), and the National Institute for Health Research (NIHR) Health Protection Research unit in Environmental Exposures and Health.

Workshop Case Study 4 —
Modelling historical air pollution and dementia/ cognitive decline: towards a life course approach[9]

This case study provides a proof-of-concept example to test the feasibility of combining life course data with air pollution modelling to assess cognitive decline.

Researchers: An interdisciplinary team including an epidemiological psychiatrist and environmental scientists (air pollution modelling).

Research Question: What role does air pollution play in the development of important chronic health conditions which develop over many years or decades, such as, for example, dementia (including Alzheimer disease and vascular dementia)?

Case study suggested by Stefan Reis (researcher on NERC-MRC-CSO proof-of-concept research grant NE/P010849/1)

The research produced modelled historical air pollution estimates for the mid-twentieth century using historical data on emission of various air pollutants (NO_X, sulphur dioxide [SO_2] and fine particulate matter [$PM_{2.5}$, PM_{10}]), in combination with historical meteorological conditions. This pollution model was then combined with two cohort studies: (a) a complete population narrow-age cohort (the Scottish Mental Survey 1947 cohort, N~70,000 all aged 11 in 1947) where dementia diagnoses have been ascertained through electronic health records and death certificates; and (b) a subset of this cohort (the Lothian Birth Cohort 1936 study, N~1000) who have had longitudinal cognitive testing and clinical dementia diagnoses ascertained since recruitment in 2004.

This project used ***unique and novel modelling of historical (1930– present day) air pollution exposure*** estimates to quantify long-term exposure effects. It demonstrated that it is possible to estimate historical air pollution data through modelling and to combine these data with existing cohort studies in order to ***investigate the life course origins of dementia.***

Future possibilities to extend this work include: (i) modelling air pollution over more time points to get a finer-grained idea of 'exposure' to air pollution throughout the course of life; (ii) linking the modelled air pollution data with further cohort studies in the UK, Europe, and internationally; and (iii) applying these principles to other chronic diseases, such as cardiovascular disease.

9 Russ, T.C. *et al.* 2020. Life course air pollution exposure and cognitive decline: modelled historical air pollution data and the Lothian Birth Cohort 1936. *Journal of Alzheimer's Disease* (published Online). Available from: https://doi.org/10.3233/JAD-200910

Workshop Case Study 5 —

The Ranch Study: impact of aircraft and road traffic noise on children's learning and health in three European countries[10]

This case study illustrates high quality replication and collaboration between countries in addition to interdisciplinarity. Primary and secondary acoustic data were used to assess the impact of aircraft and road traffic noise exposure on children.

Researchers: An interdisciplinary team of psychologists, psychiatrists, epidemiologists and acousticians.

Research Question: Do increasing levels of aircraft noise exposure in primary school children from socio-economically matched primary schools from around three European airports affect children's learning and mental health using standardised scales?

The methodology was a cross-sectional questionnaire-based study using standardised tests based in randomly selected socio-economically matched primary schools. Noise measurements were based on aircraft noise contour maps, road traffic noise maps and acute acoustic assessments at primary schools during testing. Blood pressure was measured in schools using standardised measurement.

The key findings were that aircraft noise exposure showed a linear association with impairment of reading comprehension and memory in 2844 primary school children. Reading age in children exposed to high levels of aircraft noise was delayed by up to 2 months in the UK and by up to 1 month in the Netherlands for a 5 dB change in noise exposure. It also found evidence that both aircraft and road traffic noise are related to increased levels of annoyance in children and that aircraft noise is possibly associated with raised blood pressure and hyperactivity.

10 Matheson, M. *et al*. 2010. The effects of road traffic and aircraft noise exposure on children's episodic memory: The RANCH Project. *Noise & Health*. 12, pp.244–54. doi: 10.4103/1463-1741.70503

Innovations that contributed to the success of the research were the selection of schools across a ***range of noise exposure,*** and ***replication*** of the methodology across three European countries. This research project amassed a convincing body of evidence linking aircraft noise exposure and effects on children's cognitive performance on complex tasks, notably reading comprehension and memory.

Findings were considered in the development of the European Environmental Noise Directive (END) and included in the WHO burden of disease document on the impact of noise on health. The findings also informed the British Airports Authority's decision to fund installation of double glazing in schools around Heathrow Airport in the UK.

Case study suggested by Stephen Stansfeld (researcher on the RANCH project).

Workshop Case Study 6 —
Efficacy of Nature Based Therapy: Narcadia® [11]

This case study illustrates the innovative use of cumulative research on natural environments, the therapeutic effects of nature and a living laboratory to create and design optimum landscapes for nature-based therapy.

Researchers: An interdisciplinary team of landscape architects, ecologists, social scientists, psychologists, and psychiatrists.

Research Question: What is the efficacy of nature-based therapy for patients with stress-related illnesses?

One of the *first studies* to test the efficacy of nature-based therapy vs cognitive behaviour therapy for stress-related illnesses using a *randomised control trial*. Nature-based therapy refers to a therapeutic intervention that incorporates natural elements and nature-related activities often in a specially designed natural environment. The nature-based therapy (called Narcadia®) in this study took place in a 1.4 hectare wild forest garden, using evidence-based health design. Nature-based therapy builds on theories such as attention restoration theory (Kaplan and Kaplan 1989) – which emphasises sensory stimulation from natural environments. The cognitive behaviour therapy took place in private treatment with practising psychologists.

Both nature-based therapy and cognitive behaviour therapy resulted in a significant increase in the Psychological General Well-being Index and a decrease in burn-out, both of which was sustained 12 months later. There was no statistical evidence of a difference between the two therapies, validating the use of Narcadia® nature-based therapy as a treatment for stress-related illnesses.

Case study suggested by Lisa Page.

11 Stigsdotter, U.K. *et al*. 2018. Efficacy of nature-based therapy for individuals with stress-related illnesses: randomised controlled trial. *British Journal of Psychiatry*. 213; 404–411. doi: 10.1192/bjp.2018.2

Workshop Case Study 7 —
Capturing the complexity of river catchment systems to offset livelihood and well-being impacts of climate change[12]

This case study used a whole system process-based modelling approach to assess the impact of future climate and anthropogenic change in the Sutlej and Beas river basins (India) on the livelihoods and wellbeing of people living in the Himalayan foothills and plains.

Researchers: An interdisciplinary team of climate specialists, ecologists, agriculture researchers, modellers, engineers, social scientists and ecosystem service experts.

Research Question: How do spatial patterns of freshwather ecosystem services (fES) production change, under current and future climate, and what is the impact of water management adaptation strategies on fES productivity at catchment scale?

Environmental science researchers conducted freshwater ecosystem service assessments[13] for three distinct geographical zones (Himalayas, foothills and plains) which were incorporated into the river systems model and evaluated under different climate change scenarios. An improved version of the WEAP tool[14] was used.

The research also included an assessment of cultural services[15] which demonstrated the importance of river corridors to spiritual and religious festivals and practices, as well as aesthetic values and inspiration benefits. Findings from the Beas river demonstrated how crucial it was in the lives of local communities, not just for their livelihoods and economic development, but also their cultural, spiritual and religious practices. The impact of predicted changes to the flows of the Beas river on these highly valued cultural services highlighted the need to incorporate these intangible services into decisions on future river basin management.

Case study suggested by Lindsay Beevers, a researcher on this jointly funded project (NERC [NE/N016394/1 and NE/N015541/1] and the Newton-Bhabha Fund).

12 Momblanch, A. *et al.* 2020. Enhancing production and flow of freshwater ecosystem services in a managed Himalayan river system under uncertain future climate. *Climatic Change* 162:343–362. Available from: https://doi.org/10.1007/s10584-020-02795-2

13 Ncube, S., Visser, A., Beevers, L.A. 2018. Framework for assessing instream supporting ecosystem services based on hydroecological modelling. *Water.* 10(9), 1247. https://doi.org/10.3390/w10091247

14 The WEAP (Water Evaluation on Planning) tool is a generalised simulation model for the analysis of water resource systems. It represents different hydrological processes, water resources, water demands, water infrastructures and management. It uses a link and node structure to represent the various system components and processes, and their spatial dependences.

15 Ncube, S., Beevers, L., Momblanch, A. 2021. Towards intangible freshwater cultural ecosystem services: informing sustainable water resources management. *Water.* 13, 535. https://doi.org/10.3390/w13040535

Workshop Case Study 8 —
Naturally occurring lithium in drinking water and suicide rates[16]

This case study illustrates a topic area largely driven by mental health researchers which is identifying future research questions to which environmental science could contribute.

Researchers: A team drawing on expertise from psychology, psychiatry, public health and epidemiology.

Research Question: What is the state of evidence for an association between lithium levels in drinking water and suicide mortality?

Findings from this recently published systematic review and meta-analysis of 15 studies identified a consistent protective association between the lithium levels/concentration in publicly available drinking water and the incidence of suicide. In areas with higher levels of natural lithium in drinking water, suicide mortality rates were lower. This association was statistically significant for total and female suicide rates. Water samples, collected from publicly available drinking water sources, were analysed using mass spectrometry or inductively coupled plasma emission spectroscopy. Suicide mortality rates were drawn from publicly available data. Confounders included in analyses considered socio-economic conditions, measures of local climate, altitude and availability of medical professionals. Future research opportunities identified include: the stability of naturally occurring lithium levels over time; the cumulative effect of exposure to low-dose lithium; exploring the mechanisms by which lithium reduces suicide rates (e.g. improving mood); and the interrelationship between lithium levels in water, soil, diet and suicide rates.

Case study suggested by Anjum Memon, a researcher on the project. The work was supported by Brighton and Sussex Medical School and part funded by the National Institute for Health Research (NIHR) Biomedical Research Centre at South London and Maudsley NHS Foundation Trust and King's College London.

16 Memom, A. *et al.* 2020. Association between naturally occurring lithium in drinking water and suicide rates: systematic review and meta-analysis of ecological studies. *British Journal of Psychiatry.* 2020 Dec;217(6):667–678. doi: 10.1192/bjp.2020.128. PMID: 32716281.

3. Gaps and opportunities

Gaps and opportunities were identified through the scoping review and the participatory workshops. Workshop participants were asked to consider the gaps, opportunities and challenges for future research at the intersection of environmental science and mental health from their respective disciplinary and interdisciplinary perspectives and experiences. Six key areas of opportunity were identified, five by workshop participants supported by the scoping review literature (detailed in boxes), and one by the authors of this report directly from the scoping review literature **(section 3.1)**. Workshop participants also noted a case for caution. These opportunities consider both the approach to research as well as topic areas for further investigation.

3.1 The geography of environmental science and mental health research

The scoping review identified that research from the past decade has largely occurred in North America, the European Economic Area (including UK at time of research), Australia and China. Given the scale of ongoing environmental degradation globally, and differences in environmental regulations, relationships to the environment, and effects of environmental change, promoting research outside of these locations provides a valuable opportunity to increase scientific understanding and develop relevant policy and innovation.

3.2 Interdisciplinary research — an opportunity to understand complexity

To understand mental health and wellbeing in its totality, mental health research needs to fully encompass the fundamental role of the environmental sciences. There was a general view amongst workshop participants that this recognition of the importance of the environment and its role in human health and wellbeing was increasing, both nationally and internationally. Examples noted include the numerous intergovernmental panels, programmes, and conferences that seek to integrate environment and health, such as the Sustainable Development Goals (UN 2021), the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES 2021),

the upcoming UN Climate Change Conference (COP26; UN 2021a), Resilient Cities (OECD 2021), the European Green Deal (European Commission 2021), the WHO European Environment Health Process (WHO Europe 2021), and the collaboration between the Convention on Biological Diversity and WHO to promote awareness of the influence of biodiversity on human health and wellbeing (Convention on Biological Diversity 2016).

The complexity of such research – from the bio-medical, environmental, social, economic, and psychological disciplines – necessitates ***more interdisciplinary research.*** It was noted that support for such research has increased and that the UKRI, through ***a cross council approach*** to funding calls, is well placed to further foster and support novel collaborations in research and innovation. An example mentioned is the 2019–2025 Clean Air Programme,[17] funded through the UKRI's Special Priority Fund and co-led by NERC and the Met Office, which utilises 'champions' and collaborative networks to bring together expertise from disparate research areas, business and policy to drive forward innovative research on air quality and health. One strategy might be to make mental health a priority topic within this scheme for one of its funding rounds (covering mental health and air pollution) or develop a separate funding initiative for broader engagement of the environmental sciences with mental health.

Even for some tightly defined disciplinary research questions, such as those focused on understanding the environmental science detail of a single, individual step that might exist along the pathway from environmental exposure to mental health disease, it is critical for these to be ***situated within a recognition of the complexity of the whole system.*** Here the opportunity lies in finding ways to ***join up individually funded strands of inquiry*** (i.e. those funded by separate research councils) through, for example, the lens of a systems approach **(see section 3.5)**.

Several workshop participants described the, in their opinion, unhealthy siloed approach to research that had been fostered under previous funding calls, structures which focused on a single component of the environmental sciences to try and answer complex societal challenges. This raised the question of to what extent this siloed approach has been driven by protectionism around available research budgets and the fear that bringing in other disciplines will result in a diminishing *'slice of the research funding pie'*. Discussion also highlighted the institutional barriers, such as siloed disciplinary working, or concerns over appropriate attribution for contributions to interdisciplinary research that exist. The related challenge – and by extension opportunity – is to examine how current and future funding mechanisms have and would overcome such concerns.

Funding bodies interested in supporting interdisciplinary research need to ***acknowledge the challenges associated with successful, integrative work across disciplines.*** This includes ***ensuring adequate funding and resources*** are available for cross-cutting and innovative research, for example, bringing diverse scientific methodologies together or co-constructing and designing new ones. Such research incurs ***transaction costs in communication and idea development*** not seen in single discipline research.

17 https://nerc.ukri.org/research/funded/programmes/clean-air/

Box 1: **Integrating different types of evidence**

Qualitative methods were largely absent across the studies reviewed. There is potential for including qualitative methods and mixed methods designs into future interdisciplinary work in environmental science and mental health. Qualitative approaches could contribute to building understanding of the depth and breadth of the relationship between environment and mental health. These approaches can help give a holistic view of the experience of individuals. Exploratory qualitative research is also valuable for identifying promising research questions and hypotheses for quantitative research in under-researched areas. Such integration would call for interdisciplinary project teams that incorporate the social sciences as well as environmental and health sciences, and the building of shared understandings amongst team members of the value of different types of evidence and research methods in contributing to knowledge on the environment and mental health.

3.3 Improving awareness, data sharing and linkages across large data sets

Due to the complexity of different intersecting factors, ***establishing causality in mental health research is challenging.*** A further complication arises from the reality that levels of environmental exposure are not static; people move around within and between places resulting in different exposures. ***Interrogation of large-scale environmental and public (and medical) health data sets,*** of composite and longitudinal studies over different timescales, provides opportunities for researchers to tackle such complex research challenges.

Workshop participants felt that there was ***still a lack of knowledge and understanding about the different data sets and repositories*** held by different organisations. Therefore, to facilitate such effort, ***greater awareness of, accessibility to and linkages between*** data sets need to occur. Making these data sets ***accessible*** (e.g. open access) is a non-trivial challenge as there are considerations of both confidentiality (e.g. if utilising individual-level records from a cohort study) and recognition of intellectual contribution (e.g. of the groups who created the datasets). Moreover, the process of linking public/mental health records with large environmental data sets ***requires time,*** hence a commitment of funds; as one participant said, *'you can't link for free'*. Thus, in addition to the novel insight that can come through the analysis of linked datasets, innovation is needed in the development of methods to bring datasets together (e.g. to maintain confidentiality, to integrate data sets across different temporal scales).

The establishment of a ***central body to curate data sharing*** could provide a formal structure through which these issues and opportunities could be facilitated. For example, a central repository of national cohort resources could outline available metadata, the nature and type of bio-banked material, and the ethics under which the study was conducted. Similarly, a central body or focused initiative could review issues such as whether current cohorts are configured to answer questions linking environmental science and mental health research, and their representativeness.

Box 2: **Datasets to support longitudinal analyses**

Most studies identified through the scoping review took a cross-sectional approach to investigating the relationship between environment and mental health. Longitudinal studies would improve the potential to understand longer-term impacts of environment, as well as causal relationships. The nature of much of the environment-related issues considered within the identified literature (e.g. natural disasters, oil spills) means that understanding of pre-event mental health is limited. Interaction between environmental scientists and mental health researchers in the development of longitudinal datasets may provide opportunity to understand the impacts of such events.

Box 3: **Considering variations between and within communities**

At the study level, the often local but coarse scale of research (e.g. a single community, but only limited consideration of variation of environments or exposure within the community) means that there is a gap in understanding of individual experiences. Within some thematic areas there was also a lack of analyses investigating differential impacts of exposure on different groups of the population (e.g. gender disaggregated analyses), and how socio-demographic factors might moderate the impact of exposures. There is also a lack of replication in populations in different locations, particularly relevant for meteorological conditions with regard to latitude and altitude.

3.4 Engaging with Natural Experiments

Place-based natural experiments provide a key opportunity for environmental science to contribute to mental health research. Such involvement would not only ***help to design the details of potential interventions*** but also contribute to ***monitoring the impact*** of large scale planned interventions (which effect the chemical, physical and ecological environment). For example, could nature-based solutions or ecological restoration projects also monitor aspects of psychological restoration or wellbeing? One workshop attendee noted that it would be beneficial if ***funding for interventions*** by local authorities or developers could be ***linked to interdisciplinary research*** that can investigate the impact of such interventions on the environment and its inhabitants.

The use of natural experiments requires both funding calls and researchers to be able to engage more responsively with practitioners and 'live' projects. One researcher highlighted the value of putting mechanisms in place to be able to take advantage of planned interventions in order to reduce *'missed research opportunities'*. Also noted was the importance of ***'agile' research funding*** to facilitate researchers taking advantage of emerging and potentially unanticipated natural experiments, as has been demonstrated with UKRI's COVID-19 calls. One researcher commented that this type of 'before-and-after' study tends to be less expensive than longitudinal or cohort studies, which, while important, can be significantly expensive to fund.

Box 4: **Research responding to natural disasters**

Although natural disasters as a theme was strongly represented in the literature reviewed as part of the scoping review, this body of research was noted for having minimal environmental science involvement. Measures of exposure were often limited (e.g. exposed vs. not exposed). A similar observation could be made for literature investigating pollution events. Further involvement of environmental scientists here would allow for deeper understanding of 'dose-response' relationships in relation to natural disaster exposures and particular impacts of natural disaster attributes. Furthermore, many studies lacked control/comparator groups and thus would benefit from greater application of principles of experimental design to evidence causality, particularly in relation to long term impacts. Similarly, for research on natural environments, particularly interventions such as forest schools, there is a gap in understanding of the specific attributes of the environment that are relating to any observed mental health changes.

3.5 Draw on complex system approaches from environmental sciences

Approaches used in the environmental sciences to understand complex systems could usefully contribute to accounting for the multiple factors associated with mental health and wellbeing. Such approaches ***seek to incorporate intersecting factors, multiple levels and the non-linearity of a system***. As an example, traditional epidemiological approaches could be significantly enhanced through the ***application of a complex ecological systems approach and the use of big data***. Advancements in technologies to interrogate multiple -omics (e.g. epigenomics, proteomics), alongside machine learning and bioinformatic approaches could help provide insights into the origin and progression of disease. Additionally, ***a systems frame and relevant methodologies*** would offer a more thorough and complete approach to understanding how socio-ecological systems iteratively interact and impact on individual and community health.

Workshop participants felt that this more holistic understanding of contributors and relationships should include governance systems and health provision in addition to individual, community and environmental factors and was needed for investigations of general health and wellbeing alongside specific studies on mental health and wellbeing. The exposome concept, which seeks to bridge the totality of environmental exposures (internal and external, over the life course, biological, chemical and socio-economic) in relation to health impacts, was identified as a useful conceptual framework to inform research to develop such holistic understanding (see Vineis *et al*. 2020).

Box 5: **Integrating multiple conceptual models of health into analyses**

The scoping review highlighted that, overall, the range of potential confounding variables included in models was somewhat limited. Related to this, there was also limited evidence of environmental exposure perspectives being integrated with other models of mental health (e.g. genetic or social determinants of mental health). This provides further opportunities to develop understanding of the relationships between environmental science and mental health and the causal pathways involved. In the theme of natural disasters and wildfires, greater incorporation of coping mechanisms and other factors underpinning resilience would also be valuable.

3.6 Key areas to target environmental science research

Two key areas of mental health research would particularly benefit from integration of the environmental sciences: (i) the ***contribution of environmental factors to the origins and progression of mental health diseases and disorders;*** and (ii) the role the environment plays in the ***treatment of mentally ill people and the promotion of good public health and mental wellbeing.*** It is important that both the ***positive and negative factors of the environment*** are researched, for example, the benefits of diverse microbes to gut-brain health as well as the indirect effect of air pollution on brain health via impacts on the cardiovascular system.

With regards to the origins and progression of diseases, workshop participants with expertise in psychiatry and or epidemiology emphasised the importance of understanding the potential impacts of different environmental exposures at ***different stages of the life course*** (e.g. early childhood, young adulthood, menopause). Incorporating a life course perspective would generate insight into how different disorders can manifest in different stages in a person's life, how different life stages have different vulnerabilities to disorders and the effect of early life exposure on subsequent life stages. An example would be to consider how early life cognitive deficits map to adult mental health and dementia risk.

With regard to the role the environment plays in promoting good mental health and wellbeing, workshop participants agreed that one significant opportunity for environmental science is to ***characterise which elements of the environment contribute to wellbeing.*** For example, whilst it was broadly recognised that there is an established knowledge base about the beneficial effects of exposure to natural environments (e.g. green space), there was a lack of sufficient understanding and detail about what specific aspects or features effected mental health and wellbeing. One researcher reflected on how useful it would have been to have had an ecologist on their research team to help categorise the natural environment in a project which tracked daily movements of people in green space. Observing that while the GPS technology could track people down to a metre, the research project team did not have detailed ecological data to that scale and had to rely on broad landcover descriptions.

Finding ways to improve the categorisation of salient environmental features (to finer resolutions) would foster advancement of methodologies investigating mental health and wellbeing as well as help elucidate the mechanisms underpinning any associations. An additional area of opportunity is to integrate this more nuanced understanding about the environment into research that is beginning to tease apart what types of nature-based health interventions work, for whom and why.

Box 6: **Knowledge gaps in relation to mental health domains**

The scoping review identified that studies on cognitive development and decline, substance abuse disorders, delusional disorders (including schizophrenia), behavioural syndromes (e.g. sleep disorder), and suicide and self-harm have often been overlooked. The extent to which these domains are represented in the literature does, however, differ by theme identified within the scoping review literature. Beyond the literature considering the health value of natural environments, the review found limited attention to the ways in which environments can support maintenance of 'good' mental health or promote wellbeing as 'more than just the absence of mental disorders' (WHO 2004).

3.6.1 Additional specific areas needing further research

Workshop participants identified the following topic areas as fruitful areas for future research:

- Development of biomarkers for environmental exposure to chemicals with mental health implications
- Methods to monitor people's biological/ physiological state in the environment
- Understanding the physiological and psychological mechanistic pathways, and intermediate steps, between exposure and mental health disease
- Environmental microbiome to human gut pathways – and then gut-brain chemistry and impacts on behaviour
- Integrating different methods (toxicological, epidemiological, imaging, psychological, neurobiological) to understand causal pathways. It was noted that the divestment of funding for toxicology may have hindered our understanding of the causal pathways linking environmental exposure to health.
- Beneficial naturally occurring chemicals in the environment and those introduced into processed food
- Integrating multi-pollutant (and their interactions) and multi-effect assessments through better integrated systemic assessments
- Inequality and access to the benefits of nature

3.7 A word of caution from environmental researchers

The extent to which it is important to monetise the health benefits of environmental interventions (see e.g. Connswater Urban Greenway project) was a topic of debate. Whilst some workshop participants saw this as a necessity for communication with policy makers and generating impact, a number of environmental scientists expressed caution over reducing environmental science research into a health economic statistic or a monetary value.

One researcher noted that the role of environmental science is also to ensure equivalence between managing our ecosystems for biodiversity and ecosystem function, and for human health and wellbeing outcomes. Environmental science should also advocate for the environment per se, generating evidence to ensure we understood the trade-offs between managing the environment for human health and wellbeing outcomes and having healthy, functioning ecosystems.

4. Conclusions and recommendations

The aforementioned gaps and opportunities suggest the following conclusions and recommendations for consideration. These have been structured by the initial set of research questions posed.

4.1 What is the current contribution of environmental science to mental health research?

The intersectionality of environmental science and mental health research is clearly relevant, as evidenced by over 200 papers included in the scoping review and an engaged group of experts from across the environmental sciences and mental health disciplines through participatory workshops. Most of the papers, however, had a stronger mental health than environmental science focus. More substantive involvement of environmental science would strengthen measurement (e.g. moving beyond 'disaster occurrence' as a measure of the environment in natural disaster research) and facilitate deeper understanding of causal relationships.

Currently there has been a greater focus on mental ill-health than maintaining or improving good mental health and wellbeing. This continued emphasis on the environmental risks and hazards for mental health, while relevant for addressing global challenges, leaves out critical insight for generating solutions.

4.2 How does research on environmental science and mental health relate to other determinants of mental health?

From engagement with participants at the workshops it became evident that the understanding of this intersectionality is a limited ingredient in current environmental science and mental health research. This opens a critical avenue for future research, one that can enrich the existing evidence linking mental health to social, economic, demographic, and genetic determinants. Bringing a complex systems conceptual frame and methodological approaches to research designs would bring us closer to causal inference and understanding of mechanisms in order to develop and target interventions at individual- and population-level. Further, this could be aided by improved awareness of existing sources of secondary data across sectors, capacity building and infrastructure for data sharing and linking across these datasets. This would build on initiatives to link administrative data. Linkage to birth cohort studies could provide important opportunity for life course research.

Institutional barriers that prevent sharing and linking of datasets across research disciplines (often due to the presence of siloed disciplinary thinking) and the need for appropriate acknowledgement for those who created the datasets also need to be addressed. Such complex research could be commissioned through funding calls involving strong cross-council collaboration, either through targeted cross-council initiatives or aligned individual calls. Research funding would benefit from being more agile and responsive, for example to take advantage of "natural experiments" e.g. changes in pollution due to COVID-19.

4.3 What are the current research designs and methodological approaches being used in environmental science-mental health research?

The majority of studies have been designed and conducted in North America, the European Economic Area (including UK at time of study), Australia and China, with insufficient understanding from other geographical locations with different environmental characteristics. Most studies occurred at local scale, with limited national scale studies. International comparisons are largely missing apart from in systematic reviews.

Research designs are largely observational and cross-sectional. Methodological approaches are predominantly quantitative drawing primarily on existing sources of secondary data or field-based primary data collection. Many of the measures are self-report, using a variety of standardised scales to assess mental health but also to capture whether someone has come in contact with, for example, an oil spill. The natural environment theme had a greater diversity of research designs and methodological approaches; this is perhaps reflective of the maturing investigation into the complexity of the people-nature relationship with regard to potential health and wellbeing benefits from interaction with the natural environment.

4.4 What are the evidence gaps and opportunities for the contributions of environmental science to mental health research?

- Use of more **large-scale datasets —** both composite and longitudinal studies. This will require more open-access availability to datasets, relevant training and attribution guidelines. Appropriate investment, resources and guidance will need to be provided to make this happen.

- **Longitudinal approaches —** these can (i) show the impact of a change in environmental conditions over time and before an exposure; (ii) allow a more nuanced understanding of environmental exposure throughout the life course; (iii) recognise how different disorders and vulnerabilities can manifest at different life stages; and (iv) help understand causal relationships. Natural experiments offer opportunities for longitudinal studies that integrate environmental sciences and mental health.

- **Integrative complex systems research —** the systems frame used in the environmental sciences could significantly enhance understanding of the origin and progression of good and poor mental health. Methodological approaches can incorporate intersecting factors, multiple levels and the non-linearity of the system to offer a more holistic understanding of how socio-ecological systems iteratively interact and impact on individual and community health.

- **Mixed methods approach —** this emerging paradigm offers a structured route through which to integrate qualitative and quantitative approaches to generate richer understanding of a research area. Qualitative approaches help build depth and breadth of understanding, provide holistic insight of an individual's experience, and identify possible research directions for quantitative research. A mixed methods approach could help address challenges of bringing different research traditions together.

- **Community of practice —** interdisciplinary and transdisciplinary teams provide an opportunity to understand complexity. Those that are very broad can help develop novelty, contributing to research success. Collaborating with non-academic stakeholders through partnership working can help to deliver impact. The rich discussion that occurred through the interdisciplinary participatory workshops could be fostered through appropriate mechanisms.

5. References

Afifi, W.A., Felix, E.D. and Afifi, T.D., 2012. The impact of uncertainty and communal coping on mental health following natural disasters. *Anxiety, Stress & Coping, 25*(3), pp.329–347.

Agyapong, V.I., Ritchie, A., Brown, M.R., Noble, S., Mankowsi, M., Denga, E., Nwaka, B., Akinjise, I., Corbett, S.E., Moosavi, S. and Chue, P., 2020. Long-Term Mental Health Effects of a Devastating Wildfire Are Amplified by Socio-Demographic and Clinical Antecedents in Elementary and High School Staff. *Frontiers in Psychiatry, 11,* p.448.

Aiena, B.J., Buchanan, E.M., Smith, C.V. and Schulenberg, S.E., 2016. Meaning, resilience, and traumatic stress after the Deepwater Horizon oil spill: A study of Mississippi coastal residents seeking mental health services. *Journal of Clinical Psychology, 72*(12), pp.1264–1278.

Akhter, S.R., Sarkar, R.K., Dutta, M., Khanom, R., Akter, N., Chowdhury, M.R. and Sultan, M., 2015. Issues with families and children in a disaster context: a qualitative perspective from rural Bangladesh. *International Journal of Disaster Risk Reduction, 13,* pp.313–323.

Akter, S., 2019. Impact of drinking water salinity on children's education: Empirical evidence from coastal Bangladesh. *Science of the Total Environment, 690,* pp.1331–1341.

Albrecht, G., Sartore, G.M., Connor, L., Higginbotham, N., Freeman, S., Kelly, B., Stain, H., Tonna, A. and Pollard, G. 2007. Solastalgia: the distress caused by environmental change. *Australasia Psychiatry, 15(s),* p.95–98.

Alcock, I., White, M.P., Lovell, R., Higgins, S.L., Osborne, N.J., Husk, K. and Wheeler, B.W., 2015. What accounts for 'England's green and pleasant land'? A panel data analysis of mental health and land cover types in rural England. *Landscape and Urban Planning, 142,* pp.38–46.

Almendra, R., Loureiro, A., Silva, G., Vasconcelos, J. and Santana, P., 2019. Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon. *Science of the Total Environment, 647,* pp.127–133.

Al-Mutairi, N.Z., Al-Attar, M.A. and Al-Rukaibi, F.S., 2011. Traffic-generated noise pollution: exposure of road users and populations in Metropolitan Kuwait. *Environmental Monitoring and Assessment, 183*(1–4), pp.65–75.

Aschengrau, A., Janulewicz, P.A., White, R.F., Vieira, V.M., Gallagher, L.G., Getz, K.D., Webster, T.F. and Ozonoff, D.M., 2016. Long-term neurotoxic effects of early-life exposure to tetrachloroethylene-contaminated drinking water. *Annals of Global Health, 82*(1), pp.169–179.

Ayer, L., Engel, C., Parker, A., Seelam, R. and Ramchand, R., 2019. Behavioral health of Gulf Coast residents 6 years after the Deepwater Horizon Oil Spill: the role of trauma history. *Disaster Medicine and Public Health Preparedness, 13*(3), pp.497–503.

Barton, H. and Grant, M., 2006. A health map for the local human habitat. *Journal of the Royal Society for the Promotion of Health, 126*(6), pp.252–3.

Beecher, M.E., Eggett, D., Erekson, D., Rees, L.B., Bingham, J., Klundt, J., Bailey, R.J., Ripplinger, C., Kirchhoefer, J., Gibson, R. and Griner, D., 2016. Sunshine on my shoulders: Weather, pollution, and emotional distress. *Journal of Affective Disorders, 205,* pp.234–238.

Belleville, G., Ouellet, M.C. and Morin, C.M., 2019. Post-traumatic stress among evacuees from the 2016 Fort Mcmurray Wildfires: Exploration of psychological and sleep symptoms three months after the evacuation. *International Journal of Environmental Research and Public Health, 16*(9), p.1604.

Berk, M., Williams, L.J., Andreazza, A.C., Pasco, J.A., Dodd, S., Jacka, F.N., Moylan, S., Reiner, E.J. and Magalhaes, P.V., 2014. Pop, heavy metal and the blues: secondary analysis of persistent organic pollutants (POP), heavy metals and depressive symptoms in the NHANES National Epidemiological Survey. *BMJ Open, 4*(7).

Beutel, M.E., Brähler, E., Ernst, M., Klein, E., Reiner, I., Wiltink, J., Michal, M., Wild, P.S., Schulz, A., Münzel, T. and Hahad, O., 2020. Noise annoyance predicts symptoms of depression, anxiety and sleep disturbance 5 years later. Findings from the Gutenberg Health Study. *European Journal of Public Health, 30*(3), pp.516–521.

Beutel, M.E., Jünger, C., Klein, E.M., Wild, P., Lackner, K., Blettner, M., Binder, H., Michal, M., Wiltink, J., Brähler, E. and Münzel, T., 2016. Noise annoyance is associated with depression and anxiety in the general population-the contribution of aircraft noise. *PLoS ONE, 11*(5), p.e0155357.

Bevilacqua, K., Rasul, R., Schneider, S., Guzman, M., Nepal, V., Banerjee, D., Schulte, J. and Schwartz, R.M., 2020. Understanding associations between Hurricane Harvey exposure and mental health symptoms among greater Houston-area residents. *Disaster Medicine and Public Health Preparedness, 14*(1), pp.103–110.

Bezold, C.P., Banay, R.F., Coull, B.A., Hart, J.E., James, P., Kubzansky, L.D., Missmer, S.A. and Laden, F., 2018. The association between natural environments and depressive symptoms in adolescents living in the United States. *Journal of Adolescent Health, 62*(4), pp.488–495.

Block, K., Molyneaux, R., Gibbs, L., Alkemade, N., Baker, E., MacDougall, C., Ireton, G. and Forbes, D., 2019. The role of the natural environment in disaster recovery: "We live here because we love the bush". *Health & Place, 57,* pp.61–69.

Brown, M.R., Agyapong, V., Greenshaw, A.J., Cribben, I., Brett-MacLean, P., Drolet, J., McDonald-Harker, C., Omeje, J., Mankowsi, M., Noble, S. and Kitching, D.T., 2019. Significant PTSD and other mental health effects present 18 months after the Fort Mcmurray wildfire: findings from 3,070 grades 7–12 students. *Frontiers in Psychiatry, 10,* p.623.

Buttke, D., Vagi, S., Bayleyegn, T., Sircar, K., Strine, T., Morrison, M., Allen, M. and Wolkin, A., 2012. Mental health needs assessment after the Gulf Coast oil spill-Alabama and Mississippi, 2010. *Prehospital and Disaster Medicine, 27*(5), p.401.

Chan, E.Y., Lam, H.C., So, S.H., Goggins, W.B., Ho, J.Y., Liu, S. and Chung, P.P., 2018. Association between ambient temperatures and mental disorder hospitalizations in a subtropical city: A time-series study of Hong Kong special administrative region. *International Journal of Environmental Research and Public Health, 15*(4), p.754.

Chen, J., Chen, S. and Landry, P.F., 2013. Migration, environmental hazards, and health outcomes in China. *Social Science & Medicine, 80,* pp.85–95.

Chen, Y. and Yuan, Y., 2020. The neighborhood effect of exposure to blue space on elderly individuals' mental health: A case study in Guangzhou, China. *Health & Place, 63,* p.102348.

Cherry, K.E., Sampson, L., Nezat, P.F., Cacamo, A., Marks, L.D. and Galea, S., 2015. Long-term psychological outcomes in older adults after disaster: relationships to religiosity and social support. *Aging & Mental Health, 19*(5), pp.430–443.

Cherry, N. and Haynes, W., 2017. Effects of the Fort McMurray wildfires on the health of evacuated workers: follow-up of 2 cohorts. *CMAJ Open, 5*(3), p.E638.

Choi, J., 2018. Perceptions of forest contact and its therapeutic role in university students in South Korea. *Amazonia Investiga, 7*(16), pp.344–350.

Choi, K.H., Lim, M.H., Ha, M., Sohn, J.N., Kang, J.W., Choi, Y.H. and Cheong, H.K., 2016. Psychological vulnerability of residents of communities affected by the Hebei Spirit Oil spill. *Disaster Medicine and Public Health Preparedness, 10*(01), pp.51–8.

Clayton, S., Manning, C. M., Krygsman, K., and Speiser, M., 2017. *Mental Health and Our Changing Climate: Impacts, Implications, and Guidance*. Washington, D.C.: American Psychological Association, and ecoAmerica.

Convention on Biological Diversity. 2016. Decision adopted by the Conference of the Parties to the 42 1163 Convention on Biological Diversity XIII/6. *Biodiversity and human health*. Available at: 1164 https://www.cbd.int/health/cop-13-dec-06-en.pdf

Cope, M.R., Slack, T., Blanchard, T.C. and Lee, M.R., 2013. Does time heal all wounds? Community attachment, natural resource employment, and health impacts in the wake of the BP Deepwater Horizon disaster. *Social Science Research, 42*(3), pp.872–881.

Costello, L., McDermott, M.L., Patel, P. and Dare, J., 2019. 'A lot better than medicine' – Self-organised ocean swimming groups as facilitators for healthy ageing. *Health & Place, 60,* p.102212.

Crombie, R., Clark, C. and Stansfeld, S.A., 2011. Environmental noise exposure, early biological risk and mental health in nine to ten year old children: a cross-sectional field study. *Environmental Health, 10*(1), p.39.

Cunsolo, A. and Ellis, N.R. 2018. Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change, 8,* pp.275–281.

Daghagh Yazd, S., Wheeler, S.A. and Zuo, A., 2019. Exploring the Drivers of Irrigator Mental Health in the Murray–Darling Basin, Australia. *Sustainability, 11*(21), p.6097.

Dean, J.G. and Stain, H.J., 2010. Mental health impact for adolescents living with prolonged drought. *Australian Journal of Rural Health, 18*(1), pp.32–37.

Díaz, J., López-Bueno, J.A., López-Ossorio, J.J., Gónzález, J.L., Sánchez, F. and Linares, C., 2020. Short-term effects of traffic noise on suicides and emergency hospital admissions due to anxiety and depression in Madrid (Spain). *Science of the Total Environment, 710,* p.136315.

Ding, N., Berry, H.L. and Bennett, C.M., 2016. The importance of humidity in the relationship between heat and population mental health: Evidence from Australia. *PLoS ONE, 11*(10), p.e0164190.

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A. and Orbinski, J., 2018. Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health, 109*(3), pp.327–337.

Dolling, A., Nilsson, H. and Lundell, Y., 2017. Stress recovery in forest or handicraft environments – An intervention study. *Urban Forestry & Urban Greening, 27,* pp.162–172.

Dreger, S., Meyer, N., Fromme, H. and Bolte, G., 2015. Environmental noise and incident mental health problems: A prospective cohort study among school children in Germany. *Environmental Research, 143,* pp.49–54.

Dzhambov, A., Tilov, B., Markevych, I. and Dimitrova, D., 2017. Residential road traffic noise and general mental health in youth: the role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators. *Environment International, 109,* pp.1–9.

Dzhambov, A.M., Markevych, I., Hartig, T., Tilov, B., Arabadzhiev, Z., Stoyanov, D., Gatseva, P. and Dimitrova, D.D., 2018a. Multiple pathways link urban green-and bluespace to mental health in young adults. *Environmental Research, 166,* pp.223–233.

Dzhambov, A.M., Markevych, I., Tilov, B., Arabadzhiev, Z., Stoyanov, D., Gatseva, P. and Dimitrova, D.D., 2018b. Pathways linking residential noise and air pollution to mental ill-health in young adults. *Environmental Research, 166,* pp.458–465.

Dzhambov, A.M., Markevych, I., Tilov, B.G. and Dimitrova, D.D., 2018c. Residential greenspace might modify the effect of road traffic noise exposure on general mental health in students. *Urban Forestry & Urban Greening, 34,* pp.233–239.

Dzhambov, A.M., 2018d. Residential green and blue space associated with better mental health: a pilot follow-up study in university students. *Archives of Industrial Hygiene and Toxicology, 69*(4), pp.340–349.

Eze, I.C., Foraster, M., Schaffner, E., Vienneau, D., Pieren, R., Imboden, M., Wunderli, J.M., Cajochen, C., Brink, M., Röösli, M. and Probst-Hensch, N., 2020. Incidence of depression in relation to transportation noise exposure and noise annoyance in the SAPALDIA study. *Environment International, 144,* p.106014.

Felix, E.D. and Afifi, W., 2015. The role of social support on mental health after multiple wildfire disasters. *Journal of Community Psychology, 43*(2), pp.156–170.

Flores, A.B., Collins, T.W., Grineski, S.E. and Chakraborty, J., 2020. Disparities in Health Effects and Access to Health Care Among Houston Area Residents After Hurricane Harvey. *Public Health Reports, 135*(4), pp.511–523.

Forns, J., Lertxundi, N., Aranbarri, A., Murcia, M., Gascon, M., Martinez, D., Grellier, J., Lertxundi, A., Julvez, J., Fano, E. and Goñi, F., 2012. Prenatal exposure to organochlorine compounds and neuropsychological development up to two years of life. *Environment International, 45,* pp.72–77.

Friel, S., Berry, H., Dinh, H., O'Brien, L. and Walls, H.L., 2014. The impact of drought on the association between food security and mental health in a nationally representative Australian sample. *BMC Public Health, 14*(1), p.1102.

Furuyashiki, A., Tabuchi, K., Norikoshi, K., Kobayashi, T. and Oriyama, S., 2019. A comparative study of the physiological and psychological effects of forest bathing (Shinrin-yoku) on working age people with and without depressive tendencies. *Environmental Health and Preventive Medicine, 24*(1), p.46.

Gascon, M., Sánchez-Benavides, G., Dadvand, P., Martínez, D., Gramunt, N., Gotsens, X., Cirach, M., Vert, C., Molinuevo, J.L., Crous-Bou, M. and Nieuwenhuijsen, M., 2018. Long-term exposure to residential green and blue spaces and anxiety and depression in adults: A cross-sectional study. *Environmental Research, 162,* pp.231–239.

Garrett, J.K., Clitherow, T.J., White, M.P., Wheeler, B.W. and Fleming, L.E., 2019. Coastal proximity and mental health among urban adults in England: The moderating effect of household income. *Health & Place, 59,* p.102200.

Gaspar, F.W., Harley, K.G., Kogut, K., Chevrier, J., Mora, A.M., Sjödin, A. and Eskenazi, B., 2015. Prenatal DDT and DDE exposure and child IQ in the CHAMACOS cohort. *Environment International, 85,* pp.206–212.

Generaal, E., Hoogendijk, E.O., Stam, M., Henke, C.E., Rutters, F., Oosterman, M., Huisman, M., Kramer, S.E., Elders, P.J., Timmermans, E.J. and Lakerveld, J., 2019. Neighbourhood characteristics and prevalence and severity of depression: pooled analysis of eight Dutch cohort studies. *The British Journal of Psychiatry, 215*(2), pp.468–475.

Generaal, E., Timmermans, E.J., Dekkers, J.E., Smit, J.H. and Penninx, B.W., 2019a. Not urbanization level but socioeconomic, physical and social neighbourhood characteristics are associated with presence and severity of depressive and anxiety disorders. *Psychological Medicine, 49*(1), pp.149–161.

Gould, D.W., Teich, J.L., Pemberton, M.R., Pierannunzi, C. and Larson, S., 2015. Behavioral health in the gulf coast region following the Deepwater Horizon oil spill: findings from two federal surveys. *The Journal of Behavioral Health Services & Research, 42*(1), pp.6–22.

Guirguis, K., Gershunov, A., Tardy, A. and Basu, R., 2014. The impact of recent heat waves on human health in California. *Journal of Applied Meteorology and Climatology, 53*(1), pp.3–19.

Ha, H. and Shao, W., 2019. A spatial epidemiology case study of mentally unhealthy days (MUDs): air pollution, community resilience, and sunlight perspectives. *International Journal of Environmental Health Research,* pp.1–16.

Hammersen, F., Niemann, H. and Hoebel, J., 2016. Environmental noise annoyance and mental health in adults: findings from the cross-sectional German Health Update (GEDA) Study 2012. *International Journal of Environmental Research and Public Health, 13*(10), p.954.

Han, H.J., Kim, J.H., Chung, S.E., Park, J.H. and Cheong, H.K., 2018. Estimation of the national burden of disease and vulnerable population associated with natural disasters in Korea: heavy precipitation and typhoon. *Journal of Korean Medical Science, 33*(49), p.e314.

Hanigan, I.C., Butler, C.D., Kokic, P.N. and Hutchinson, M.F., 2012. Suicide and drought in new South Wales, Australia, 1970–2007. *Proceedings of the National Academy of Sciences, 109*(35), pp.13950–13955.

Hanigan, I.C., Schirmer, J. and Niyonsenga, T., 2018. Drought and distress in Southeastern Australia. *EcoHealth, 15*(3), pp.642–655.

Hartig, T., Mitchell, R., De Vries, S. and Frumkin, H., 2014. Nature and health. A*nnual Review of Public Health, 35,* pp.207–228.

Hassan, A., Tao, J., Li, G., Jiang, M., Aii, L., Zhihui, J., Zongfang, L. and Qibing, C., 2018. Effects of walking in bamboo forest and city environments on brainwave activity in young adults. *Evidence-Based Complementary and Alternative Medicine, 2018.*

Hayward, B.A., 2020. Mental health nursing in bushfire-affected communities: An autoethnographic insight. *International Journal of Mental Health Nursing, 29*(6), pp.1262–1271.

He, S., Smargiassi, A., Low, N., Bilodeau-Bertrand, M., Ayoub, A. and Auger, N., 2019. Residential noise exposure and the longitudinal risk of hospitalization for depression after pregnancy: Postpartum and beyond. *Environmental Research, 170,* pp.26–32.

Hill, E., Billington, R. and Krageloh, C., 2014. Noise sensitivity and diminished health: Testing moderators and mediators of the relationship. *Noise & Health, 16,* pp.47–56.

Hsieh, H.L., Lin, H.J., Shih, S.S. and Chen, C.P., 2015. Ecosystem functions connecting contributions from ecosystem services to human wellbeing in a mangrove system in Northern Taiwan. *International Journal of Environmental Research and Public Health, 12*(6), pp.6542–6560.

Huutoniemi, K., Klein, J.T., Bruun, H. and Hukkinen, J., 2010. Analyzing interdisciplinarity: Typology and indicators. *Research Policy, 39*(1), pp.79–88.

IPBES. 2021. *Intergovernmental Panel on Biodiversity and Ecosystem Services.* https://www.ipbes.net/ [Accessed 10th February 2021]

Ishiki, A., Okinaga, S., Tomita, N., Kawahara, R., Tsuji, I., Nagatomi, R., Taki, Y., Takahashi, T., Kuzuya, M., Morimoto, S. and Iijima, K., 2016. Changes in cognitive functions in the elderly living in temporary housing after the Great East Japan Earthquake. *PLoS ONE, 11*(1), p.e0147025.

Jensen, H.A., Rasmussen, B. and Ekholm, O., 2018. Neighbour and traffic noise annoyance: a nationwide study of associated mental health and perceived stress. *European Journal of Public Health, 28*(6), pp.1050–1055.

Johnson, E.J. and Boodram, C.A.S., 2017. Health, well-being and quality of life of community members displaced after an industrial disaster in Trinidad. *Journal of Public Health, 25*(1), pp.69–74.

Kageyama, T., Yano, T., Kuwano, S., Sueoka, S. and Tachibana, H., 2016. Exposure-response relationship of wind turbine noise with self-reported symptoms of sleep and health problems: A nationwide socioacoustic survey in Japan. *Noise & Health, 18*(81), p.53.

Kannuri, N.K. and Jadhav, S., 2018. Generating toxic landscapes: impact on well-being of cotton farmers in Telangana, India. *Anthropology & Medicine, 25*(2), pp.121–140.

Kaplan, R. and Kaplan, S., 1989. *The Experience of Nature: A Psychological Perspective*. Cambridge University Press. ISBN 978-0-521-34139-4.

Kibria, A.S., Costanza, R., Groves, C. and Behie, A.M., 2019. Does higher access ensure greater wellbeing? – In the perspective of forest ecosystem services of the Sundarbans mangrove forest, Bangladesh. *Ocean & Coastal Management, 177,* pp.22–30.

Kim, Y.M., Park, J.H., Choi, K., Noh, S.R., Choi, Y.H. and Cheong, H.K., 2013. Burden of disease attributable to the Hebei Spirit oil spill in Taean, Korea. *BMJ Open, 3*(9), p.e003334.

King, R.V., Polatin, P.B., Hogan, D., Downs, D.L. and North, C.S., 2016. Needs assessment of Hurricane Katrina evacuees residing temporarily in Dallas. *Community Mental Health Journal, 52*(1), pp.18–24.

Krishnaswamy, S., Subramaniam, K., Indran, T. and Low, W.Y., 2012. The 2004 tsunami in Penang, Malaysia: early mental health intervention. *Asia Pacific Journal of Public Health, 24*(4), pp.710–718.

Kruger, D.J., Cupal, S., Franzen, S.P., Kodjebacheva, G., Bailey, E.S., Key, K.D. and Kaufman, M.M., 2017. Toxic trauma: Household water quality experiences predict posttraumatic stress disorder symptoms during the Flint, Michigan, water crisis. *Journal of Community Psychology, 45*(7), pp.957–962.

Kruger, D.J., Kodjebacheva, G.D. and Cupal, S., 2017. Poor tap water quality experiences and poor sleep quality during the Flint, Michigan Municipal Water Crisis. *Sleep Health, 3*(4), pp.241–243.

Kyriklaki, A., Vafeiadi, M., Kampouri, M., Koutra, K., Roumeliotaki, T., Chalkiadaki, G., Anousaki, D., Rantakokko, P., Kiviranta, H., Fthenou, E. and Bitsios, P., 2016. Prenatal exposure to persistent organic pollutants in association with offspring neuropsychological development at 4 years of age: The Rhea mother-child cohort, Crete, Greece. *Environment International, 97,* pp.204–211.

Lee, H., Jung, J., Myung, W., Baek, J.H., Kang, J.M., Kim, D.K. and Kim, H., 2019. Association between dust storm occurrence and risk of suicide: Case-crossover analysis of the Korean national death database. *Environment International, 133,* p.105146.

Lee, H.J., Son, Y.H., Kim, S. and Lee, D.K., 2019. Healing experiences of middle-aged women through an urban forest therapy program. *Urban Forestry & Urban Greening, 38,* pp.383–391.

Lewis, K.M., Langley, A.K. and Jones, R.T., 2015. Impact of coping efficacy and acculturation on psychopathology in adolescents following a wildfire. *Journal of Child and Family Studies, 24*(2), pp.317–329.

Lim, J., Kweon, K., Kim, H.W., Cho, S.W., Park, J. and Sim, C.S., 2018. Negative impact of noise and noise sensitivity on mental health in childhood. *Noise & Health, 20*(96), p.199.

Lin, S., Lu, Y., Justino, J., Dong, G. and Lauper, U., 2016. What happened to our environment and mental health as a result of Hurricane Sandy?. *Disaster Medicine and Public Health Preparedness, 10*(3), pp.314–319.

Liu, J.A., Chen, Y., Gao, D., Jing, J. and Hu, Q., 2014. Prenatal and postnatal lead exposure and cognitive development of infants followed over the first three years of life: a prospective birth study in the Pearl River Delta region, China. *Neurotoxicology, 44,* pp.326–334.

Liu, X., Liu, H., Fan, H., Liu, Y. and Ding, G., 2019. Influence of heat waves on daily hospital visits for mental illness in Jinan, China—a case-crossover study. *International Journal of Environmental Research and Public Health, 16*(1), p.87.

Lu, H., Yue, A. and Liu, X., 2018. Who is susceptible to perceive higher smog-induced health risk? Comparative analysis between physical and mental health dimensions. *Human and Ecological Risk Assessment: An International Journal, 26,* pp.459–482

Ma, J., Li, C., Kwan, M.P. and Chai, Y., 2018. A multilevel analysis of perceived noise pollution, geographic contexts and mental health in Beijing. *International Journal of Environmental Research and Public Health, 15*(7), p.1479.

Ma, J., Li, C., Kwan, M.P., Kou, L. and Chai, Y., 2020. Assessing personal noise exposure and its relationship with mental health in Beijing based on individuals' space-time behavior. *Environment International, 139,* p.105737.

Maclean, J.C., Popovici, I. and French, M.T., 2016. Are natural disasters in early childhood associated with mental health and substance use disorders as an adult?. *Social Science & Medicine, 151,* pp.78–91.

Magalhães, S.D.S., Miranda, D.K., Paula, J.J.D., Miranda, D.M.D., Romano-Silva, M.A. and Malloy-Diniz, L.F., 2018. Psychometric properties of a Brazilian Portuguese version of the Children's Revised Impact of Event Scale (CRIES-8). *Archives of Clinical Psychiatry (São Paulo), 45*(2), pp.27–32.

Manczak, E.M., Miller, J.G. and Gotlib, I.H., 2020. Water contaminant levels interact with parenting environment to predict development of depressive symptoms in adolescents. *Developmental Science, 23*(1), p.e12838.

Mayner, L., Arbon, P. and Usher, K., 2010. Emergency department patient presentations during the 2009 heatwaves in Adelaide. *Collegian, 17*(4), pp.175–182.

Min, J.Y. and Min, K.B., 2018. Night noise exposure and risk of death by suicide in adults living in metropolitan areas. *Depression and Anxiety, 35*(9), pp.876–883.

Min, M., Shi, T., Ye, P., Wang, Y., Yao, Z., Tian, S., Zhang, Y., Liang, M., Qu, G., Bi, P. and Duan, L., 2019. Effect of apparent temperature on daily emergency admissions for mental and behavioral disorders in Yancheng, China: a time-series study. *Environmental Health, 18*(1), p.98.

Morris Jr, J.G., Grattan, L.M., Mayer, B.M. and Blackburn, J.K., 2013. Psychological responses and resilience of people and communities impacted by the Deepwater Horizon oil spill. *Transactions of the American Clinical and Climatological Association, 124,* p.191.

Motreff, Y., Pirard, P., Goria, S., Labrador, B., Gourier-Fréry, C., Nicolau, J., Le Tertre, A. and Chan-Chee, C., 2013. Increase in psychotropic drug deliveries after the Xynthia storm, France, 2010. *Prehospital and Disaster Medicine, 28*(5), p.428.

Mullins, J.T. and White, C., 2019. Temperature and mental health: Evidence from the spectrum of mental health outcomes. *Journal of Health Economics, 68,* p.102240.

Munn, R., Peters, M.D.J., Stern, C., Tufanaru, C., McArthur, A., and Aromataris, R., 2018. Systematic review or scoping review? Guidance for authors when choosing between a systematic review or scoping review approach. *BMC Medical Research Methodology, 18,* 413.

NERC. 2021. *Clean Air.* https://nerc.ukri.org/research/funded/programmes/clean-air/ [Accessed 10th February 2021]

Nitschke, M., Tucker, G., Simon, D.L., Hansen, A.L. and Pisaniello, D.L., 2014. The link between noise perception and quality of life in South Australia. *Noise & Health, 16*(70), p.137.

Norra, C., Ngoc, D.T.M., Trang, P.T.K., Lan, V.T.M., Viet, P.H., Norra, S. and Kunert, H.J., 2012. Mental health burden and neuropsychiatric deficits of chronic arsenic exposure: First results of the Vietnamese field study. In Ng. J.C., Noller, B.N., Naidu, R., Bundschuh, J., Bhattacharya, P., *Understanding the Geological and Medical Interface of Arsenic,* Taylor and Francis Group, London, pp.168–170.

Nugent, N., Gaston, S.A., Perry, J., Rung, A.L., Trapido, E.J. and Peters, E.S., 2019. PTSD symptom profiles among Louisiana women affected by the 2010 Deepwater Horizon Oil Spill: A latent profile analysis. *Journal of Affective Disorders, 250,* pp.289–297.

O'Brien, L., 2019. Carrying out Physical Activity as Part of the Active Forests Programme in England: What Encourages, Supports and Sustains Activity? – A Qualitative Study. International Journal of *Environmental Research and Public Health, 16*(24), p.5118.

Obradovich, N., Migliorini, R., Paulus, M.P. and Rahwan, I., 2018. Empirical evidence of mental health risks posed by climate change. *Proceedings of the National Academy of Sciences, 115*(43), pp.10953–10958.

O'Brien, L.V., Berry, H.L., Coleman, C. and Hanigan, I.C., 2014. Drought as a mental health exposure. *Environmental Research, 131,* pp.181–187.

OECD 2021. *Resilient Cities.* https://www.oecd.org/regional/resilient-cities.htm [Accessed 10th February 2021)

Okokon, E.O., Yli-Tuomi, T., Turunen, A.W., Tiittanen, P., Juutilainen, J. and Lanki, T., 2018. Traffic noise, noise annoyance and psychotropic medication use. *Environment International, 119,* pp.287–294.

Page, L.A., Hajat, S., Kovats, R.S. and Howard, L.M., 2012. Temperature-related deaths in people with psychosis, dementia and substance misuse. *The British Journal of Psychiatry, 200*(6), pp.485–490.

Papanikolaou, V., Adamis, D., Mellon, R.C. and Prodromitis, G., 2011. Psychological distress following wildfires disaster in a rural part of Greece: a case-control population-based study. *International Journal of Emergency Mental Health, 13,* pp.11–26.

Park, J., Chung, S., Lee, J., Sung, J.H., Cho, S.W. and Sim, C.S., 2017. Noise sensitivity, rather than noise level, predicts the non-auditory effects of noise in community samples: a population-based survey. *BMC Public Health, 17*(1), p.315.

Pasanen, T.P., White, M.P., Wheeler, B.W., Garrett, J.K. and Elliott, L.R., 2019. Neighbourhood blue space, health and wellbeing: the mediating role of different types of physical activity. *Environment International, 131,* p.105016.

Pearson, A.L., Shortridge, A., Delamater, P.L., Horton, T.H., Dahlin, K., Rzotkiewicz, A. and Marchiori, M.J., 2019. Effects of freshwater blue spaces may be beneficial for mental health: A first, ecological study in the North American Great Lakes region. *PLoS ONE, 14*(8), p.e0221977.

Poulsen, A.H., Raaschou-Nielsen, O., Peña, A., Hahmann, A.N., Nordsborg, R.B., Ketzel, M., Brandt, J. and Sørensen, M., 2019. Impact of long-term exposure to wind turbine noise on redemption of sleep medication and antidepressants: a nationwide cohort study. *Environmental Health Perspectives, 127*(3), p.037005.

Powers, J.R., Dobson, A.J., Berry, H.L., Graves, A.M., Hanigan, I.C. and Loxton, D., 2015. Lack of association between drought and mental health in a cohort of 45–61 year old rural Australian women. *Australian and New Zealand Journal of Public Health, 39*(6), pp.518–523.

Powers, J.R., Loxton, D., Baker, J., Rich, J.L. and Dobson, A.J., 2012. Empirical evidence suggests adverse climate events have not affected Australian women's health and well-being. *Australian and New Zealand Journal of Public Health, 36*(5), pp.452–457.

Psarros, C., Theleritis, C., Kokras, N., Lyrakos, D., Koborozos, A., Kakabakou, O., Tzanoulinos, G., Katsiki, P. and Bergiannaki, J.D., 2018. Personality characteristics and individual factors associated with PTSD in firefighters one month after extended wildfires. *Nordic Journal of Psychiatry, 72*(1), pp.17–23.

Pun, V.C., Manjourides, J. and Suh, H.H., 2019. Close proximity to roadway and urbanicity associated with mental ill-health in older adults. *Science of the Total Environment, 658,* pp.854–860.

Putrik, P., de Vries, N.K., Mujakovic, S., van Amelsvoort, L., Kant, I., Kunst, A.E., van Oers, H. and Jansen, M., 2015. Living environment matters: relationships between neighborhood characteristics and health of the residents in a Dutch municipality. *Journal of Community Health, 40*(1), pp.47–56.

Ritchie, A., Sautner, B., Omege, J., Denga, E., Nwaka, B., Akinjise, I., Corbett, S.E., Moosavi, S., Greenshaw, A., Chue, P. and Li, X.M., 2020. Long-Term Mental Health Effects of a Devastating Wildfire Are Amplified by Sociodemographic and Clinical Antecedents in College Students. *Disaster Medicine and Public Health Preparedness,* pp.1–11.

Roberts, A., 2017. *Forest schools and mental wellbeing* (Doctoral dissertation, Canterbury Christ Church Univer).

Roswall, N., Høgh, V., Envold-Bidstrup, P., Raaschou-Nielsen, O., Ketzel, M., Overvad, K., Olsen, A. and Sørensen, M., 2015. Residential exposure to traffic noise and health-related quality of life—a population-based study. *PLoS ONE, 10*(3), p.e0120199.

Rung, A.L., Gaston, S., Oral, E., Robinson, W.T., Fontham, E., Harrington, D.J., Trapido, E. and Peters, E.S., 2016. Depression, mental distress, and domestic conflict among Louisiana women exposed to the Deepwater Horizon oil spill in the WaTCH study. *Environmental Health Perspectives, 124*(9), pp.1429–1435.

Ryan, B.J., Franklin, R.C., Burkle, F.M., Smith, E.C., Aitken, P. and Leggat, P.A., 2019. Determining key influences on patient ability to successfully manage noncommunicable disease after natural disaster. *Prehospital and Disaster Medicine, 34*(3), pp.241–250.

Sarkar, C., Gallacher, J. and Webster, C., 2013. Urban built environment configuration and psychological distress in older men: Results from the Caerphilly study. *BMC Public Health, 13*(1), p.695.

Schreckenberg, D., Griefahn, B. and Meis, M., 2010. The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance. *Noise & Health, 12*(46), p.7.

Settineri, S., Mucciardi, M., Leonardi, V., Schlesinger, S., Gioffrè Florio, M., Famà, F., Anna Muscatello, M.R. and Mento, C., 2016. Metereological conditions and psychiatric emergency visits in Messina, Italy. *International Journal of Psychological Research, 9*(1), pp.72–82.

Seyedin, H., HabibiSaravi, R., Djenab, V.H. and Hamedani, F.G., 2017. Psychological sequels of flood on residents of southeast Caspian region. *Natural Hazards, 88*(2), pp.965–975.

Shenesey, J.W. and Langhinrichsen-Rohling, J., 2015. Perceived resilience: Examining impacts of the deepwater horizon oil spill one-year post-spill. *Psychological Trauma: Theory, Research, Practice, and Policy, 7*(3), p.252.

Shih, H.I., Chao, T.Y., Huang, Y.T., Tu, Y.F., Wang, J.D. and Chang, C.M., 2020. Increased incidence of stress-associated illnesses among elderly after Typhoon Morakot. *Journal of the Formosan Medical Association, 120,* pp.337–345.

Shrestha, R., 2019. Early Life Exposure to Air Pollution, Cognitive Development, and Labor Market Outcome. *Asian Economic Papers, 18*(2), pp.77–95.

Shultz, J.M., Walsh, L., Garfin, D.R., Wilson, F.E. and Neria, Y., 2015. The 2010 Deepwater Horizon oil spill: the trauma signature of an ecological disaster. *The Journal of Behavioral Health Services & Research, 42*(1), pp.58–76.

Song, M.K., Bang, K.S., Kim, S., Lee, G. and Jeong, Y., 2020. Effects of an Urban Forest-Based Health Promotion Program on Children Living in Group Homes. *Journal of Psychosocial Nursing and Mental Health Services, 58*(6), pp.18–29.

Song, Y., Zhou, A., Zhang, M. and Wang, H., 2019. Assessing the effects of haze pollution on subjective well-being based on Chinese General Social Survey. *Journal of Cleaner Production, 235,* pp.574–582.

Sonntag-Öström, E., Nordin, M., Dolling, A., Lundell, Y., Nilsson, L. and Slunga Järvholm, L., 2015. Can rehabilitation in boreal forests help recovery from exhaustion disorder? The randomised clinical trial ForRest. *Scandinavian Journal of Forest Research, 30*(8), pp.732–748.

Stanley, I.H., Hom, M.A., Gai, A.R. and Joiner, T.E., 2018. Wildland firefighters and suicide risk: Examining the role of social disconnectedness. *Psychiatry Research, 266,* pp.269–274.

Staudt, K., Dane'el, M. and Márquez-Velarde, G., 2016. In the shadow of a steel recycling plant in these neoliberal times: health disparities among Hispanics in a border colonia. *Local Environment, 21*(5), pp.636–652.

Stickley, A., Ng, C.F.S., Konishi, S., Koyanagi, A. and Watanabe, C., 2017. Airborne pollen and suicide mortality in Tokyo, 2001–2011. *Environmental Research, 155,* pp.134–140.

Stough, L.M. and North. C.S., 2018. The association of adverse mental health effects with repeated exposure to disasters. *Annals of Clinical Psychiatry, 30,* pp.17–24.

Sygna, K., Aasvang, G.M., Aamodt, G., Oftedal, B. and Krog, N.H., 2014. Road traffic noise, sleep and mental health. *Environmental Research, 131,* pp.17–24.

Tapak, L., Maryanaji, Z., Hamidi, O., Abbasi, H. and Najafi-Vosough, R., 2018. Investigating the effect of climatic parameters on mental disorder admissions. *International Journal of Biometeorology, 62*(12), pp.2109–2118.

Tawatsupa, B., Yiengprugsawan, V., Kjellstrom, T., Seubsman, S.A., Sleigh, A. and Thai Cohort Study Team, 2012. Heat stress, health and well-being: findings from a large national cohort of Thai adults. *BMJ Open, 2*(6).

Tricco, AC, Lillie, E, Zarin, W, O'Brien, KK, Colquhoun, H, Levac, D, Moher, D, Peters, MD, Horsley, T, Weeks, L, Hempel, S. *et al*. 2018. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of Internal Medicine, 169*(7), pp.467–473.

UN. 2021. *17 Sustainable Development Goals.* https://sdgs.un.org/goals [Accessed 10th February 2021]

UN. 2021a. *UN Climate Change Conference (COP26).* https://ukcop26.org/ [Accessed 10th February 2021]

Vida, S., Durocher, M., Ouarda, T.B. and Gosselin, P., 2012. Relationship between ambient temperature and humidity and visits to mental health emergency departments in Québec. *Psychiatric Services, 63*(11), pp.1150–1153.

Vineis, P., Robinson, O., Chadeau-Hyam, M., Dehghan, A., Mudway, I. and Dagnino, S. 2020. What is new in the exposome? *Environment International, 143,* p.10588.

von Lindern, E., Bauer, N., Frick, J., Hunziker, M. and Hartig, T., 2013. Occupational engagement as a constraint on restoration during leisure time in forest settings. *Landscape and Urban Planning, 118,* pp.90–97.

Ward Thompson, C., Silveirinha de Oliveira, E., Tilley, S., Elizalde, A., Botha, W., Briggs, A., Cummins, S., Leyland, A.H., Roe, J.J., Aspinall, P. and Brookfield, K., 2019. Health impacts of environmental and social interventions designed to increase deprived communities' access to urban woodlands: A mixed-methods study. *Public Health Research, 7*(2), pp.1–172.

Wasiak, J., Mahar, P., Lee, S., Paul, E., Spinks, A., Pfitzer, B., Cleland, H. and Gabbe, B., 2013. 12-month generic health status and psychological distress outcomes following an Australian natural disaster experience: 2009 Black Saturday Wildfires. *Injury, 44*(11), pp.1443–1447.

Wass, S.V., Smith, C.G., Daubney, K.R., Suata, Z.M., Clackson, K., Begum, A. and Mirza, F.U., 2019. Influences of environmental stressors on autonomic function in 12-month-old infants: understanding early common pathways to atypical emotion regulation and cognitive performance. *Journal of Child Psychology and Psychiatry, 60*(12), pp.1323–1333.

White, M.P., Alcock, I., Wheeler, B.W. and Depledge, M.H., 2013. Coastal proximity, health and well-being: results from a longitudinal panel survey. *Health & Place, 23,* pp.97–103.

World Health Organization Europe 2021. *European Environment and Health Process (EHP).* https://www.euro.who.int/en/health-topics/environment-and-health/pages/european-environment-and-health-process-ehp [Accessed 10th February 2021]

World Health Organization, 2005. *Promoting Mental Health: Concepts, Emerging Evidence, Practice: A report of World Health Organization, Department of Mental Health and Substance Abuse in collaboration with the Victorian Health Promotion Foundation and the University of Melbourne*. World Health Organization.

World Health Organization. (2015). *International statistical classification of diseases and related health problems, 10th revision, Fifth edition*. [Accessed from: https://icd.who.int/browse10/2019/en#/V]

Wright, D.M., Newell, K., Maguire, A. and O'Reilly, D., 2018. Aircraft noise and self-assessed mental health around a regional urban airport: a population based record linkage study. *Environmental Health, 17*(1), p.74.

Xu, Y., Wheeler, S.A. and Zuo, A., 2018. Will boys' mental health fare worse under a hotter climate in Australia?. *Population and Environment, 40*(2), pp.158–181.

Xue, T., Zhu, T., Zheng, Y. and Zhang, Q., 2019. Declines in mental health associated with air pollution and temperature variability in China. *Nature Communications, 10*(1), pp.1–8.

Yazd, S.D., Wheeler, S.A. and Zuo, A., 2020. Understanding the impacts of water scarcity and socio-economic demographics on farmer mental health in the Murray-Darling Basin. *Ecological Economics, 169,* p.106564.

Yoon, J.H., Won, J.U., Lee, W., Jung, P.K. and Roh, J., 2014. Occupational noise annoyance linked to depressive symptoms and suicidal ideation: a result from nationwide survey of Korea. *PLoS ONE, 9*(8), p.e105321.

Zhu, X., Gao, M., Zhao, W. and Ge, T., 2020. Does the Presence of Birdsongs Improve Perceived Levels of Mental Restoration from Park Use? Experiments on Parkways of Harbin Sun Island in China. *International Journal of Environmental Research and Public Health, 17*(7), p.2271.

Zock, J.P., Verheij, R., Helbich, M., Volker, B., Spreeuwenberg, P., Strak, M., Janssen, N.A., Dijst, M. and Groenewegen, P., 2018. The impact of social capital, land use, air pollution and noise on individual morbidity in Dutch neighbourhoods. *Environment International, 121,* pp.453–460.

Appendix A: Scoping review search strings

Initial keywords were identified with experts via the participatory workshops (physical and chemical), and via email (biological). These included:

Mental health	"mental health" OR "mental ill*" OR "mental disorder" OR "general health questionnaire" OR "GHQ" OR "quality of life" OR "QOL" OR "life satisf*" OR content* OR Resilien* OR Relax* OR "self esteem" OR "self-esteem" OR "Psychological Restor*" OR Stress* OR destress OR "cognitive development" OR "cognitive decline" OR "neurocognitive disorder" OR "neuro-cognitive disorder" OR "Behaviour* problem" OR "Behaviour* disorder" OR "conduct disorder" OR ADD OR "attention deficit disorder" OR ADHD OR "attention deficit hyperactivity disorder" OR dementia OR Alzheimer's OR Psych*OR "general psychopathology score" OR "positive and negative syndrome scale" OR "PANSS" OR "Revised Clinical Interview Schedule" OR "CIS-R" OR Schizo* OR hallucinat* OR delusion* OR Trauma* OR PTSD OR "internalising symptoms" OR "externalising symptoms" OR Anxi* OR Phobi* OR "panic disorder" OR OCD OR "obsessive compulsive disorder" OR neuros* OR Depress* OR Suicid* OR "self harm" OR "self injury" OR "self mutiliat*" OR "self destruct*" OR Dissociat* OR dysthymic OR Mani* OR hypomani* OR "substance abuse" OR alcohol* OR addict* OR "mood disorder" OR Bipolar OR "manic depress*" OR psychosocial OR "Solastalgia" OR "ecological anxiety" OR "ecological grief" OR "climate anxiety" OR "climate grief"
Environmental science	flood* OR "water inundation" OR "river avulsion" OR Sediment* OR Drought OR "water stress" OR "water level" OR "wild fire" OR "bush fire" OR "forest fire" OR "heat wave" OR "air temperature" OR Landslide* OR "climate change" OR "global warming" OR warming OR "sea level rise" OR geomorph* OR water OR "Riparian corridor" OR river OR Coast* OR "rock pool" OR "sea stack" OR "sea arch" OR cliff OR Mountain OR Beach* OR Dune* OR Waterfall* OR soil OR landscape OR "geomorphic hazard" OR Noise OR soundscape OR weather OR Rain OR Sun OR sunshine OR sunlight OR dark OR daylight OR storm OR "natural disaster" OR hurricane OR cyclone OR Tsunami OR "tidal wave" OR earthquake OR aesthetics OR ero* OR pollut* OR "particulate matter" OR PM2.5 OR PM10 OR "air quality" OR "CO" OR "carbon monoxide" OR NOX OR "nitrogen oxides" OR SO2 OR "sulphur dioxide" OR "sulfur dioxide" OR PAH OR "Polycyclic aromatic hydrocarbon" OR Aeroallerg* OR ozone OR "water quality" OR "heavy metal*" OR lead OR mercury OR cadmium OR Microplastic* OR micro-plastic* OR "micro plastic*" OR "acidification" OR "endocrine disrupt*" OR neurotoxicity OR biodivers* OR natur* OR Tree* OR forest* OR wood* OR Wild* OR animal OR plant OR "Normalised difference vegetation" OR "NDVI" OR Greenspace OR "green space" OR greenness OR "open space" OR park OR "botanic garden" OR greenbelt OR "green belt" OR garden OR yard OR outdoors OR Bluespace OR "blue space" OR "invasive species" OR "non-native species" OR "alien species" OR "introduced species" OR Disease OR Pathogen* OR "planetary health"

This returned over 3 million results from Web of Science. Further refinement was therefore carried out:

Mental health: Terms were limited to broad areas rather than specific disorders. We anticipated that this would identify the range of mental health and wellbeing measures and methods applied, but recognise that specific disorders or components of wellbeing may be missed if not described in these terms.

"mental health" OR "mental ill*" OR "mental disorder" OR "mental health and wellbeing" OR "mental wellbeing" OR "cognitive development" OR "cognitive decline"OR "psychopatholog*"

Environmental science: As with mental health terms environmental science search terms were restricted to broad areas of study, capturing the breadth of topics studies, but potentially missing highly specialised areas. We took the decision to exclude 'greenspace' itself as a search term, firstly because the experience of the research team suggests that greenspace literature has already been reviewed with regards to mental health, and secondly because the benefits of greenspace would be identified via other terms such as pollution, noise, or ecosystem. 'Nature' was also not included as a term due to the additional meanings of the word (e.g. 'the nature of...'). As with previous reviews (Hossain *et al.*, 2020; Kuo *et al.*, 2019; van den Bosch and Meyer-Lindenberg, 2019) we therefore used the terms: "natural environment" OR "natural land" OR "natural space" OR "natural area" to capture those papers.

flood* OR drought OR "wild fire" OR "bush fire" OR "forest fire" OR Landslide* OR "climate change" OR "global warming" OR landscape OR Noise OR soundscape OR pollut* OR biodivers* OR Tree* OR forest* OR wood* OR Wild* OR "natural environment" OR "natural land" OR "natural space" OR "natural area" OR"air quality" OR "water quality" OR ecosystem OR lake OR river OR coastal OR erosion

Additionally, we restricted our search to only the last decade (2010-2020). This therefore enabled us to capture the most recent breadth of work, covering multiple funding cycles, but maintain a reasonable number of papers for review. We also excluded: mice OR mouse OR rat* OR rodent* OR drosophila, to remove papers using animal models, which were not relevant to this review.

References for Appendix A

Hossain, M., Sultana, A., Ma, P., Fan, Q., Sharma, R., Purohit, N., and Sharmin, E.F., 2020. Effects of natural environment on mental health: an umbrella review of systematic reviews and meta-analyses. https://doi.org/10.31234/osf.io/4r3mh

Kuo, M., Barnes, M. and Jordan, C., 2019. Do Experiences With Nature Promote Learning? Converging Evidence of a Cause-and-Effect Relationship. *Frontiers in Psychology, 10,* p.305. doi: 10.3389/fpsyg.2019.00305

van den Bosch, M. and Meyer-Lindenberg, A., 2019. Environmental exposures and depression: biological mechanisms and epidemiological evidence. *Annual Review of Public Health, 40,* pp.239–259.

Appendix B: List of participants per participatory workshop

Participants	Affiliation
Physical Environmental Sciences and MHR Workshop (31 July 2020)	
1. Lisa Page	Brighton and Sussex Medical School
2. Stephen Stansfeld	Queen Mary University of London
3. Tara Quinn	University of Exeter
4. Ian Mudway	Imperial College London
5. Larissa Naylor	University of Glasgow
6. Ken Loades	James Hutton Institute
7. Lindsay Beevers	Heriot-Watt University
8. Pete Smith	University of Aberdeen
Chemical Environmental Sciences and MHR Workshop (5 Aug 2020)	
1. Helen Fisher	King's College London
2. Stefan Reis	UK Centre of Ecology and Hydrology
3. George Morris	NHS Scotland (retired)
4. Rebecca Wade	Abertay University
5. Scott Ferguson	Robert Gordon's University
6. Zulin Zhang	James Hutton Institute
7. Anjum Memon	Brighton and Sussex Medical School
8. Isobel Braithwaite	University College London
Ecological Environmental Sciences and MHR Workshop (18 Aug 2020)	
1. Melody Rhydderch	Natural Resources Wales
2. Martin Dallimer	University of Leeds
3. Ben Wheeler	University of Exeter
4. Stephanie Wilkie	University of Sunderland
5. Chris Gidlow	Staffordshire University
6. Lisa Avery	James Hutton Institute

Appendix C: Example workshop agenda

1pm	Welcome and Introductions	
1.20pm	Activity:	Exploring and situating your research
1.40pm	Activity:	Exemplar case studies and factors for success
2.10pm	Discussion:	Scoping Review Protocol
2.40pm	Tea break	
3pm	Activity:	Gaps, Opportunities and Challenges
3.20pm	Discussion:	What research is needed to advance our knowledge and understanding of the role of the environment on mental health and wellbeing?
3.50pm	Wrap up and next steps	
4pm	Finish	

Appendix D: Other suggested case studies

IM	Roberts S., Arseneault L., Barratt B., Beevers S., Danese A., Odgers C.L., Moffitt T.E., Reuben A., Kelly F.J., Fisher H.L. 2019. Exploration of NO2 and PM2.5 air pollution and mental health problems using high-resolution data in London-based children from a UK longitudinal cohort study. *Psychiatry Research, 272,* pp. 8-17. doi: 10.1016/j.psychres.2018.12.050.
LN	Ph.D. by Rachel Clive Use of performance art to engage neurodivergent performers with rivers to explore issues of flooding, natural flood management, nurture, adaptation and stewardship
LP	Cuthbert, S. 2020. Nature Based Care: The Woodland Group for Early Intervention in Psychosis A service evaluation report.
TQ	French, C.E., Waite, T.D., Armstrong, B., *et al.* 2019. Impact of repeat flooding on mental health and health-related quality of life: a cross-sectional analysis of the English National Study of Flooding and Health. *BMJ Open, 9*(11), p.e031562. doi:10.1136/bmjopen-2019-031562. A quantitative longitudinal cohort study of the impact of the 2013–14 English floods on mental health (approx. 1500–2000) alongside a mixed methods study of the impacts of the flood (Survey n 1000, interview 60).
GM	Royal College of Physicians. *Every breath we take: the lifelong impact of air pollution.* Report of a working party. London: RCP, 2016. https://www.rcplondon.ac.uk/file/2912/download
GM	Antonsen, S. *et al.* 2020. Exposure to air pollution during childhood and risk of developing schizophrenia: a national cohort study. *Lancet Planet Health, 4*: e64–73
IB	Khan, A., Plana-Ripoll, O., Antonsen, S., Brandt, J., Geels, C., *et al.* 2019. Environmental pollution is associated with increased risk of psychiatric disorders in the US and Denmark. *PLoS Biology, 17*(8), p.e3000353. https://doi.org/10.1371/journal.pbio.3000353 An exploration of the relationship between environmental pollution (particularly ambient air pollution) and the risk of 6 neuropsychiatric disorders.
RW	Hossain, M. *et al.* 2020. Effects of natural environment on mental health: an umbrella review of systematic reviews and meta-analyses. PsyArXiv, January 8. doi:10.31234/osf.io/4r3mh.
ZZ	Schug, T.T. *et al.* 2015. Elucidating the Links Between Endocrine Disruptors and Neurodevelopment. *Endocrinology, 156*(6), pp.1941–1951. https://doi.org/10.1210/en.2014-1734
LA	Naturally-diverse airborne environmental microbial exposures modulate the gut microbiome and may provide anxiolytic benefits in mice. https://pubmed.ncbi.nlm.nih.gov/31704402/ https://digital.library.adelaide.edu.au/dspace/handle/2440/121893
SW	Calogiuri, G., Evensen, K., Weydalh, A., Patil, G., Ihelebeack, C., Raanaas, R. 2015. Green exercise as a workplace intervention to reduce job stress. Results from a pilot study. *Work, 53,* pp.99–11.
SW	Sonti, N.F., Campbell, L., Svendsen, E., *et al.* 2020. Fear and fascination: Use and perceptions of New York City's forests, wetlands, & landscaped park areas. *Urban Forestry & Urban Greening, 49,* p.126601.
CG	Gidlow, C.J., Jones, M.V., Hurst, G., *et al.* 2016. Where to put your best foot forward: Psycho-physiological responses to walking in natural and urban environments. *Journal of Environmental Psychology, 45,* pp.22–9. doi:10.1016/j.jenvp.2015.11.003 (www.phenotype.eu)

Appendix E: Overview of review papers

The scoping review identified 133 review papers covering topics of environmental sciences and mental health. We considered a review 'robust' if it:

- Reported a systematic search protocol, including search strings; and,
- Searched at least one scientific database and one source of grey literature

Once robust reviews had been identified they were grouped by theme. A theme was considered covered sufficiently to be excluded from our scoping review if the combined papers:

- Covered a time period of at least 10 years, with the latest date being no earlier than 2017 (allowing for realistic publishing delay);
- Had global geographic coverage;
- Included the entire population (e.g. not only children); and,
- Covered multiple dimensions of mental health (i.e. not limited to a single named disorder)

This led us to remove papers from our scoping review on: climate change, flooding, air pollution and urban greenspace. Coverage and opportunities for future research were instead taken from these systematic reviews **(Table E1).**

Table E1: Systematic review papers identified during scoping review search and which formed basis for summary of literature related to climate change, flooding, air pollution and urban greenspace.

Review topic	Paper	Years covered	Including grey literature	Geographic scope	Mental health areas
Climate change	Berry *et al.* 2011	Not specified	Yes	Global	Depression, anxiety, psychosis, suicide, mood disorders and PTSD
	Chan *et al.* 2019	2000–2018	Yes	China	General mental health
	van den Bosch and Meyer-Lindenberg 2019	Not specified	Yes	Global	Suicide and depression
	Veenema *et al.* 2017	Not specified	No	Global	General mental health
	Hayes *et al.* 2019	2000–2017	Yes	Global	General mental health
	Hayes *et al.* 2018	2000–2017	Yes	Global	General mental health
	Kinay *et al.* 2019	2000 onwards	Yes	China	General mental health
	Jaakkola *et al.* 2018	1990–2017	Yes	Canada	Wellbeing
	Patz *et al.* 2014	2009–2014	Yes	Global	General mental health
	Mousavi *et al.* 2020	to 2017	Yes	Iran	General mental health
	Schulte *et al.* 2016	2008–2014	Yes	Global	General mental health
	Verner *et al.* 2016	1990–2014	No	Global	General mental health

Review topic	Paper	Years covered	Including grey literature	Geographic scope	Mental health areas
Flooding	Berry *et al.* 2011	Not specified	Yes	Global	Depression, anxiety, psychosis, suicide, mood disorders and PTSD
	Chan *et al.* 2019	2000–2018	Yes	China	General mental health
	Veenema *et al.* 2017	Not specified	No	Global	General mental health
	Garcia and Sheehan 2016	to 2015	Yes	Global	General mental health
	Burton *et al.* 2016	2005–2015	Yes	Canada	General mental health
	Du *et al.* 2010	1998 onwards	Yes	Global	General mental health
	Stanke *et al.* 2012	2004–2010	No	Global	General mental health

Review topic	Paper	Years covered	Including grey literature	Geographic scope	Mental health areas
Air pollution	van den Bosch and Meyer-Lindenberg 2019	Not specified	Yes	Global	Suicide and depression
	Braithwaite *et al.* 2019	1974–2017	No	Global	Psychiatric disorder, depression, anxiety, bipolar disorder, psychosis, suicide
	Tzivian *et al.* 2015	Not specified	Yes	Global	Cognition, alzheimers, cognitive decline, anxiety, mood disorders
	Bos *et al.* 2014	2009–2013	No	Global	Cognition
	Cipriani *et al.* 2018	to 2017	Yes	Global	Cognition, alzheimers, cognitive decline, dementia
	De Prado Bert *et al.* 2018	to 2017	Yes	Global	Cognitive development
Urban greenspace	van den Bosch and Meyer-Lindenberg 2019	Not specified	Yes	Global	Suicide and depression
	Gladkikh *et al.* 2019	to 2018	Yes	Global	General mental health
	Hankey and Marshall 2017	Not specified	Yes	Global	General mental health
	Kabisch 2019	2013 onwards	No	Global	General mental health and wellbeing

References for Appendix E

Berry, H.L., Hogan, A., Owen, J., Rickwood, D. and Fragar, L., 2011. Climate change and farmers' mental health: risks and responses. *Asia Pacific Journal of Public Health, 23*(2_suppl), pp.119S–132S.

Bos, I., De Boever, P., Panis, L.I. and Meeusen, R., 2014. Physical activity, air pollution and the brain. *Sports Medicine, 44*(11), pp.1505–1518.

Braithwaite, I., Zhang, S., Kirkbride, J.B., Osborn, D.P. and Hayes, J.F., 2019. Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: a systematic review and meta-analysis. *Environmental Health Perspectives, 127*(12), p.126002.

Burton, H., Rabito, F., Danielson, L. and Takaro, T.K., 2016. Health effects of flooding in Canada: a 2015 review and description of gaps in research. *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques, 41*(1–2), pp.238–249.

Chan, E.Y., Ho, J.Y., Hung, H.H., Liu, S. and Lam, H.C., 2019. Health impact of climate change in cities of middle-income countries: the case of China. *British Medical Bulletin, 130*(1), pp.5–24.

Cipriani, G., Danti, S., Carlesi, C. and Borin, G., 2018. Danger in the air: air pollution and cognitive dysfunction. *American Journal of Alzheimer's Disease & Other Dementias®, 33*(6), pp.333–341.

de Prado Bert, P., Mercader, E.M.H., Pujol, J., Sunyer, J. and Mortamais, M., 2018. The effects of air pollution on the brain: a review of studies interfacing environmental epidemiology and neuroimaging. *Current Environmental Health Reports, 5*(3), pp.351–364.

Du, W., FitzGerald, G.J., Clark, M. and Hou, X.Y., 2010. Health impacts of floods. *Prehospital and Disaster Medicine, 25*(3), pp.265–272.

Garcia, D.M. and Sheehan, M.C., 2016. Extreme weather-driven disasters and children's health. *International Journal of Health Services, 46*(1), pp.79–105.

Gladkikh, T.M., Gould, R.K. and Coleman, K.J., 2019. Cultural ecosystem services and the well-being of refugee communities. *Ecosystem Services, 40,* p.101036.

Hankey, S. and Marshall, J.D., 2017. Urban form, air pollution, and health. *Current Environmental Health Reports, 4*(4), pp.491–503.

Hayes, K. and Poland, B., 2018. Addressing mental health in a changing climate: Incorporating mental health indicators into climate change and health vulnerability and adaptation assessments. *International Journal of Environmental Research and Public Health, 15*(9), p.1806.

Hayes, K., Berry, P. and Ebi, K.L., 2019. Factors Influencing the Mental Health Consequences of Climate Change in Canada. *International Journal of Environmental Research and Public Health, 16*(9), p.1583.

Jaakkola, J.J., Juntunen, S. and Näkkäläjärvi, K., 2018. The holistic effects of climate change on the culture, well-being, and health of the Saami, the only indigenous people in the European Union. *Current Environmental Health Reports, 5*(4), pp.401–417.

Kabisch, N., 2019. The Influence of socio-economic and socio-demographic factors in the association between urban green space and health. In: Marselle M., Stadler J., Korn H., Irvine K., Bonn A. (eds). *Biodiversity and Health in the Face of Climate Change,* pp. 91–119. Springer, Cham.

Kinay, P., Morse, A.P., Villanueva, E.V., Morrissey, K. and Staddon, P.L., 2019. Direct and indirect health impacts of climate change on the vulnerable elderly population in East China. *Environmental Reviews, 27*(3), pp.295–303.

Mousavi, A., Ardalan, A., Takian, A., Ostadtaghizadeh, A., Naddafi, K. and Bavani, A.M., 2020. Climate change and health in Iran: a narrative review. *Journal of Environmental Health Science and Engineering, 18*(1), pp.367–378.

Patz, J.A., Frumkin, H., Holloway, T., Vimont, D.J. and Haines, A., 2014. Climate change: challenges and opportunities for global health. *JAMA, 312*(15), pp.1565–1580.

Schulte, P.A., Bhattacharya, A., Butler, C.R., Chun, H.K., Jacklitsch, B., Jacobs, T., Kiefer, M., Lincoln, J., Pendergrass, S., Shire, J. and Watson, J., 2016. Advancing the framework for considering the effects of climate change on worker safety and health. *Journal of Occupational and Environmental Hygiene, 13*(11), pp.847–865.

Stanke, C., Murray, V., Amlôt, R., Nurse, J. and Williams, R., 2012. The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. *PLoS Currents, 4*.

Tzivian, L., Winkler, A., Dlugaj, M., Schikowski, T., Vossoughi, M., Fuks, K., Weinmayr, G. and Hoffmann, B., 2015. Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults. *International Journal of Hygiene and Environmental Health, 218*(1), pp.1–11.

van den Bosch, M. and Meyer-Lindenberg, A., 2019. Environmental exposures and depression: biological mechanisms and epidemiological evidence. *Annual Review of Public Health, 40,* pp.239–259.

Veenema, T.G., Thornton, C.P., Lavin, R.P., Bender, A.K., Seal, S. and Corley, A., 2017. Climate change–related water disasters' impact on population health. *Journal of Nursing Scholarship, 49*(6), pp.625–634.

Verner, G., Schütte, S., Knop, J., Sankoh, O. and Sauerborn, R., 2016. Health in climate change research from 1990 to 2014: positive trend, but still underperforming. *Global Health Action, 9*(1), p.30723.

Acknowledgement

This report was funded by NERC, as part of the Valuing Nature Programme.

The Valuing Nature Programme is a 5 year £7M research programme which aims to improve understanding of the value of nature both in economic and non-economic terms, and improve the use of these valuations in decision making. It funds interdisciplinary research and builds links between researchers and people who make decisions that affect nature in business, policy-making and in practice. See **www.valuing-nature.net**

The Valuing Nature Programme is funded by the Natural Environment Research Council, the Economic and Social Research Council, the Biotechnology and Biological Sciences Research Council, the Arts and Humanities Research Council, and the Department for Environment, Food and Rural Affairs.

Further information visit: valuing-nature.net/environmental-science-and-mental-health-review

info@valuing-nature.net
@ValuingN
valuing-nature.net

The James Hutton Institute

Suggested citation: Irvine, K.N., Roberts, M., Eastwood, A., Colley, K., Currie, M. and Zhang, Z. (2021) *Environmental Science and Mental Health Review.* Valuing Nature Programme, UKCEH, Wallingford.