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Connecting Biodiversity With Mental Health and Wellbeing — A Review of Methods and Disciplinary Perspectives

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Biodiversity conservation and mental health and wellbeing are of increasing global concern, with growing relevance to planning and policy. A growing body of literature exploring the relationships between biodiversity and mental health and wellbeing—based on early research conducted largely from social science perspectives—suggests that particular qualities within natural environments confer particular benefits. Results so far have been inconclusive and inconsistent, contributing to an incohesive body of evidence. While past reviews have focused on reporting variations in results, the present study builds on early reviews by exploring variations from the perspective of author disciplines and the use of different guiding theories, and variables used to measure biodiversity, mental health and wellbeing. This aims to address a research gap in understanding whether research in this topic has become more interdisciplinary or has employed more consistent study designs, which were highlighted as priorities in past reviews, but the progress of which has not yet been explored in depth. We found that research connecting biodiversity and mental health and wellbeing has become only marginally more interdisciplinary in recent years, and there is still a large inconsistency in the use of guiding theories, variables and overall study designs. The variation in disciplinary perspectives and methods reflects a growing interest in this field and the variety of ways researchers are trying to understand and test the complex relationships between biodiversity and mental health and wellbeing. Our study shows that there are unique perspectives that different disciplines can contribute to this body of research and continuing to increase collaboration between disciplines with the use of consistent mixed methods approaches in future may contribute to a more cohesive body of evidence. We provide a framework to conceptualize recommendations for future research, highlighting the importance of interdisciplinary collaboration at multiple scales, and importantly focusing on more specific, mechanistic studies to inform decision-making that provides co-benefits for biodiversity and mental health and wellbeing.

Keywords: subjective wellbeing, green prescription, research methods, systematic literature search, species richness, urban greenspace, interdisciplinary science

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INTRODUCTION

Increasing global urbanization presents significant challenges for both human mental health and biodiversity (Marselle et al., 2020). In recent decades, there has been immense research interest in demonstrating the importance of natural environments to human health and wellbeing (Beute et al., 2020; Felappi et al., 2020; Kosanic and Petzold, 2020), which has produced strong evidence that nature promotes various dimensions of human health and wellbeing. An initial search on the Web of Science for research connecting nature and health and wellbeing (for the years 2006–2021) returns approximately 800 results. In early research, measures of greenspace as they relate to health and wellbeing considered greenspace as a relatively homogenous "green" treatment, such as assessing the amount of greenness, or merely presence or absence. The relationships were predominantly explored in the context of aesthetic preference (Gobster et al., 2007), drawing upon psychoevolutionary theories such as savannah theory, which describe our natural affinity for relatively homogenous greenspaces (Hartig et al., 2011). Attention Restoration Theory (ART) is another theory that guided early work in this space, and which has continued to feature strongly in subsequent research. This theory is based on the ability of a landscape to renew personal adaptive resources and cognitive abilities to meet the demands of everyday life (Kaplan and Kaplan, 1989). As such, early work in this field has been driven from a social science perspective.

More recently, researchers have been interested in understanding the mechanisms by which correlations between health and wellbeing, and different greenspace characteristics arise. Studies that connect nature and health have highlighted that particular qualities within a natural space might provide particular benefits (Thompson Coon et al., 2011; Van den Berg et al., 2015; Reining et al., 2020). Thus, while earlier work looked at the quantity of green within an environment, more recent work seeks to explore more specific qualities of those environments. From this, a body of research has emerged which examines health and wellbeing benefits in the context of the ecological characteristics of particular spaces, such as naturalness or ecological integrity (Reining et al., 2020). Measures of biodiversity within a space, such as species richness, can provide an indication of the ecological functioning of that space. Additionally, more recent studies have begun to distinguish different aspects of human health and wellbeing, such as understanding whether landscapes with ecological benefit can also provide mental health and wellbeing benefits. This moves beyond the measures of greenness to uncover complexities and inform ways to approach the development of synergistic scenarios for biodiversity conservation and human health and wellbeing (Giusti and Samuelsson, 2020). The relevant definitions of biodiversity, mental health and psychological wellbeing for this research are as follows:

> Biodiversity: *the variability among all living organisms from all sources and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems* (United Nations Convention on Biological Diversity, 2006).

> Mental health: *a state of wellbeing in which an individual realizes their own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to their community* (World Health Organisation, 2018).

> Psychological wellbeing: *a combination of positive affective states such as happiness (the hedonic perspective) and functioning with optimal effectiveness in individual and social life (the eudaimonic perspective)* (Winefield et al., 2012).

More in depth studies of the biological quality of greenspace are essential for conservation purposes, and benefits to human mental health and psychological wellbeing are key for understanding how to best design, manage and conserve landscapes for both objectives. Understanding synergies between biodiversity and human wellbeing is particularly important within urban landscapes, because planners and policy makers around the globe are seeking to incorporate ecological restoration or design within the fabric urban environments (Fisher et al., 2021). Simultaneously, those involved in decision making are becoming increasingly aware of the importance of understanding landscapes in the context of social values, and the health and wellbeing benefits that natural spaces can provide (Jorgensen and Gobster, 2010).

Given the importance of mental health and psychological wellbeing to people, there is a growing interest in their presence as a societal aspiration with increasing relevance to decision making. There is therefore a need to understand which social, environmental and economic conditions can provide optimal population level wellbeing (Balvanera et al., 2016; Mavoa et al., 2019). However, significant challenges still exist in connecting research fields of biodiversity and health and wellbeing, particularly with regard to the lack of consistent metrics and outcomes explored (Jorgensen and Gobster, 2010).

Numerous studies have demonstrated that biodiversity can enrich the appreciation of natural spaces (Collar, 2003). Measures of biodiversity such as species richness or abundance have been shown to contribute to wellbeing; however, trends are inconsistent and inconclusive, and complicated largely by the use of different wellbeing and biodiversity variables (Dallimer et al., 2012; Fisher et al., 2021). While it has been shown that people generally perceived natural settings with high levels of complexity to be favorable (Kaplan and Kaplan, 1989; Southon et al., 2017), different people have vastly different preferences for landscapes and there are many environmental, social and personal factors that influence the benefits obtained from natural spaces. While some studies have found that objectively measured biodiversity is positively associated with wellbeing, others have found either weak positive, no correlation or inverse effects. For example, while Fuller et al. (2007) and Wolf et al. (2017) found that higher plant and bird diversity correlated positively with psychological wellbeing, Dallimer et al. (2012) and Methorst et al. (2020) found that psychological wellbeing decreased with higher plant diversity, while no correlations were found for measures such as butterfly diversity.

In **Figure 1** we show the growth in research connecting biodiversity to health and wellbeing, since 2006. An early work of this topic by Lovell et al. (2014) reviewed just eight studies,

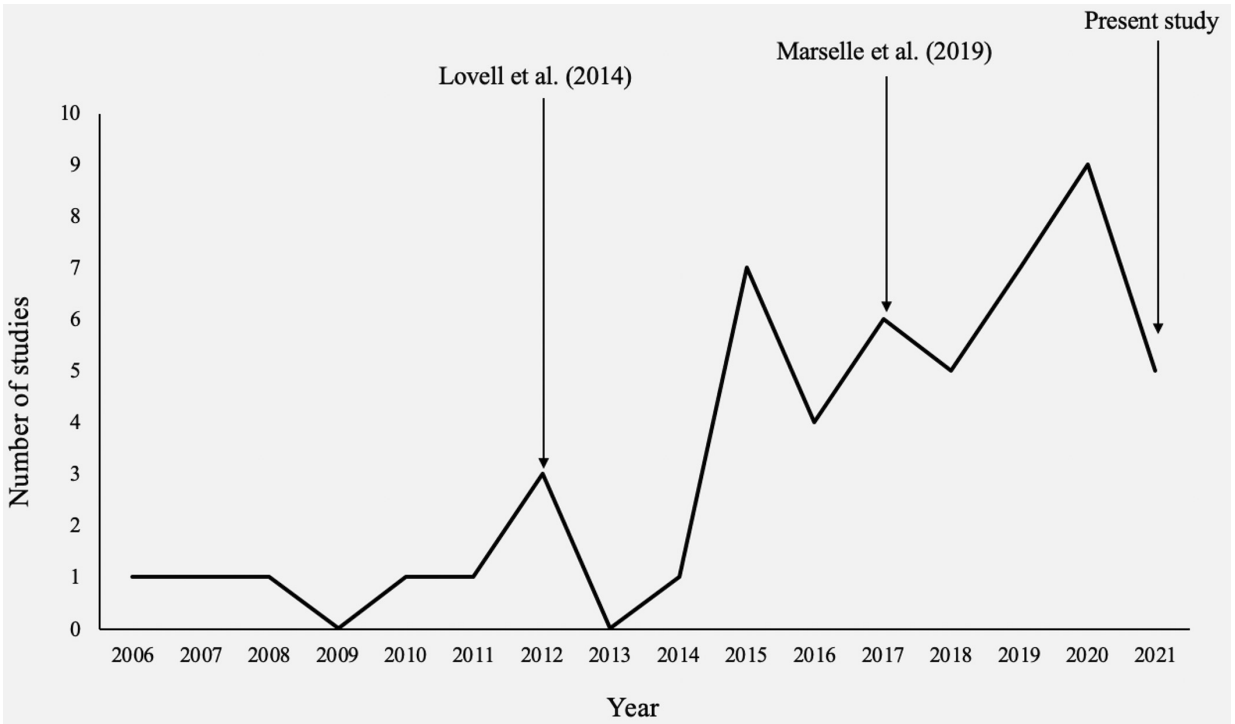

FIGURE 1 | Growth in research connecting biodiversity to mental health, between the years 2006–2021. Captions across the top with arrows indicate the years that have been included in the reviews conducted by Lovell et al. (2014) and Marselle et al. (2019) upon which this current study builds.

which explicitly explored links between biodiversity indicators and mental health. A more recent review conducted by Marselle et al. (2019) explored a further 16 studies. In the present study, we build upon this body of literature, and focus on the epistemological framing, disciplinary approaches and specific methodologies used to date. Earlier research connecting health and biodiversity called for interdisciplinary approaches that integrate multiple perspectives to guide planning and design (Chiang et al., 2017). Furthermore, previous reviews (Aerts et al., 2018; Collins et al., 2020; Methorst et al., 2020) have focused largely on reporting the variability in results. Reviews such as Marselle et al. (2019) highlight the need for more interdisciplinary work and robust experimental designs with consistent use of metrics, to provide for a more replicable and cohesive body of evidence of biodiversity-mental health relationships (Lovell et al., 2014; Chiang et al., 2017; Giusti and Samuelsson, 2020). There has, however, been little exploration of how different academic disciplines have contributed to the body of work so far, and how the use of different metrics has been evolving.

In order to understand whether there has been progress in terms of interdisciplinary work or consistent use of metrics, we aim to compare the 24 earlier studies reported by Marselle et al. (2019) with more recent works that have been published since 2018, which explicitly examine relationships between biodiversity and mental health and/or psychological wellbeing. In doing so, we seek to address a research gap in our understanding of how different disciplines have contributed to this body of research, and how different variables have been incorporated into study designs and may be contributing to inconsistencies in results. In order to address this research gap, we investigate the following research questions:

(1) which academic disciplines have contributed to research connecting biodiversity and mental health and psychological wellbeing, and have recent studies become more interdisciplinary than earlier studies? And (2) are the guiding theories and methods used in recent studies connecting biodiversity and mental health and psychological wellbeing similar or different from earlier studies?

By answering these questions, we seek to contribute to the current state of research linking biodiversity with health and wellbeing and how it is evolving based on early recommendations for interdisciplinary work and consistent use of methods. This may shed light on the understanding of how different academic disciplines have contributed to the body of research and highlight any robust elements of study designs to inform future research.

METHODS

Systematic Search Process

The systematic search conducted by Marselle et al. (2019) and previously by Lovell et al. (2014) was replicated for this study using the Web of Science, to capture more recent studies conducted following the Marselle et al. (2019) review. From this, it was determined that 28 recent studies met the inclusion

criteria for full-text review. Data extraction methods used by Marselle et al. (2019) have been replicated and built upon. In doing this, together with determining the author disciplines as with earlier studies, changes in disciplinarity and use of variables in recent works could be compared.

Using the Web of Science, journal articles which had published original work between the years 2017–2021 were searched for. The search terms used and process of identifying papers appropriate for full-text review are summarized in **Table 1** and **Figure 2**. Although the year 2017 was included in the review by Marselle et al. (2019), this year was included in the present study in order to capture any potential studies that were missed in that review. The search terms (**Table 1**) and inclusion and exclusion criteria were adapted from Marselle et al. (2019), with the aim of being able to build upon and draw comparisons with the evidence base they obtained in their review.

Inclusion and Exclusion Criteria

The following inclusion criteria were used during the systematic search process:

1. Any peer reviewed study published between 01/01/2017 and 05/04/2021.
2. Any recognized and reliable study design with any population group, from any country—English language only.
3. An explicit exploration of one or more biodiversity variables such as species richness, or a setting protected for its biodiversity.
4. An explicit exploration of one or more mental health/wellbeing related outcome, including both objective and subjective measure of mental health or wellbeing.

Studies were excluded if they did not directly assess (i) biodiversity and (ii) mental health or mental wellbeing related outcome measures. Studies assessing preference, or the amount of greenspace without specifically measuring its biodiversity were excluded. Studies not reporting primary research such as review papers, were also excluded. In contrast to Marselle et al. (2019), studies assessing physiological stress measures were included in this search. It is acknowledged that including studies written only in English may have reduced the full scope of research that has been conducted on this topic.

TABLE 1 | Search terms used in the systematic search of the Web of Science.

Search terms	Number of studies
Biodiversity and "mental health"	86
Biodiversity and "mental wellbeing"	5
Biodiversity and "mental well-being"	7
Biodiversity and "psychological wellbeing"	5
Biodiversity and "subjective wellbeing"	1
Species diversity and "mental health"	16
Species richness and "mental health	8
Biodiversity and "psychological restoration"	13
Biodiversity and "perceived restorativeness"	12
Species richness and "psychological restoration"	2
Biodiversity and "attention restoration"	10
Total number of studies	165

With each search, only original, peer reviewed journal articles were searched for, between the years 2017–2021.

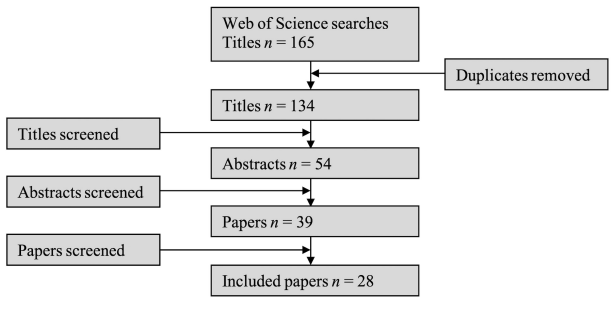

FIGURE 2 | Flow chart representing the systematic search and subsequent processes resulting in the inclusion of 28 additional papers, added to the body of 24 papers previously reviewed by Marselle et al. (2019).

Author Disciplines

This study builds upon the work of Marselle et al. (2019). Using the 24 studies they reviewed and the additional 28 recent studies found, the authorship of each of these studies has been reviewed. A novel approach was adopted to determine author disciplines for this research. To do this, Google Scholar author searches were used to determine author affiliations, "key words" and the topics on which they had previously written. Author "key words" were determined to be reflective of the focus discipline of researchers, as the particular school or organization that they belonged to did not always reflect their specific research interests or expertise. The discipline of the author was defined as the research specialization as self-described by the author on their Google Scholar profile. Where this information was not available, the school and home institution to which the author belonged was recorded from the relevant journal article webpage. This enabled the disciplinary framing of each study to be determined (acknowledging that this is a novel and rudimentary approach). For each of the 52 studies included in this review, each author was recorded and included in the analysis.

Key Elements of Study Design

Based on potential sources of inconsistency as described in previous works, key elements of study designs that may be contributing to inconsistent findings were extracted from each study:

- Guiding psychological theory.
- Biodiversity variables.
- Mental health and wellbeing variables.
- Type of study: correlational or mechanistic.

As seen in Marselle et al. (2019), biodiversity variables were assigned to one of three levels: (i) ecosystem/habitat, which includes variables such as landscape heterogeneity and

structural diversity, (ii) species communities, which includes variables such as species richness, perceived species richness and the abundance of a specific taxonomic group, and (iii) single species level. Mental health and wellbeing variables were recorded as described in each study. Mental wellbeing variables were separated out and included attention restoration, recovery from stress, emotion/mood, and quality of life/life satisfaction, while "mental health" as a variable was recorded individually. In this study, a correlational type of study refers to an observational study that explores relationships between two or more variables, and may have obtained data using cross-sectional, longitudinal, cohort or retrospective record methods MacDonald et al. (2015). A mechanistic study refers to a study that directly explores the mechanisms of action of a particular experimental intervention.

Narrative Synthesis

A standardized spreadsheet was used to record all data, and a process of narrative synthesis, as developed by Popay et al. (2006), was used to interpret and compare the data from the two time periods. This type of synthesis has been used in previous reviews, including Marselle et al. (2019), and is a form of vote-counting synthesis that is useful when dealing with variables and data that are heterogenous, and where other forms of quantitative or statistical analyses are not suitable. This involves extracting key themes from the literature in order to compare and highlight points of difference.

RESULTS

Author Disciplines

Similar results emerge for disciplinarity from the two time periods, with environmental psychology continuing to be the most prominent author discipline. There has been a slight increase in interdisciplinary work in recent years, shown by a greater number of studies including three disciplinary perspectives (**Table 2**). The majority of studies, however, continue to include collaboration from just two disciplines. This is not necessarily surprising considering the two fields that this research combines. Again, unsurprisingly, the most prominent collaboration occurs between the disciplines of environmental psychology, and ecology or biological sciences. These results do, however, show that there is quite a diversity of disciplines that have contributed to the research so far. In recent works there has also been a greater contribution from the perspectives

TABLE 2 | Summary of results for author disciplines, comparing level of interdisciplinarity between early studies (2006–2017) and recent studies (2018–2021).

Number of disciplines	1	2	3	4
Study (2006–2017)	Johansson et al. (2014) (EP) Jones (2017) (EE) Duarte-Tagles et al. (2015) (PH) Saw et al. (2015) (BC)	Annerstedt et al. (2012) (EP, PH) van den Bosch et al. (2015) (EP, PH) Chiang et al. (2017) (EP, LA) Cracknell et al. (2016) (EP, MB) Marselle et al. (2015) (EP, PH) Marselle et al. (2016) (EP, PH) Carrus et al. (2015) (EP, EAS) Cox et al. (2017) (E, BC) de Jong et al. (2012) (EP, EOM) Fuller et al. (2007) (EP, BC) Grahn and Stigsdotter (2010) (EP, LA) Hoyle et al. (2017) (H, E) Luck et al. (2011) (EP, E) King et al. (2017) (BC, E, EAS)	Chang et al. (2016) (LA, H, E) Dallimer et al. (2012) (EP, BC, E) Huby et al. (2006) (M, E, BC) Wolf et al. (2017) (EP, EE, BC)	Björk et al. (2008) (EP, EOM, EAS, G) Wheeler et al. (2015) (EP, PH, E, M)
Total number of studies	4	14	4	2
Study (2018–2021)	Coldwell and Evans (2018) (BC) Meyer-Grandbastien et al. (2020) (E) Simkin et al. (2021) (EP) Reining et al. (2020) (G) Rantakokko et al. (2018) (HS)	De Bell et al. (2020) (G, HS) Fisher et al. (2021) (EP, BC) Harvey et al. (2020) (EP, BC) Giusti and Samuelsson (2020) (M, ES) Kortmann et al. (2021) (E, BC) Nghiem et al. (2021) (EP, BC) Young et al. (2020) (E, EP) Southon et al. (2018) (BC, H) Hussain et al. (2019) (BC, PH) Raymond et al. (2019) (EE, EAS) Methorst et al. (2021) (E, EE) Skevington et al. (2019) (EP, BC) Lindemann-Matthies and Matthies (2018) (E, BC)	Cameron et al. (2020) (EP, LA, M) Schebella et al. (2019) (EP, PH, M) Schebella et al. (2020) (EP, M, PH) Marselle et al. (2020) (EP, E, M) Mavoa et al. (2019) (E, G, M) Methorst et al. (2021) (EP, EE, EAS) Wyles et al. (2019) (EP, EE, MB)	Mears et al. (2019) (LA, M, E, PH) Wood et al. (2018) (EP, E, BC, PH)
Total number of studies	5	13	7	2

The disciplines contributing to each study are abbreviated in brackets beside each citation, with the key to disciplines below the table.
Key: EP, environmental psychology/psychology; EE, environmental economics; BC, biological and conservation sciences; M, mapping/mathematics and statistics; E, ecology; MB, marine biodiversity; PH, public health; HS, health sciences; EAS, environmental and agricultural sciences/engineering; G, geography; LA, landscape architecture; H, horticulture.

of landscape architecture, horticulture, health sciences and environmental economics. This may have implications for subsequent study designs and the application of findings.

Guiding Theory

Attention Restoration Theory (ART) and Stress Recovery Theory (SRT) are the most prominent guiding theories for studies from both time periods (**Figure 3**). These theories are similarly based on the notion that natural elements within landscapes provide the opportunity for mental relief from the many things that demand attention in everyday life and enable recovery from stress or the use of active attention through passive engagement with the environment (Kaplan and Kaplan, 1989).

The use of these theories reflects the short-term nature of most of the studies, which examine what may be referred to as "momentary wellbeing" (Fisher et al., 2021). Another theory that has been used in both early and recent works is the Biophilia Hypothesis (**Figure 3**), which suggests that humans have an innate tendency to seek connections with nature and other forms of life (Kellert, 1995). In recent work, new theories have been used such as Cultural Ecosystem Services, which describes the non-material benefits offered by natural environments, and which has importance for environmental economics and decision making (Milcu et al., 2013).

The most surprising finding here is that the majority of studies in both earlier and recent years do not refer to a guiding theory at all (**Figure 3**). This is reflected in the type of correlational study design used in most of the research as opposed to experimental, mechanistic studies. This may also have flow on effects in subsequent aspects of study designs and interpretation of findings. There is no notable correlation between author disciplines and the use of guiding theoretical frameworks. There are many studies with the perspective of environmental psychology without being guided by ART or other theory (e.g., Wheeler et al., 2015; Schebella et al., 2019), and conversely, there are numerous studies without this psychological perspective but which utilize a guiding psychological theory (e.g., Hoyle et al., 2017; Meyer-Grandbastien et al., 2020).

Biodiversity and Mental Health and Psychological Wellbeing Variables

There is a significant variation in the biodiversity and health and wellbeing variables used across the 52 studies reviewed (**Figures 4**, **5**). So far, there are no two studies which used the same study design or variables. Furthermore, it is important to note that many studies utilize multiple variables of both biodiversity and mental health.

The relative frequency with which particular metrics of biodiversity have been utilized are summarized in **Figure 4**. Comparing the two sets of studies [Early (E) and Recent (R)], it can be seen that species richness, measuring biodiversity at a species communities' level, is the most prominent metric used to evaluate biodiversity in the studies in both time periods, however, the variables and instruments used across studies are highly heterogeneous. The ecosystem/habitat level of biodiversity is also studied frequently across both time periods. In recent works, there is a greater representation of perceived species richness

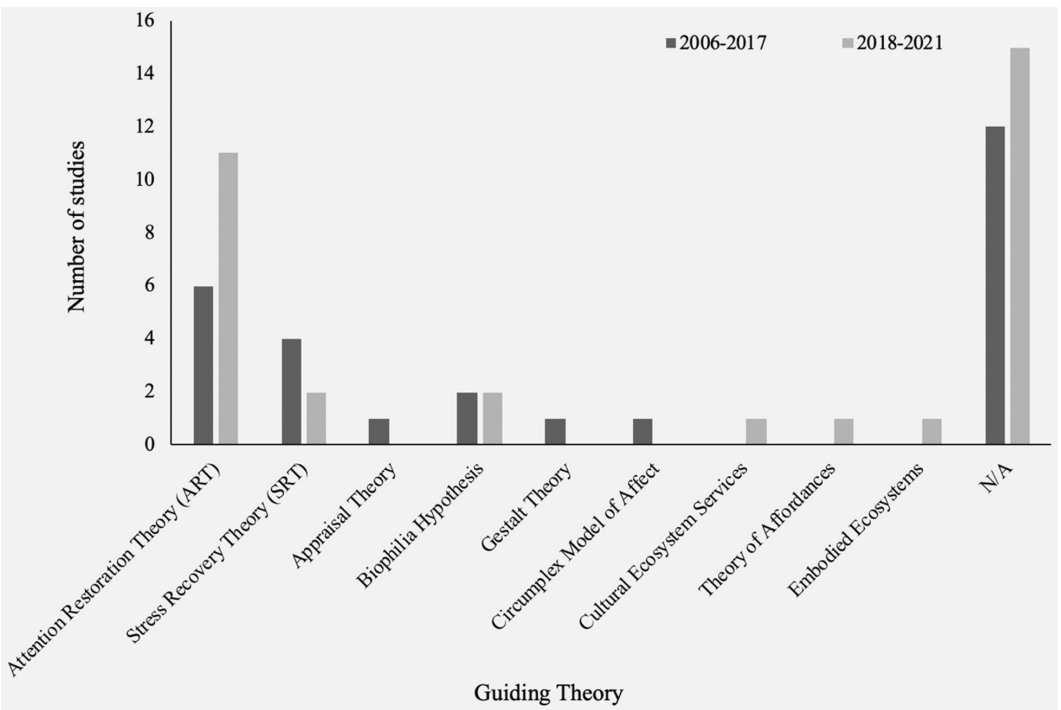

FIGURE 3 | Summary of the guiding theories used in studies from 2006–2017, compared to those between 2018–2021. The number of studies may exceed the total number of studies reviewed (52) as some studies utilized more than one guiding theory.

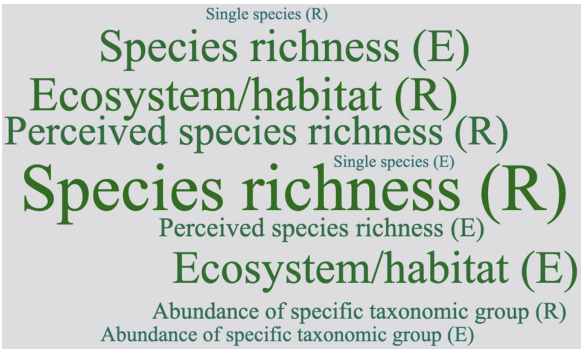

FIGURE 4 | Visual summary of results for biodiversity variables used in early studies (E) compared to recent studies (R). The three biodiversity levels represented are ecosystem/habitat, species communities (which includes species richness, perceived species richness, abundance of specific taxonomic group) and single species. The size of each variable represents the relative frequency with which it occurred in the body of literature, noting that some studies included more than one biodiversity variable (produced with worditout.com). A numerical representation of this data may be found in **Supplementary Appendix 1**.

FIGURE 5 | Visual summary of results for the mental health variables used in early studies (E) compared to recent studies (R). The size of each variable represents the relative frequency with which it occurred in the body of literature, noting that some studies included more than one mental health and/or wellbeing variable (produced with worditout.com). a numerical representation of this data may be found in **Supplementary Appendix 1**.

as a biodiversity variable. As reflected in the results for guiding theory (**Figure 3**), attention restoration continues to be the most prominent variable by which mental health is measured. This is followed by the use of the broader "mental health" variable, for both time periods. As with the biodiversity variables, many studies measured multiple different outcomes of mental health and/or wellbeing.

There is such a diversity of both mental health and biodiversity indicators utilized across studies that it remains difficult to compare or draw any correlation between discipline and use of variables. In recent work we do see a move to diversify the range of biodiversity variables tested, moving beyond just simply vegetation indices to include other taxa such as birds and insects (Wood et al., 2018; Cameron et al., 2020). We also see a large number of studies that include *perceived* biodiversity metrics, which have been shown to be of great importance to obtaining mental health and wellbeing benefits from nature (White et al., 2017; Nghiem et al., 2021).

Throughout the two time periods, correlational study designs continue to pervade, as reflected by the frequent use of ecosystem/habitat level of biodiversity, and broader "mental health" as a variable (**Figures 4**, **5**). There have yet only been five experimental studies conducted within the recent body of literature, and only one experimental study conducted in early literature. Within recent literature, newly emerging experimental study designs include those with the planting of specific experimental plots (Lindemann-Matthies and Matthies, 2018; Southon et al., 2018), which have been conducted from horticultural and/or landscape architectural perspective. Other emerging methodologies include measuring physiological stress responses in a quasi-experimental environment *in situ* (Lindemann-Matthies and Matthies, 2018; Hussain et al., 2019) or in response to the presentation of photographs or short videos (Schebella et al., 2020).

DISCUSSION

The diversity of methodologies, guiding frameworks and findings we found in our review are reflective of how interdisciplinary this topic area is and that researchers are only just beginning to develop ways to explore and understand the relationships between biodiversity and human mental health and psychological wellbeing. It is clear from the literature that exploring biodiversity-mental health relationships remains complex due to an underdeveloped yet growing understanding of the underlying mechanisms, and the large number of potential variables to be tested. More recent studies in particular (e.g., Southon et al., 2018; Schebella et al., 2020; Nghiem et al., 2021) highlight the importance of perceived biodiversity for psychological benefits and combining these with technology that measures physiological responses to biodiversity could continue to contribute to an understanding of the mechanisms underlying these relationships.

It is not surprising given the two disciplinary fields this research combines, that contribution from two disciplinary perspectives continues to be most prevalent in recent works. However, there are a number of unique contributions that can be made from additional disciplines outside of environmental psychology and ecology/biology. Increased representation of disciplines such as urban ecology, horticulture and landscape architecture in more recent studies (**Table 1**) indicates growing interest in using findings from this research to guide the design of urban landscapes, for which biodiversity conservation/restoration is becoming an increasingly prevalent objective.

The type of passive engagement with nature as described by the Attention Restoration Theory and the Stress Recovery Theory has been demonstrated by research to be the main way that we obtain psychological benefits from natural environments (Berto, 2014), so it is not surprising that these theories continue to feature heavily within the literature. However, given the psychological underpinnings of this research, a surprisingly low proportion of studies from both time blocks utilize guiding theoretical frameworks. This may have thus flow on effects within subsequent study designs, contributing to the inconsistency in methodologies and results. The prominent use of Attention Restoration Theory as a guiding framework reflects the short-term nature of many of these studies and the uncertainty still surrounding the mechanisms of biodiversity-mental health relationships.

A large proportion of studies explore relationships at the ecosystem/habitat level, as metrics such as habitat structural heterogeneity have been suggested to be the lens through which we perceive biodiversity within a landscape (Fuller et al., 2007; Beninde et al., 2015; Mears et al., 2019). The metrics of mental health, as compared to metrics of "momentary wellbeing" such as attention restoration or affect (Fisher et al., 2021) that consider the mechanisms by which health benefits arise, tend to show weak associations (Mears et al., 2019). Using these broader scale variables of health may therefore be contributing to inconsistent results. Additionally, there are a range of potential moderators and mediators that may be contributing to variations in the relationships between biodiversity and mental health, such as biodiversity knowledge and connection to nature (Van den Berg et al., 2015; Coldwell and Evans, 2018). Only two studies have investigated the role of a specific species on mental health and wellbeing and it will be important for future research to consider this scale to understand the role of specific species in contributing to mental wellbeing, and to understand whether particular species or combinations of species are more important than others, which could also be important in the context of particular endangered species or communities (Aerts et al., 2018; Mavoa et al., 2019).

The move toward the use of perceived biodiversity in recent literature is important as people's perception of a given environment, which can differ greatly from the actual environment, can have a strong impact on the wellbeing benefits derived (Coldwell and Evans, 2018; Nghiem et al., 2021). Perceived metrics such as species richness may have even greater influence than objectively measured biodiversity. Reining et al. (2020) highlight the fact that these studies have been conducted in distinctly different environments such as meadows and coastal areas, making it even more difficult to replicate or apply findings. Few studies focus on the diverse environments that might exist within one protected area, for example. Studying particular protected areas or particular species or communities therein may be of great importance in the context of particular locally endangered species or communities.

Findings from the present study are consistent with the mixed and inconclusive evidence reported in previous reviews (Aerts et al., 2018; Marselle et al., 2019), which describe the limited and conflicting evidence base for relationships between biodiversity and mental health. Inconsistencies in methods and results also highlights difficulties in studying these relationships within existing paradigmatic frameworks (Aerts et al., 2018; Giusti and Samuelsson, 2020). One way of addressing this in future could be to consider how these findings fit within alternative frameworks such as sustainable social-ecological systems, and the way interactions between mental health and biodiversity may help to understand and promote the restoration of the relationships between human and ecological functioning (Giusti and Samuelsson, 2020).

Recommendations for Future Research

It is clear that researchers are only just beginning to understand the nuances of relationships between biodiversity and mental health and psychological wellbeing, and the variation in methodologies and results reflects the growing interest in this area, and the many perspectives from which people are trying to understand and test these relationships. Although there is yet little consistency in terms of disciplinarity and methodologies, there are some key elements of study designs that can be informed by the unique perspective of particular disciplines. For example, the use of physiological measurements as informed by health sciences indicates a growing interest in understanding the underlying mechanisms at play, and the use of experimental planting plots from the perspective of landscape architecture or horticulture indicates an interest in using these findings to apply to landscape design. The importance of contribution from perspectives of psychology and ecology is clear for this type of research, however, the contribution of additional disciplines would be of great benefit for both understanding the underlying mechanisms of these relationships and applying them to decision-making or design.

To assist with bringing in a wider range of perspectives, we have created a visualization of how different disciplines might contribute to the body of research at various scales (**Figure 6**). At the top of this inverted triangle there are correlational studies, which so far have tended to work at large geographic scales, obtaining for example, census data for mental health variables and satellite derived biodiversity data. These operate at the larger ecosystem/habitat scales of biodiversity. As we move to the bottom of the triangle, there are the more experimental, mechanistic studies, which study biodiversity at the community or single species level, and which measure mental health at physiological or attention restoration level. These tend to be on much smaller geographic scales, in for example a specific greenspace or planting plot, with an accordingly small sample size. These are the findings that would be more specific than those at the top of the triangle, as indicated by the arrows on the right-hand side.

Beside the triangle on the left-hand side, some of the key research disciplines which may make the greatest impact at various scales are displayed. Environmental psychology and ecology are displayed across the whole length of the triangle as these will be of greatest importance at every level of this research. Collaboration between psychology and ecology could greatly benefit from additional perspectives, for different outcomes and applications of findings and to develop a more

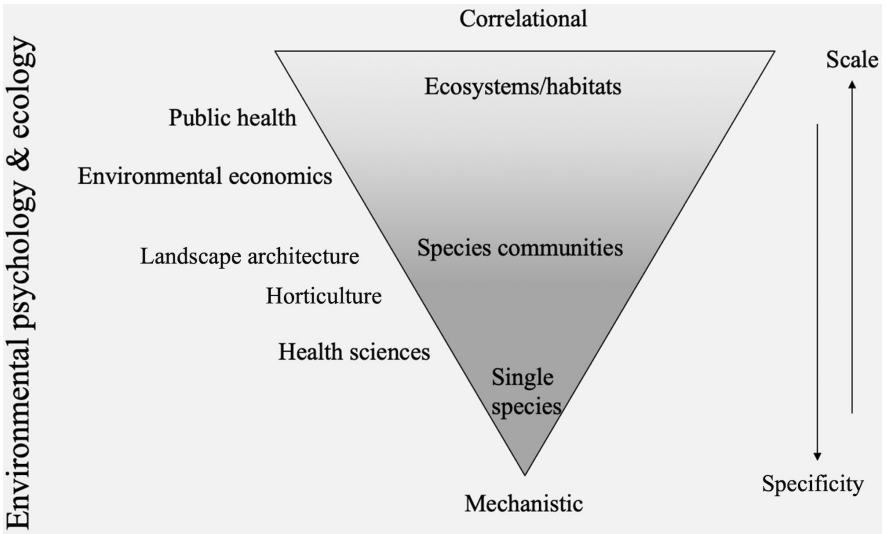

FIGURE 6 | Visual conceptualization of recommendations for future research exploring relationships between biodiversity and mental health and wellbeing.

mechanistic understanding of these relationships. In addition to the importance of foundations in psychology and ecology, perspectives such as public health and environmental economics could assist in framing the research from the perspective of decision making. For example, it could be important from the perspective of environmental economics and decision making to consider the concept of Cultural Ecosystem Services (including psychological restoration, improved physiological health, better social relations and spiritual development) (Kosanic and Petzold, 2020). A challenge exists in ascertaining whether cultural ecosystem benefits are sensitive to variations in biodiversity (King et al., 2017). Cultural Ecosystem Services could be an important concept for guiding decision making based on findings from research in this topic and warrants further investigation, as so far only one study has framed their research and findings in the context of this concept. Toward the mechanistic end of the research, perspectives of landscape architecture, horticulture, medical and health sciences may contribute important elements for experimental study designs, such as the use of physiological measurements in response to biodiversity, or the establishment of specific planting plots in which the ecology is well-documented. From a medical perspective for example, demonstrating stronger mechanistic links between biodiversity and mental health and wellbeing variables could provide important evidence to support healthcare approaches that formalize the role of nature, through concepts such as "green prescription" (Ulmer et al., 2016).

It is important to note that the categories shown in **Figure 6** are not clear-cut, and that important interactions would occur between various aspects of studies at different scales. However, overall, it will be more consistent work in these lower, more mechanistic areas of the inverted triangle, that will help to understand the underlying mechanisms and relationships on local scales that can account for variables such as sociodemographic factors and the importance of place-based data (Harvey et al., 2020). Mixed methods approaches that combine perspectives from multiple disciplines, with clear theoretical foundations and use of robust experimental study designs would enable a clearer progression of findings in this field. It is clear that a longer period of time, including the use of longitudinal research may be needed for these relationships to be understood, particularly in how biodiverse environments might contribute to mental health over time, for example beginning in childhood (Harvey et al., 2020). There is also a need to understand the full range of potential mediators and moderators of these relationships, such as biodiversity knowledge, connectedness to nature and socioeconomic factors, as these have been shown to influence the way benefits are obtained from biodiverse environments (Schebella et al., 2020). For example, psychological benefits have been reported as being greatest for those with lower socio-economic status, lower education level or low biodiversity knowledge in multiple studies (Hoyle et al., 2017; Coldwell and Evans, 2018; Marselle et al., 2020). Further investigation of the relative benefits of biodiversity for a greater diversity of populations and socioeconomic factors could be of great importance in the context of environmental equity. Similarly, it would be valuable to see a greater representation of non-western populations such as those represented in Fisher et al. (2021), Chiang et al. (2017), Chang et al. (2016), and Nghiem et al. (2021). We acknowledge, however, that the inclusion of English language only studies in our review may have precluded representation of such populations within the body of literature.

In order to progress toward transdisciplinary research within this field, there are several theoretical frameworks that future researchers might consider as a means of framing studies in a more holistic manner. The Actor Network Theory for example, provides a means by which researchers may frame relationships between biodiversity and health in the context of social-ecological system resilience (Horgan and Dimitrijević, 2018),

which may be of great importance for applying findings to urban planning. Given the importance of perceived biodiversity as a metric conferring health and wellbeing benefits, we believe that tools such as the "Place Standard," which invite community participation in assessing greenspace qualities, may provide important information for decision-makers in understanding how communities relate to biodiversity through concepts such as place attachment and sense of place (Hasler, 2018; Colley and Craig, 2019). These concepts, which describe cognitive-emotional connections between people and their valued places have been demonstrated to mediate the wellbeing benefits obtained from greenspace (Scannell and Gifford, 2017; Basu et al., 2020; Han et al., 2021) and could therefore be important for future research to consider. However, by drawing upon a common set of metrics used to represent biodiversity, it will become easier to identify consistent pathways through which biodiversity contributes to human mental health, regardless of the frameworks being used. The metrics identified by this study make an excellent starting point for future studies looking to quantify biodiversity, particularly when they are combined with the conceptual framework we present in **Figure 6**.

One limitation of our study is the novel approach used to determine authorship, which may not have captured the true research specialization or interests of each author. However, our method does provide a useful indication of the disciplinary framing of the paper, and this brings a unique perspective that hasn't previously been examined. The 3 years gap between the two time periods studied is also a potential limitation, as a longer period of time may be required in order to draw meaningful conclusions as to whether research in this field is progressing toward a cohesive body of evidence. This may have also largely contributed to the lack of differences found between time periods for the variables examined. Furthermore, we acknowledge that the wide variation in terminology used by different disciplines contributing to this body of research may have precluded several studies from being included in our analysis. For example, a mechanistic study of frontal alpha asymmetry as a direct neurological response to urban green spaces was not included in our study as they used a contemplative landscape model to represent variation between greenspaces, rather than a direct measure of real or perceived biodiversity (e.g., Olszewska-Guizzo et al., 2020). Bringing together these diverse fields and framings is one of the key challenges that need to be addressed. The simplest solution is to ensure that biodiversity is explicitly included in the title, abstract or keywords of studies that include it as a consideration; and that a simplified search term such as "human health" or "wellbeing" is included in the keywords for studies with more specific measures, as demonstrated by Olszewska-Guizzo et al. (2020). This will be particularly important for studies that employ additional frameworks and tools such as the Actor Network Theory or Place Standard mentioned above, as these approaches do not always explicitly consider biodiversity, and therefore could potentially be overlooked in the absence of an additional signal.

The range of contributing disciplines and use of variables to the body of research reviewed in this study reflects a growing interest in this topic, and the complexity of relationships between biodiversity and mental health and wellbeing. The variation in uses of guiding theory and variables also reflects the many different ways by which researchers are trying to understand and test these relationships. The use of mixed methods approaches within recent works demonstrates a growing interest in understanding the underlying mechanisms (physiology) and how these relationships can inform greenspace design (experimental planting plots). This study has shown that while there is still great inconsistency and lack of coherence in study designs even in recent works, it is clear that different disciplines have unique perspectives to offer, and that continued interdisciplinary collaboration within mechanistic studies could contribute to a cohesive body of evidence, to inform strategies or policies that aim for win-win scenarios for both biodiversity conservation and mental health and wellbeing.

AUTHOR CONTRIBUTIONS

MH, AH, LM, and KL: conceptualization, development of methodology, and reviewing and editing draft manuscript. MH: investigation, compiling and curating data, analysis, and writing initial draft. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.865727/full#supplementary-material

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