frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 18 February 2025
DOI 10.3389/fenvs.2025.1461601

OPEN ACCESS

EDITED BY
Rui Leandro Maia,
Fernando Pessoa Energy, Environment and Health Research Unit (FP-ENAS), Portugal

REVIEWED BY
Diogo Guedes Vidal,
University of Coimbra, Portugal
Marina Prieto Afonso Lencastre,
Fernando Pessoa University, Portugal

*CORRESPONDENCE
Rachel R. Y. Oh,
r.oh@uq.edu.au

RECEIVED 08 July 2024
ACCEPTED 13 January 2025
PUBLISHED 18 February 2025

CITATION
Oh RRY, Suarez-Castro AF, Fuller RA, Tervo M, Rozario K, Peters B, Chowdhury S, von Gönner J, Friedrichs-Manthey M, Berger A, Schultz T, Dean AJ, Tulloch A and Bonn A (2025) Using nature-based citizen science initiatives to enhance nature connection and mental health. *Front. Environ. Sci.* 13:1461601. doi: 10.3389/fenvs.2025.1461601

Using nature-based citizen science initiatives to enhance nature connection and mental health

Rachel R. Y. Oh[1,2]*, Andres F. Suarez-Castro[3], Richard A. Fuller[4], Michael Tervo[5], Kevin Rozario[1,2,6,7], Birte Peters[1,2], Shawan Chowdhury[1,2,6,8], Julia von Gönner[1,2,6], Martin Friedrichs-Manthey[1,2,6], Ambros Berger[9], Tracy Schultz[4], Angela J. Dean[4,10], Ayesha Tulloch[11] and Aletta Bonn[1,2,6]

[1]Helmholtz Centre for Environmental Research – UFZ, Department of Biodiversity and People, Leipzig, Germany, [2]Department of Biodiversity and People, German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany, [3]School of Environment and Science, Australian Rivers Institute, Griffith University, Nathan, QLD, Australia, [4]School of the Environment, The University of Queensland, Brisbane, QLD, Australia, [5]Queensland Trust for Nature, Brisbane, QLD, Australia, [6]Institute of Biodiversity, Friedrich Schiller University Jena, Jena, Germany, [7]Wilhelm Wundt Institute for Psychology, Leipzig University, Leipzig, Germany, [8]Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, Czechia, [9]Department of Landscape, Spatial and Infrastructure Science, Institute of Statistics, University of Natural Resources and Life Sciences, Vienna, Vienna, Austria, [10]School of Agriculture and Food Sustainability, The University of Queensland, Brisbane, QLD, Australia, [11]School of Biology and Environmental Science and Resilience Centre, Queensland University of Technology, Brisbane, QLD, Australia

The global rise in mental health issues underscores the critical importance of assessing the mental health benefits of engaging with nature. Beyond their primary aim of involving citizens in scientific data collection, nature-based citizen science initiatives offer significant potential for enhancing outcomes related to conservation (e.g., connection to nature) and human health and wellbeing (e.g., emotions, depression, stress, anxiety). However, the effectiveness of various types of initiatives in achieving specific outcomes remain unclear. This study evaluates changes in eight outcomes related to nature connection and health and wellbeing before and after participation in five initiatives in Australia and Germany. These initiatives varied in ecosystem type (urban parks, terrestrial forests and freshwater streams) and the participation duration (from 15 min to 48 h). We assessed three dimensions of connection to nature (Self, Experience and Perspective) measured by the Nature-Relatedness scale, mental health outcomes (symptoms of depression, stress and anxiety) using the DASS-21 scale, and emotional states (positive and negative emotions) using the Scale of Positive and Negative Experience (SPANE). We found that while participants generally reported improvements across all measured outcomes, only participation in the Queensland Trust for Nature initiative, characterized by its extended duration and social interactions, demonstrated statistically significant enhancements in mental health and emotions after controlling for socio-economic confounders. These findings suggest that while short-term nature-based interventions can effectively alleviate anxiety and stress symptoms and boost emotions, significant changes in nature connection and depression may require more intensive interventions than what is available through typical citizen science experiences. We advocate for reframing

nature-based initiatives as integral components of broader health-promoting strategies. By aligning citizen science efforts with health promotion frameworks, these initiatives can achieve greater impact and simultaneously advance scientific understanding, support conservation strategies while improving human health.

KEYWORDS

nature exposure, nature dose, nature-based health intervention, nature connection, health and wellbeing, community science

1 Introduction

In recent decades, citizen science initiatives aimed at crowd-sourcing biodiversity data have expanded in scale and scope. These initiatives engage the public in scientific research and knowledge production, and have become a well-developed and valued approach with global applicability across various scientific disciplines (Fraisl et al., 2020; Kullenberg and Kasperowski, 2016). Advancements in digital technologies and increasing literacy rates have played a pivotal role in empowering individuals to contribute to scientific knowledge creation, fostering the growth of citizen science initiatives (Aristeidou and Herodotou, 2020). As such, citizen science data has emerged as a vital source of biodiversity information (Fritz et al., 2019) as they bridge important temporal and spatial knowledge gaps (Bradter et al., 2018; La Sorte and Somveille, 2020). These data are widely used to monitor biodiversity changes (Forister et al., 2021), inform on-the-ground species management strategies (Beninde et al., 2023), and to understand ecological processes and species interactions (Groom et al., 2021). For example, eBird, a global citizen science initiative has provided bird biodiversity data instrumental in modelling species' distributions, abundances, and temporal changes (Fink et al., 2020).

Beyond contributing valuable biodiversity data, engagement in biodiversity citizen science initiatives also offers benefits for participants' personal wellbeing and indirectly strengthens conservation outcomes. For instance, participation has been associated with enhanced wellbeing through enjoyment of the activity, improved scientific literacy and opportunities for social connection with like-minded individuals (Peter et al., 2021). These activities have been shown to increase environmental and/or scientific knowledge in both adults (Peter et al., 2021) and children (Kelemen-Finan et al., 2018), and strengthen collective action to conserve natural ecosystems (Dean A. J. et al., 2018; Von Gönner et al., 2024). Engagement could also strengthen participants' connection to nature (Pocock et al., 2023), which is an important driver of active participation in conservation efforts (Whitburn et al., 2020).

From a health perspective, biodiversity citizen science initiatives can be considered a form of nature-based health intervention—programs or strategies designed to enhance health and wellbeing through engagement with natural elements such as vegetation and water bodies (Shanahan et al., 2019). These initiatives encompass a diverse range of activities, ranging from horticulture and sea swimming, to wilderness programs (Hunter et al., 2019) and have shown great potential for improving mental health (Coventry et al., 2021). In fact, the growing interest in nature-based interventions reflects the global mental health crisis (Van Den Bosch and Ode Sang, 2017), and the substantial healthcare cost savings provided by nature areas, estimated at US$6 trillion annually (Buckley et al., 2019). Urban and public health authorities increasingly recognized the importance of accessible green and blue spaces as proactive health measures (Maller et al., 2006). For example, England's Environmental Improvement Plan aims to ensure everyone lives within a 15-min' walk of a green or blue space (Natural England, 2024), while Belgium's "Green Deal for Sustainable Healthcare" promotes integrating nature into healthcare infrastructure (Department of Omgeving, 2024). However, biodiversity citizen science initiatives differ from general nature-based interventions in their objectives and outcomes. While both leverage the benefits of natural environments, biodiversity citizen science initiatives actively engage participants in contributing data and generating scientific knowledge that advances research. In contrast, nature-based interventions priortize experiential engagement with nature, focusing on wellbeing without producing scientific outputs.

Given that most biodiversity citizen science initiatives require outdoor participation for data collection, they typically foster health-promoting behaviors in nature such as physical exercise through walking and hiking (Biddle et al., 2019; Warburton et al., 2006) or help reduce stress and enhance cognitive function (Jimenez et al., 2021). The inherently social and collaborative nature of these initiatives further fosters social connections, reducing social isolation—an essential component of building long-term mental resilience and health (Jordan et al., 2011). These characteristics position biodiversity citizen science initiatives as a valuable opportunity for healthcare systems—including organizations, resources, and professionals—to broaden their range of lifestyle interventions to integrate nature-based solutions to promote human health (Britton et al., 2020). The dual benefits of supporting conservation and enhancing wellbeing have gained recognition from conservation organizations (Carr and Hughes, 2023) and global biodiversity and human health policy platforms (IPBES, 2019), highlighting the potential of these initiatives to advance both biodiversity and societal health objectives. By emphasizing health and wellbeing in their recruitment strategies, citizen science initiatives can attract a broader demographic, engaging individuals beyond those already interested in environmental conservation, thus amplifying their societal impact.

There is a pressing need to comprehensively investigate whether engagement in citizen science initiatives influence nature connection and associated health outcomes, given the weak evidence base (Oh et al., 2024). While prior studies have identified potential benefits, the specific components (of

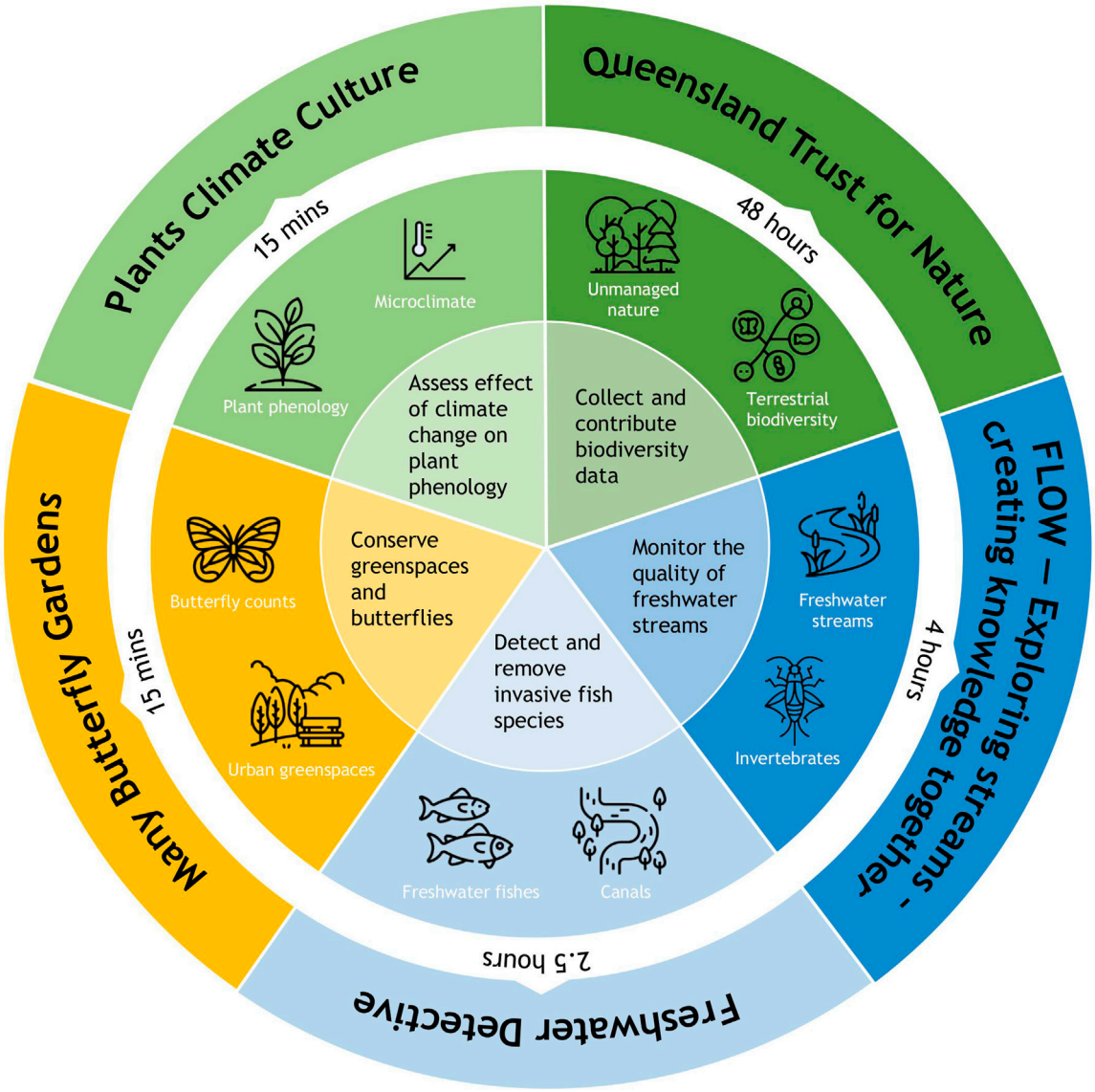

FIGURE 1
An overview of the five nature-based citizen science initiatives, encompassing four initiatives based in Germany (Exploring Streams, Creating Knowledge Together—FLOW; Freshwater Detectives; VielFalterGarten—Many Butterfly Gardens; and Pflanze KlimaKultur!—Plant Climate Culture!) and one from Australia (Queensland Trust for Nature—QTFN). Each data collection event (depicted by the white ring) varied in average duration, ranging from 15 min to 48 h. Each initiative is unique in the ecosystem and taxa studied, which varied from freshwater streams and canals, to unmanaged and urban greenspaces, and how the collected data is used to inform conservation efforts (innermost circle). The biodiversity data contributions from initiatives are detailed in Supplementary Table S1.

initiatives) driving these outcomes remain unclear because of variations in duration of nature exposure, and the use of different tools to assess outcomes. For instance, participation in a 10-min activity, repeated five times over 8 days, was linked to strengthened nature connection, increased happiness, and greater life satisfaction (Pocock et al., 2023) while a 15-min butterfly count was associated with strengthened nature connection and reduced anxiety (Butler et al., 2024). In contrast, no significant changes in nature connection was observed following a 30-min bee count (Ganzevoort & Van Den Born, 2021), or 8 months engagement (Eichholtzer et al., 2023), suggesting that outcomes may depend on factors beyond activity duration, such as social interactions and depth of engagement (Ganzevoort & Van Den Born, 2021; Lynch et al., 2018).

In this study, we employed a before-and-after design to evaluate how participation in five distinct nature-based citizen science initiatives—varying in duration and intensity of participants' engagement, and ecological focus—affects outcomes related to nature connection and mental health. Understanding which aspects of citizen science initiatives enhance nature connection and health outcomes is crucial for designing initiatives that achieve dual objectives: promoting human wellbeing while advancing biodiversity research and conservation.

2 Materials and methods

2.1 The five nature-based citizen science initiatives

We compared five nature-based citizen science initiatives (Figure 1), comprising four initiatives based in Germany (Exploring Streams, Creating Knowledge Together—FLOW; Freshwater Detectives; VielFalterGarten—Many Butterfly Gardens; and Pflanze KlimaKultur!—Plant Climate Culture!) and one from Australia (Queensland Trust for Nature—QTFN). Each initiative featured distinct characteristics in participant engagement and data collection approaches. Data collection events varied in average duration, ranging from 15 min to 48 h, with participants engaging in only one initiative. Biodiversity data for all initiatives was collected individually, except for FLOW and QTFN, where the data was collected collaboratively as a group. Additional details of these variations are presented in Figure 1 and Supplementary Table S1. Despite a shared focus on collecting biodiversity and environmental data using standardized methods across diverse ecosystems such as unmanaged nature, freshwater streams, canals and urban greenspaces, each initiative is unique in how the collected data are used to inform conservation efforts (Figure 1; Supplementary Table S1). For example, biodiversity data from the Germany-based initiatives were submitted directly to researchers via tailored apps and recording schemes, while the Australian-based initiative used iNaturalist as the reporting platform (Supplementary Table S1).

2.2 Participant recruitment and study design

Participants were recruited through public outreach by research and initiative partners, supplemented by social media promotion. Participation was open to all adults aged 18 years and above, with no screening criteria or prerequisites. This study was conducted in accordance with the Declaration of Helsinki, ethical guidelines provided by the University of Griffith Institutional Human Research Ethics (Reference Number: 2023/190) and the UFZ Datenschutz (Data Protection Committee) at the Helmholtz-Zentrum für Umweltforschung GmbH–UFZ (Approval: 08132024).

Surveys were administrated across five nature-based citizen science initiatives in Australia and Germany between March and November 2023. In-person surveys were administered immediately before participants began their participation in the initiative, and again immediately afterward, prior to their departure from the venue. Each participant provided informed consent by ticking a consent box before survey commencement. The full surveys administrated included the Nature-Relatedness scale (Nisbet et al., 2009), the Depression, Anxiety and Stress Scale (DASS-21; Lovibond and Lovibond, 1995), the Scale of Positive and Negative Experience (SPANE; Diener et al., 2009) and additional questions on individual nature experiences and socio-economic status. We describe these measures in more detail in Section 2.3, while the full surveys are available in the Supplementary Material (Supplementary Appendices B, C).

2.3 Response variables (nature connection and mental health and wellbeing)

We assessed outcomes related to individuals' nature connection and mental health and wellbeing, described in detail below.

2.3.1 Connection to nature

Participants assessed their connection to nature using the Nature-Relatedness scale (Nisbet et al., 2009). Participants were invited to rate a set of 21 statements using a five-point Likert scale ranging from 1 (disagree strongly) to 5 (agree strongly). This scale captures three dimensions of an individual's relationship with nature—experiential (NR-Experience), which indicates physical familiarity with, and attraction to, nature (e.g., "I enjoy being outdoors, even in unpleasant weather"; affective (NR-Self), which assesses how strongly one identifies with nature (e.g., "My relationship to nature is an important part of who I am"); and cognitive (NR-Perspective), which indicates one's personal attitude and behaviors towards the environment (e.g., "Conservation is unnecessary because nature is strong enough to recover from any human impact").

While a composite score across all 21 statements provides an overall measure of nature connection, we analyzed these dimensions separately to better understand how participation could shape three different elements of connection, such as physical proximity to nature (e.g., by being outside and physically immerse in nature) or a deeper psychological connection (e.g., a sense of feeling as part of nature; Butler et al., 2024). Moreover, a meta-analysis has suggested that while physical exposure to nature can enhance indicators of mental wellbeing, it is the psychological connection with nature that has a stronger influence on conservation behaviors (Barragan-Jason et al., 2023).

2.3.2 Mental health

We assessed the severity of depression, anxiety and stress symptoms experienced before and after engagement using the Depression, Anxiety and Stress Scale (DASS-21), a standardized global self-reporting questionnaire (Lovibond and Lovibond, 1995). Participants rated 21 statements on a four-point Likert scale ('0 – Not applicable to me', '1 = Applicable some of the time', '2 = Applicable for a good part of time', and '3 = Applicable for most of the time'). Within these statements, three sets of seven statements measured symptoms of depression such as feelings of disinterest and inertia, anxiety such as situational anxiety and subjective experiences of anxious effects and stress such as having difficulty relaxing, nervous arousal, and irritability. While the DASS-21 is typically used to assess mental health symptoms over extended periods (weeks or months), our choice to employ it in this context was deliberate. We intend to evaluate through a follow-up study, the cumulative benefits of repeated participation in initiatives to understand if brief interventions could foster incremental and sustained positive changes. Moreover, prior studies have demonstrated the sensitivity of DASS-21 in detecting short-term changes within similar nature-based interventions (e.g., Raman et al., 2021).

2.3.3 Wellbeing (positive and negative affect)

We assessed participants' broad range of experiences and feelings using the Scale of Positive and Negative Experience

(SPANE; Diener et al., 2009)). Participants were invited to indicate the frequency with which they experienced six positive (e.g., happy, contented) and six negative emotions (e.g., angry, sad) before and after participating in the citizen science initiative. There were five response options for each emotion, ranging from "very rarely or never" to "very often or always. We chose the SPANE over the Positive and Negative Affect Scale (PANAS; Watson et al., 1988) as it offered a more balanced range of emotions in terms of arousal, and is sensitive to differences across cultures and contexts (Diener et al., 2009). Prior studies such as White et al. (2019) and Souter-Brown et al. (2021) have demonstrated that even brief nature-based interventions, such as reading a paragraph or spending 30-min in nature, can elicit notable changes in emotions, supporting our use of SPANE.

2.4 Predictor variables (socio-demographic variables)

We collected socio-demographic covariates including age, gender, number of hours worked per week and number of hours spent in greenspaces in the past week, as these have been tied to mental health outcomes and experiences of nature in previous studies (Elliott et al., 2023; Shanahan et al., 2016; White M. E et al., 2023).

2.5 Statistical analyses

We conducted all analyses using R version 4.4.1 (R Core Team, 2024). After excluding incomplete surveys, our analyses included data from 253 completed surveys, representing 91% of 278 received surveys. This comprised 49 surveys (19.4%) from QTFN, 68 surveys (26.9%) from FLOW, 35 surveys (13.8%) from Freshwater Detectives, eight surveys from VielFalterGarten—Many Butterfly Gardens (3.2%) and 93 surveys (36.7%) from Pflanze KlimaKultur!—Plant Climate Culture!

We developed eight global models to assess the relationship between each outcome and its predictor variables. We used cumulative link mixed models (CLMM; *ordinal* package in R; Christensen, 2023) for eight outcomes—three dimensions of connection to nature (NR-Self, NR-Experience, NR-Perspective); depression, stress and anxiety symptoms (DASS-21); and positive and negative affect (SPANE). We did so as the response variable was ordered, and defined as the *change* in rating for each statement, which was computed as the rating of statement after participation minus rating of statement before participation. This change could range from −4 to 4 for the dimensions of nature relatedness (NR-Self, NR-Experience, NR-Perspective); −3 to 3 for symptoms of depression, anxiety and stress measured using the DASS-21, and −4 to 4 for positive and negative affect. An improvement after engagement in the nature-based citizen science initiatives was defined as an enhanced connection to nature, a reduction in symptoms of depression, anxiety and stress, fewer negative emotions, and more positive emotions. We chose mixed-effects models as they are well-suited for analyzing longitudinal (pre- and post-measures of outcomes) and clustered (by citizen science initiative) data, and allows the specification of random effects to model variation at different levels (e.g., between participants).

For all models, the predictor variables specified were initiative, age, gender, number of hours worked and number of hours spent in greenspaces, which are summarized in Table 1. All continuous predictors were standardized. For the CLMMs, each respondent was additionally specified as a random intercept. We assessed the goodness-of-fit for CLMMs using the Hessian condition number as per Christensen (2023). Prior to all analyses, multicollinearity was assessed in each global model using the *vif* function from the *car* package in R (Fox and Weisberg, 2023), and found no such issues (VIF <3).

As it was possible that a different statistical treatment of the response variables (from ordered to continuous) might result in a different set of significant predictors, we then conducted an additional analysis that used generalized linear models instead of CLMMs. We aggregated the responses for each outcome to form a continuous score that provided a measure of an individual's connection to nature, mental health and wellbeing (as per Diener et al., 2009; Lovibond and Lovibond, 1995; Nisbet et al., 2009). We report these results in the Supplementary Material (Supplementary Table S2; Supplementary Figure S2) given that the significant predictors and direction of relationships with response variables of generalized linear models were generally consistent with the CLMMs.

3 Results

3.1 Overall change in nature connection and mental health and wellbeing

Across all eight outcomes related to nature connection and mental health and wellbeing, the highest percentage of change (in ratings) was observed for negative and positive affect, as well as symptoms of stress (Figure 2, but see Supplementary Figure S1 for a detailed distribution of change in ratings for each citizen science initiative). 55.8% of participants reported lower negative affect, while 42% reported greater positive affect (Figure 2). 47.7% of participants reported lesser symptoms of stress (Figure 2). These results indicate that participants experienced improved mental health and wellbeing outcomes after participating in the nature-based citizen science initiatives. Regardless of whether participants reported a change in mental health and wellbeing, there were consistently more improvements than worsened outcomes, ranging from 1.3 times more improved *versus* worsened outcomes for NR-Self and NR-Experience (which also had the highest percentage of outcomes categorized as worsened: 13.1% and 12.3%, respectively) to 11.6 times more reports of improved *versus* worsened outcomes for negative affect. Anxiety exhibited the lowest percentage of outcomes classified as worsened (3.2%).

3.2 Relationship between citizen science participation and outcome measures

After adjusting for socio-demographic variables, we found that engagement in citizen science initiatives was not consistently associated with an enhanced connection to nature or improved health and wellbeing. Significant predictors were observed for only six outcomes (Figure 3). First, a stronger connection to nature (NR-Experience) was associated with increased time spent in greenspaces

10.3389/fenvs.2025.1461601

TABLE 1 Description of the response and predictor variables specified in the global models.

	Variable	Description
Response	NR–Self (ordinal)	Measured using the Nature-Relatedness scale
	NR–Experience (ordinal)	
	NR–Perspective (ordinal)	
	Symptoms of depression (ordinal)	Measured using the DASS-21 scale
	Symptoms of anxiety (ordinal)	
	Symptoms of stress (ordinal)	
	Positive Affect (ordinal)	Measured using the SPANE scale
	Negative Affect (ordinal)	
Predictor	Initiative (categorical)	Five different initiatives: QTFN—Queensland Trust for Nature; Exploring Streams, Creating Knowledge Together— FLOW; Freshwater Detectives; VielFalterGarten—Many Butterfly Gardens; and Pflanze KlimaKultur!—Plant Climate Culture!
	Age (continuous)	Participants provided their age in years
	Gender (categorical)	Female, male, non-binary
	Number of hours worked per week (continuous)	The number of hours the participant worked in an average week
	Duration of greenspace visits (continuous)	Self-reported average number of hour(s) spent during each visit to public outdoor greenspaces in the week prior to participating in the initiative

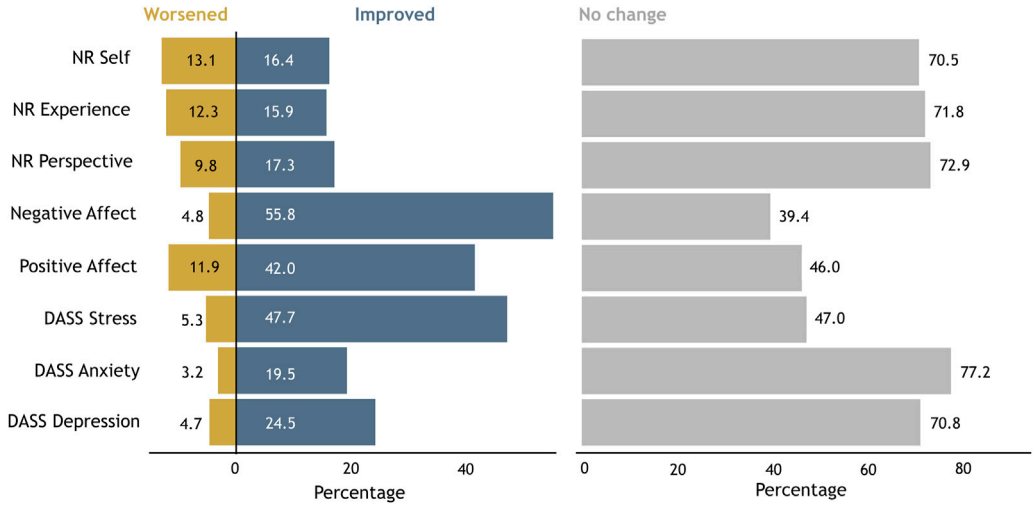

FIGURE 2
The percentage change in ratings for each outcome was categorized as improved (colored blue), worsened (colored gold), or remained unchanged (colored grey). The ratings in the improved and worsened categories have been aggregated; to illustrate, changes in ratings under the DASS-21 scale have been aggregated as follows: negative changes (−3, −2, −1) are categorized as "improved," positive changes (+3, +2, +1) are categorized as "worsened," and no change (0) is categorized as "unchanged" and refers to no variation in ratings or scores.

(Figure 3A). Second, reductions in depression, anxiety and stress symptoms was associated with participation in the QTFN initiative, while reduced stress symptoms was associated with participation in the FLOW initiative. Reductions in anxiety symptoms was also reported in older participants (Figure 3B). Third, greater positive emotions and lesser negative emotions were linked to QTFN participation, but male participants reported lower positive emotions than female participants (Figure 3C).

4 Discussion

4.1 Mental health and wellbeing outcomes vary in size of response to short-term nature-based interventions

Using a consistent assessment method across five nature-based citizen science initiatives, we found that the magnitude of effects

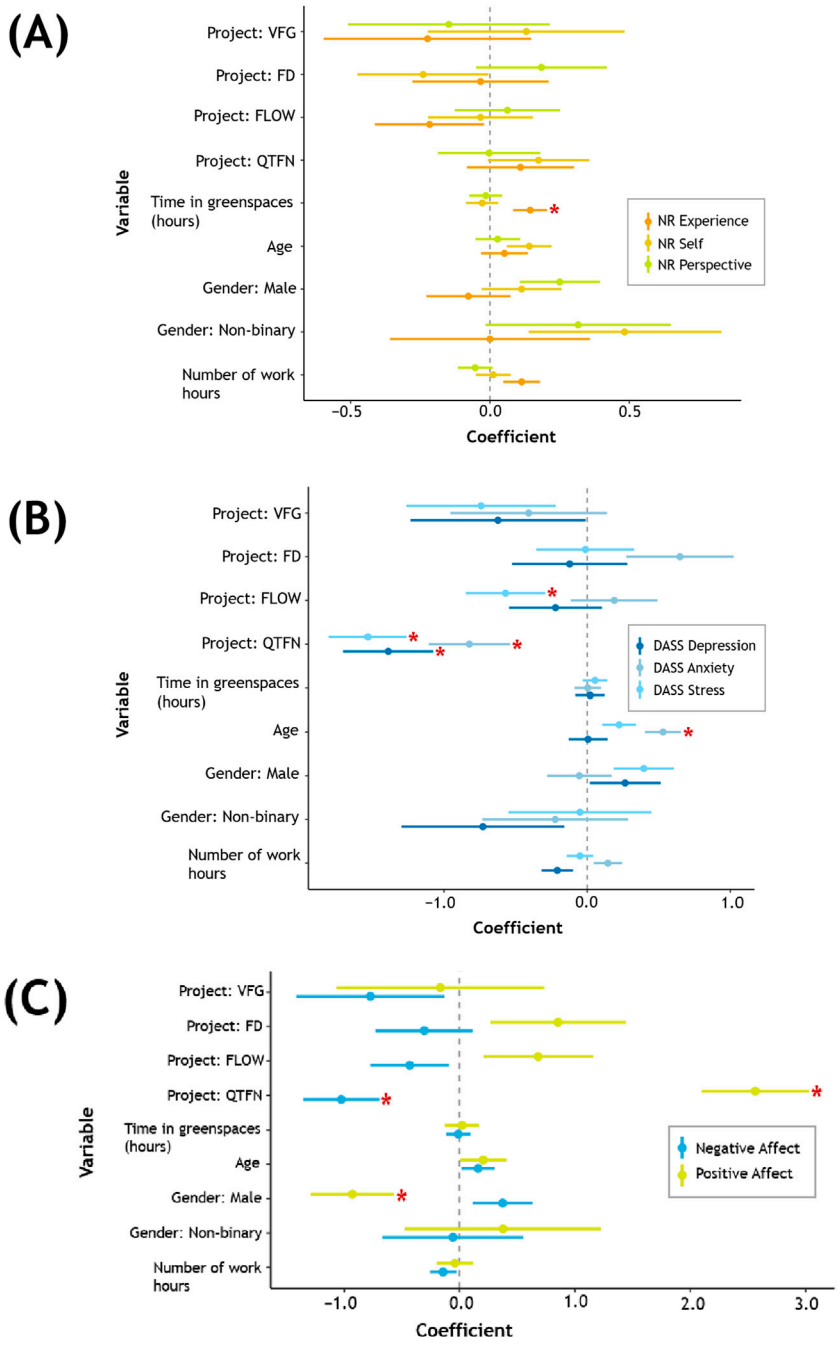

FIGURE 3
The model outputs from the CLMMs, showing the effect sizes and standard errors for predictor variables across the following outcomes: **(A)** the three dimensions of nature connection (NR-Experience, NR-Self and NR-Perspective); **(B)** depression, anxiety and stress as measured using the DASS-21; and **(C)** negative and positive affect. While the effect sizes and standard errors for all predictor variables are presented, only statistically significant predictors (p-value ≤0.05) are marked with a red asterisk (e.g., Age for Anxiety). Effect sizes and standard errors for categorical variables are presented relative to their reference levels: Project (Plant Climate Culture) and Gender (Female).

varied across the eight measured outcomes. Participants generally reported enhanced nature connection and improved mental health and wellbeing, with the most substantial changes observed in negative and positive emotions, as well as stress symptoms (Figure 2). This suggests that changes in emotions and stress symptoms are more responsive to short-term nature-based intervention than other indicators of wellbeing. This finding aligns with studies suggesting that emotions are preconditions to human behaviors, and shape how we process and responds to external situations (Brosch, 2021; Fredrickson, 2004). As such, emotions and stress outcomes are more responsive to short-term changes compared to other health outcomes such as depression and anxiety, which are influenced by cumulative life experiences, and may persist over time (Kessler and Bromet, 2013). Observing

positive influences on depression and anxiety symptoms is therefore likely to require more intensive interventions or lifestyle changes than what is available through typical citizen science experiences (Sarris et al., 2020; Shorey et al., 2022).

Therefore, at the individual level, the efficacy of nature-based (health) interventions is likely maximized when (i) targeting outcomes responsive to short-term interventions such as emotions and stress; and (ii) engaging in these interventions regularly, rather than as one-off events, to ensure sustained benefits over time. At the society or population level, the efficacy of such nature-based interventions is likely better suited to foster and amplify health-promoting behaviors (rather than treating disorders *per se*), such as increased positive emotions and physical activity, and stronger social connections. These are fundamental building blocks that cultivate resilience (*sensu* Southwick et al., 2014), vitality and life satisfaction and which contribute to a suite of long-term, tangible and positive physical and mental health outcomes (Alexander et al., 2021; Diener et al., 2017; Fredrickson and Joiner, 2018).

4.2 Nature connection exhibited a ceiling effect

Engagement in citizen science initiatives is often proposed as a means to strengthen individuals' connection with, and concern for nature (Schuttler et al., 2018). However, our study found significant improvement only in experiential nature connection (NR-Experience; Figure 3A). This could be attributed to two factors. First, a ceiling effect stemming from self-selection bias among participants may have constrained further improvements. As participation was entirely voluntary, it likely attracted individuals with inherently high baseline nature connection. Indeed, the average baseline values observed in our study for NR-Self, NR-Experience and NR-Perspective were 4.1, 4.0 and 4.1, respectively (on a scale of 1–5; Supplementary Table S2). These were notably higher than average population scores reported in prior studies from Australia and Hungary (3.29–3.67, 3.24–3.48 and 3.60–3.87, respectively; Dean J. H. et al., 2018; Zsido et al., 2022). To optimize the impact of citizen science initiative as an intervention, it would be strategic to target individuals with baseline scores below the population average. This approach is likely to maximize the potential for measurable gains in participants' connection to nature (or other targeted outcomes).

Second, the relationship between people and nature is theorized to mirror personality traits, which exhibit individual variation but remain relatively stable over time and across contexts (Mayer and Frantz, 2004; Nisbet et al., 2009). Consequently, substantial changes in nature connection may require more intensive interventions, such as prolonged and repeated exposure to nature which could be achieved through regular participation in citizen science initiatives. While Whitburn et al. (2023) demonstrated that environmental education fieldtrips can enhance children's connection to nature, this enhancement was greater for those with higher baseline connection. Given there is a general lack of studies that explicitly assess interventions and demonstrate their effectiveness in strengthening nature connection, we recommend that future studies could consider two approaches: (i) adopting a randomized controlled study design to mitigate self-selection bias to more accurately determine the effects of nature exposure, notwithstanding potentially small effect sizes; and (ii) monitor longitudinal changes in nature connection through repeated assessments of individuals' connection with nature.

Our findings on nature connection contrast recent quasi-experimental studies that report increased levels of nature connectedness following short-term engagement in citizen science initiatives. For example, Pocock et al. (2023) observed enhanced nature connection and wellbeing among 500 participants who engaged in 10-min citizen science and nature-noticing activities at least five times over 8 days. However, it remains unclear whether these changes were due to engagement in citizen science itself, or simply from being outside the home, as the study was conducted during the 2020 COVID-19 restrictions—a period characterized by high levels of uncertainty, stress, indoor confinement and social isolation. Similarly, White M. P et al. (2023) reported improved nature connection and wellbeing among participants who interacted with birds in their gardens for at least 30 min, while Butler et al. (2024) found comparable results for those who engaged in a 15-min butterfly count. However, both analyses did not fully control for potential confounding effects from demographic differences, despite known variations in nature connection and wellbeing across factors such as age and gender (Dean A. J. et al., 2018; Oh R. R. Y. et al., 2021).

4.3 Trade-offs and synergies in measured outcomes across citizen science initiatives

After controlling for potential socio-demographic confounders, we found significant mental health and wellbeing improvements through engagement in the QTFN initiative (Figures 3B, C), but only reduced stress through participating in the FLOW initiative (Figure 3B). This finding suggests the existence of a critical "threshold" of nature exposure, such as duration, below which health and wellbeing benefits are not realized, but above which tangible benefits become apparent. Engagement in the QTFN initiative lasted 48 h, while that for the other initiatives ranged from 15 min to 4 h. To gain deeper insights into this threshold effect, future studies could therefore employ longitudinal study designs where the same group of participants is exposed to progressive increases in durations of engagement. However, it is essential to recognize that any identified thresholds will likely vary within and between populations (Cox et al., 2017; Oh R. Y. R. et al., 2021; Shanahan et al., 2016; White et al., 2019), influenced by individuals' baseline levels of health and nature connection, as well as the types of nature exposure and outcomes studied (Oh et al., 2021b).

Second, the observed changes in health outcomes at the conclusion of the initiatives highlight the complex interplay (trade-offs and synergies) of various components underpinning citizen science initiatives, such as the duration and intensity of engagement, and extent of social interactions (Eichholtzer et al., 2023). For example, a 4-h engagement through the FLOW initiative may have sufficed to reduce stress. However, identifying invertebrates to the family level required sustained patience and

concentration (Supplementary Appendix A), which may have been demanding for some participants and could have mitigated the activity's overall positive impact on emotional wellbeing. Conversely, the QTFN initiative demonstrated significant positive changes, likely due to the synergies between the duration and social components inherent to the initiative. Participants in the QTFN initiative engaged with researchers and other volunteers over an entire weekend, in contrast to shorter durations and less-social components of other initiatives. This extended engagement provided greater opportunities for participants to apply acquired research skills in fieldwork, and to engage in problem-solving and idea exchange with a larger group. This aligns with studies highlighting the importance of social interactions within nature-based citizen science initiatives, and how participants' satisfaction often hinge on fostering teamwork, a sense of community, and personal growth through interactions with like-minded others (Church et al., 2025; Day et al., 2022).

4.4 Considerations for implementation

To harness the full potential of nature-based citizen science initiatives to achieve enhanced outcomes for people and biodiversity, a thoughtful consideration of participant recruitment, and the design of engagement components is essential. Citizen science initiatives like the QTFN, which balances the duration and intensity of engagement with opportunities for extended social interaction, are more likely to yield positive health outcomes in addition to achieving their primary goals of bridging biodiversity data gaps. Rethinking of scientific data collection protocols, such as the duration and frequency of data collection, as measures of participants' exposure to nature, can provide valuable insights into the health benefits derived from nature-based citizen science engagement (Oh et al., 2024). However, tailored approaches will be needed to assess outcomes-of-interest, and these could range from administrating pre- and post-engagement surveys, to employing holistic frameworks involving health practitioners (Skivington et al., 2021). Future studies could attempt a multi-factorial or longitudinal study design to isolate the influence of individual factors, while accounting for their potential interactions. It is crucial to select scales and tools that are sensitive to cultural and linguistic differences, as well as to the duration of the intervention. Many commonly used tools are designed for Western, high-income, English-speaking contexts, which may limit their applicability in other settings. Ensuring cultural and contextual relevance is essential to obtain valid and meaningful results.

Achieving all scientific and non-scientific project goals to a high standard may prove challenging, but integrating social and health considerations in the goals and design of these citizen science initiatives can unlock new synergies that amplify their utility and impact. Citizen science initiatives can leverage the universal appeal of human health by elevating the health and wellbeing aspects of their recruitment strategies to attract a broader subset of society and diversify participant demographics. Collaborations with health experts can facilitate targeted evaluations of health outcomes, and the processes through which these happen, since these extend beyond the scope of citizen science coordinators. For citizen science coordinators keen to commence these evaluations, the validated scales used in our study (see Supplementary Appendices B, C) provide a valuable starting point for implementation and future research endeavors. By adopting an interdisciplinary approach to evaluation and collaboration, citizen science initiatives can maximize their impact and contribute meaningfully to both scientific understanding and public health agendas.

4.5 Limitations

While we have chosen to retain responses from the VFG project for completeness, we acknowledge that their removal is unlikely to significantly affect the results due to the small sample size (n = 8). We also recommend that future studies aim for comparable sample sizes across projects, even if this may be challenging in practice. A second limitation of survey administration is the potential for social desirability bias, where participants provide responses they think are expected of them or that will be viewed favorably by others (Fisher, 1993). While this bias cannot be eliminated entirely, we have attempted to minimize it by (i) keeping responses anonymous; (ii) using neutral, non-judgmental wording; and (iii) providing clear instructions (e.g., that there are no right or wrong answers and to not overthink their responses). These instructions are clearly outlined in the full survey provided in the Supplementary Material. Lastly, our choice to anchor participants' recall periods to each specific intervention, instead of how they felt "in the moment" might have constrained our results. As such, the use of scales designed to support momentary measures such as UWIST-MACL (Matthews et al., 1990) could be applied instead of SPANE. Alternatively, it could be combined with longer-timeframe assessment methods like DASS-21 to provide a balanced evaluation, and to better differentiate between immediate and cumulative health outcomes.

5 Conclusion

Our study investigated the impact of engagement across five nature-based citizen science initiatives on eight outcomes related to nature connection and human health and wellbeing. We observed overall improvements in all outcomes, with the greatest improvements in improved positive emotions and reduced anxiety and stress symptoms. These changes are crucial antecedents to long-term positive health outcomes. Conversely, improvements in nature connection, depression, and anxiety were modest, consistent with the view that these outcomes are less responsive to short-term interventions. The varying degrees of improvement could be attributed to several factors, including the type of participants recruited, the targeted outcomes, and the design of the citizen science initiatives, particularly the nature and social engagement components. We nonetheless advocate for reimaging citizen science initiatives as integral components of broader health-promoting interventions. By doing so, these nature-based citizen science initiatives can enhance their impact and relevance to scientific understanding, societal wellbeing and policy development.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by ethical guidelines provided by the University of Griffith Institutional Human Research Ethics (Reference Number: 2023/190) and the UFZ Datenschutz (Data Protection Committee) at the Helmholtz-Zentrum für Umweltforschung GmbH – UFZ (Approval: 08132024). This research was also conducted in accordance with the Declaration of Helsinki. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RO: Writing–original draft, Writing–review and editing, Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization. AS-C: Funding acquisition, Project administration, Writing–review and editing. RF: Funding acquisition, Investigation, Writing–review and editing. MT: Investigation, Project administration, Writing–review and editing. KR: Methodology, Writing–review and editing. BP: Investigation, Writing–review and editing. SC: Formal Analysis, Visualization, Writing–review and editing. JG: Investigation, Project administration, Writing–review and editing. MF-M: Investigation, Project administration, Writing–review and editing. AmB: Formal Analysis, Visualization, Writing–review and editing. TS: Writing–review and editing. AD: Methodology, Writing–review and editing. AT: Investigation, Methodology, Writing–review and editing. AlB: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. RO, KR, BP, SC, JG, MF-M, and AlB acknowledge funding from the German Research Foundation (DFG-FZT 118, 202548816) that supports the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig. We also acknowledge funding from the Universities Australia and Deutscher Akademischer Austauschdienst (German Academic Exchange Service, DAAD) under the Australia-Germany Joint Research Co-operation Scheme, the German Ministry of Education and Research (BMBF, project grants 01BF1906 and 01UT2103A) and the Germany Agency for Nature Protection (FZ: 3520685A01). AT was funded by an Australian Research Council Future Fellowship FT210100655.

Acknowledgments

We express our sincere gratitude to all participants in the citizen science initiatives, and to the passionate and dedicated teams leading these initiatives. We extend our thanks to past and present members from the Biodiversity and People group (UFZ/iDiv), and to our collaborators for their invaluable support, including but not limited to Franziska Lausen, Volker Grescho, Luise Ohmann, Andrea Büermann, Wayne Schmidt, Birgit Nordt, Anna Bochmann, Guy Pe'er and Kayleen Campbell. We are grateful to both reviewers for their invaluable feedback. Figure 1 has been designed using resources from https://www.Flaticon.com.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2025.1461601/full#supplementary-material

References

Alexander, R., Aragón, O. R., Bookwala, J., Cherbuin, N., Gatt, J. M., Kahrilas, I. J., et al. (2021). The neuroscience of positive emotions and affect: implications for cultivating happiness and wellbeing. *Neurosci. and Biobehav. Rev.* 121, 220–249. doi:10.1016/j.neubiorev.2020.12.002

Aristeidou, M., and Herodotou, C. (2020). Online citizen science: a systematic review of effects on learning and scientific literacy. *Citiz. Sci. Theory Pract.* 5 (1), 11. doi:10.5334/cstp.224

Barragan-Jason, G., Loreau, M., de Mazancourt, C., Singer, M. C., and Parmesan, C. (2023). Psychological and physical connections with nature improve both human well-being and nature conservation: a systematic review of meta-analyses. *Biol. Conserv.* 277, 109842. doi:10.1016/j.biocon.2022.109842

Beninde, J., Delaney, T. W., Gonzalez, G., and Shaffer, H. B. (2023). Harnessing iNaturalist to quantify hotspots of urban biodiversity: the Los Angeles case study. *Front. Ecol. Evol.* 11. doi:10.3389/fevo.2023.983371

Biddle, S. J. H., Ciaccioni, S., Thomas, G., and Vergeer, I. (2019). Physical activity and mental health in children and adolescents: an updated review of reviews and an analysis of causality. *Psychol. Sport Exerc.* 42, 146–155. doi:10.1016/j.psychsport.2018.08.011

Bradter, U., Mair, L., Jönsson, M., Knape, J., Singer, A., and Snäll, T. (2018). Can opportunistically collected Citizen Science data fill a data gap for habitat suitability models of less common species? *Methods Ecol. Evol.* 9 (7), 1667–1678. doi:10.1111/2041-210X.13012

Britton, E., Kindermann, G., Domegan, C., and Carlin, C. (2020). Blue care: a systematic review of blue space interventions for health and wellbeing. *Health Promot. Int.* 35 (1), 50–69. doi:10.1093/heapro/day103

Brosch, T. (2021). Affect and emotions as drivers of climate change perception and action: a review. *Curr. Opin. Behav. Sci.* 42, 15–21. doi:10.1016/j.cobeha.2021.02.001

Buckley, R., Brough, P., Hague, L., Chauvenet, A., Fleming, C., Roche, E., et al. (2019). Economic value of protected areas via visitor mental health. *Nat. Commun.* 10 (1), 5005. doi:10.1038/s41467-019-12631-6

Butler, C. W., Hamlin, I., Richardson, M., Lowe, M., and Fox, R. (2024). Connection for conservation: the impact of counting butterflies on nature connectedness and wellbeing in citizen scientists. *Biol. Conserv.* 292, 110497. doi:10.1016/j.biocon.2024.110497

Carr, V., and Hughes, J. (2023). Identifying nature activities that promote adult nature connection using the Evaluating Nature Activities for Connection Tool (ENACT). *Biol. Conserv.* 286, 110287. doi:10.1016/j.biocon.2023.110287

Christensen, R. H. B. (2023). Package 'ordinal; version. Available at: https://cran.r-project.org/web/packages/ordinal/ordinal.pdf.

Church, E. K., Wilson, K. A., Loder, J., and Dean, A. J. (2025). From citizen science experiences to stewardship action: the importance of both nature and social experiences. *Mar. Policy* 173, 106537. doi:10.1016/j.marpol.2024.106537

Coventry, P. A., Brown, J. V. E., Pervin, J., Brabyn, S., Pateman, R., Breedvelt, J., et al. (2021). Nature-based outdoor activities for mental and physical health: systematic review and meta-analysis. *SSM - Popul. Health* 16, 100934. doi:10.1016/j.ssmph.2021.100934

Cox, D. T. C., Hudson, H. L., Shanahan, D. F., Fuller, R. A., and Gaston, K. J. (2017). The rarity of direct experiences of nature in an urban population. *Landsc. Urban Plan.* 160, 79–84. doi:10.1016/j.landurbplan.2016.12.006

Day, G., Fuller, R. A., Nichols, C., and Dean, A. J. (2022). Characteristics of immersive citizen science experiences that drive conservation engagement. *People Nat.* 4 (4), 983–995. doi:10.1002/pan3.10332

Dean, A. J., Church, E. K., Loder, J., Fielding, K. S., and Wilson, K. A. (2018a). How do marine and coastal citizen science experiences foster environmental engagement? *J. Environ. Manag.* 213, 409–416. doi:10.1016/j.jenvman.2018.02.080

Dean, J. H., Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Barber, E., et al. (2018b). Is nature relatedness associated with better mental and physical health? *Int. J. Environ. Res. Public Health* 15 (7), 1371. Article 7. doi:10.3390/ijerph15071371

Department of Omgeving (2024). Green Deal Duurzame zorg: Samen zorg dragen voor de natuur én omgekeerd. Available at: https://omgeving.vlaanderen.be/nl/inspiratie-nieuws/green-deal-duurzame-zorg-samen-zorg-dragen-voor-de-natuur-en-omgekeerd (Accessed December 1, 2024).

Diener, E., Pressman, S. D., Hunter, J., and Delgadillo-Chase, D. (2017). If, why, and when subjective well-being influences health, and future needed research. *Appl. Psychol. Health Well-Being* 9 (2), 133–167. doi:10.1111/aphw.12090

Diener, E., Wirtz, D., Biswas-Diener, R., Tov, W., Kim-Prieto, C., Choi, D., et al. (2009). "New measures of well-being,". *Assessing well-being*. Editor E. Diener (Netherlands: Springer), 39, 247–266. doi:10.1007/978-90-481-2354-4_12

Eichholtzer, A. C., Driscoll, D. A., Patrick, R., Galletta, L., and Lawson, J. (2023). The co-benefits of biodiversity citizen science for well-being and nature relatedness. *Appl. Psychol. Health Well-Being, aphw* 16, 515–536. doi:10.1111/aphw.12502

Elliott, L. R., Pasanen, T., White, M. P., Wheeler, B. W., Grellier, J., Cirach, M., et al. (2023). Nature contact and general health: testing multiple serial mediation pathways with data from adults in 18 countries. *Environ. Int.* 178, 108077. doi:10.1016/j.envint.2023.108077

Fink, D., Auer, T., Johnston, A., Ruiz-Gutierrez, V., Hochachka, W. M., and Kelling, S. (2020). Modeling avian full annual cycle distribution and population trends with citizen science data. *Ecol. Appl.* 30 (3), e02056. doi:10.1002/eap.2056

Fisher, R. J. (1993). Social desirability bias and the validity of indirect questioning. *J. Consumer Res.* 20 (2), 303. doi:10.1086/209351

Forister, M. L., Halsch, C. A., Nice, C. C., Fordyce, J. A., Dilts, T. E., Oliver, J. C., et al. (2021). Fewer butterflies seen by community scientists across the warming and drying landscapes of the American West. *Science* 371 (6533), 1042–1045. doi:10.1126/science.abe5585

Fraisl, D., Campbell, J., See, L., Wehn, U., Wardlaw, J., Gold, M., et al. (2020). Mapping citizen science contributions to the UN sustainable development goals. *Sustain. Sci.* 15 (6), 1735–1751. doi:10.1007/s11625-020-00833-7

Fredrickson, B. L. (2004). The broaden–and–build theory of positive emotions. *Philosophical Trans. R. Soc. Lond. Ser. B Biol. Sci.* 359 (1449), 1367–1377. doi:10.1098/rstb.2004.1512

Fredrickson, B. L., and Joiner, T. (2018). Reflections on positive emotions and upward spirals. *Perspect. Psychol. Sci.* 13 (2), 194–199. doi:10.1177/1745691617692106

Fritz, S., See, L., Carlson, T., Haklay, M. (M.), Oliver, J. L., Fraisl, D., et al. (2019). Citizen science and the united nations sustainable development goals. *Nat. Sustain.* 2 (10), 922–930. doi:10.1038/s41893-019-0390-3

Ganzevoort, W., and Van Den Born, R. J. G. (2021). Counting bees: learning outcomes from participation in the Dutch national bee survey. *Sustainability* 13 (9), 4703. doi:10.3390/su13094703

Groom, Q., Pernat, N., Adriaens, T., De Groot, M., Jelaska, S. D., Marčiulynienė, D., et al. (2021). Species interactions: next-level citizen science. *Ecography* 44 (12), 1781–1789. doi:10.1111/ecog.05790

Hunter, R. F., Clelanda, C., Cleary, A., Droomers, M., Wheeler, B. W., Sinnette, D., et al. (2019). Environmental, health, wellbeing, social and equity effects of urban green space interventions: a meta-narrative evidence synthesis. *Environ. Int.* 130, 104923. doi:10.1016/j.envint.2019.104923

Jimenez, M. P., DeVille, N. V., Elliott, E. G., Schiff, J. E., Wilt, G. E., Hart, J. E., et al. (2021). Associations between nature exposure and health: a review of the evidence. *Int. J. Environ. Res. Public Health* 18 (9), 4790. Article 9. doi:10.3390/ijerph18094790

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., and Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs. *Conserv. Biol.* 25 (6), 1148–1154. doi:10.1111/j.1523-1739.2011.01745.x

Kelemen-Finan, J., Scheuch, M., and Winter, S. (2018). Contributions from citizen science to science education: an examination of a biodiversity citizen science project with schools in Central Europe. *Int. J. Sci. Educ.* 40, 2078–2098. doi:10.1080/09500693.2018.1520405

Kessler, R. C., and Bromet, E. J. (2013). The epidemiology of depression across cultures. *Annu. Rev. Public Health* 34 (1), 119–138. doi:10.1146/annurev-publhealth-031912-114409

Kullenberg, C., and Kasperowski, D. (2016). What is citizen science? – a scientometric meta-analysis. *PLOS ONE* 11 (1), e0147152. doi:10.1371/journal.pone.0147152

La Sorte, F. A., and Somveille, M. (2020). Survey completeness of a global citizen-science database of bird occurrence. *Ecography* 43 (1), 34–43. doi:10.1111/ecog.04632

Lovibond, P. F., and Lovibond, S. H. (1995). The structure of negative emotional states: comparison of the depression anxiety stress scales (DASS) with the beck depression and anxiety inventories. *Behav. Res. Ther.* 33 (3), 335–343. doi:10.1016/0005-7967(94)00075-U

Lynch, L., Dauer, J., Babchuk, W., Heng-Moss, T., and Golick, D. (2018). In their own words: the significance of participant perceptions in assessing entomology citizen science learning outcomes using a mixed methods approach. *Insects* 9 (1), 16. doi:10.3390/insects9010016

Maller, C., Townsend, M., Pryor, A., Brown, P., and St Leger, L. (2006). Healthy nature healthy people: 'Contact with nature' as an upstream health promotion intervention for populations. *Health Promot. Int.* 21 (1), 45–54. doi:10.1093/heapro/dai032

Matthews, G., Jones, D. M., and Chamberlain, A. G. (1990). Refining the measurement of mood: the UWIST mood adjective checklist. *Br. J. Psychol.* 81 (1), 17–42. doi:10.1111/j.2044-8295.1990.tb02343.x

Mayer, F. S., and Frantz, C. M. (2004). The connectedness to nature scale: a measure of individuals' feeling in community with nature. *J. Environ. Psychol.* 24 (4), 503–515. doi:10.1016/j.jenvp.2004.10.001

Natural England (2024). Joining up nature recovery and health priorities. Available at: https://naturalengland.blog.gov.uk/2024/03/01/joining-up-nature-recovery-and-health-priorities/.

Nisbet, E. K., Zelenski, J. M., and Murphy, S. A. (2009). The nature relatedness scale: linking individuals' connection with nature to environmental concern and behavior. *Environ. Behav.* 41 (5), 715–740. doi:10.1177/0013916508318748

Oh, R. R. Y., Fielding, K. S., Chang, C.-C., Nghiem, L. T. P., Tan, C. L. Y., Quazi, S. A., et al. (2021a). Health and wellbeing benefits from nature experiences in tropical settings depend on strength of connection to nature. *Int. J. Environ. Res. Public Health* 18 (19), 10149. doi:10.3390/ijerph181910149

Oh, R. R. Y., Fuller, R. A., Peters, B., Dean, A. J., Pachana, N. A., Callaghan, C. T., et al. (2024). Enhancing the health and wellbeing benefits of biodiversity citizen science. *Front. Environ. Sci.* 12, 1444161. doi:10.3389/fenvs.2024.1444161

Oh, R. Y. R., Fielding, K. S., Nghiem, T. P. L., Chang, C., Shanahan, D. F., Gaston, K. J., et al. (2021b). Factors influencing nature interactions vary between cities and types of nature interactions. *People Nat.* 3 (2), 405–417. doi:10.1002/pan3.10181

Peter, M., Diekötter, T., Höffler, T., and Kremer, K. (2021). Biodiversity citizen science: outcomes for the participating citizens. *People Nat.* 3 (2), 294–311. doi:10.1002/pan3.10193

Pocock, M. J. O., Hamlin, I., Christelow, J., Passmore, H., and Richardson, M. (2023). The benefits of citizen science and nature-noticing activities for well-being, nature connectedness and pro-nature conservation behaviours. *People Nat.* 5 (2), 591–606. doi:10.1002/pan3.10432

Raman, T. L., Abdul Aziz, N. A., and Yaakob, S. S. N. (2021). The effects of different natural environment influences on health and psychological well-being of people: a case study in selangor. *Sustainability* 13 (15), 8597. doi:10.3390/su13158597

Sarris, J., Thomson, R., Hargraves, F., Eaton, M., De Manincor, M., Veronese, N., et al. (2020). Multiple lifestyle factors and depressed mood: a cross-sectional and longitudinal analysis of the UK Biobank (N = 84,860). *BMC Med.* 18 (1), 354. doi:10.1186/s12916-020-01813-5

Schuttler, S. G., Sorensen, A. E., Jordan, R. C., Cooper, C., and Shwartz, A. (2018). Bridging the nature gap: can citizen science reverse the extinction of experience? *Front. Ecol. Environ.* 16 (7), 405–411. doi:10.1002/fee.1826

Shanahan, D., Astell–Burt, T., Barber, E., Brymer, E., Cox, D., Dean, J., et al. (2019). Nature–based interventions for improving health and wellbeing: the purpose, the people and the outcomes. *Sports* 7 (6), 141. doi:10.3390/sports7060141

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E., et al. (2016). Health benefits from nature experiences depend on dose. *Sci. Rep.* 6 (1), 28551. doi:10.1038/srep28551

Shorey, S., Ng, E. D., and Wong, C. H. J. (2022). Global prevalence of depression and elevated depressive symptoms among adolescents: a systematic review and meta-analysis. *Br. J. Clin. Psychol.* 61 (2), 287–305. doi:10.1111/bjc.12333

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., et al. (2021). A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ* n2061, n2061. doi:10.1136/bmj.n2061

Souter-Brown, G., Hinckson, E., and Duncan, S. (2021). Effects of a sensory garden on workplace wellbeing: a randomised control trial. *Landsc. Urban Plan.* 207, 103997. doi:10.1016/j.landurbplan.2020.103997

Southwick, S. M., Bonanno, G. A., Masten, A. S., Panter-Brick, C., and Yehuda, R. (2014). Resilience definitions, theory, and challenges: interdisciplinary perspectives. *Eur. J. Psychotraumatology* 5 (1), 25338. doi:10.3402/ejpt.v5.25338

Van Den Bosch, M., and Ode Sang, Å. (2017). Urban natural environments as nature-based solutions for improved public health – a systematic review of reviews. *Environ. Res.* 158, 373–384. doi:10.1016/j.envres.2017.05.040

Von Gönner, J., Masson, T., Köhler, S., Fritsche, I., and Bonn, A. (2024). Citizen science promotes knowledge, skills and collective action to monitor and protect freshwater streams. *People Nat.* 6 (6), 2357–2373. doi:10.1002/pan3.10714

Warburton, D. E. R., Nicol, C. W., and Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *CMAJ* 174 (6), 801–809. doi:10.1503/cmaj.051351

Watson, D., Clark, L. A., and Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *J. Personality Soc. Psychol.* 54 (6), 1063–1070. doi:10.1037/0022-3514.54.6.1063

Whitburn, J., Abrahamse, W., and Linklater, W. (2023). Do environmental education fieldtrips strengthen children's connection to nature and promote environmental behaviour or wellbeing? *Curr. Res. Ecol. Soc. Psychol.* 5, 100163. doi:10.1016/j.cresp.2023.100163

Whitburn, J., Linklater, W., and Abrahamse, W. (2020). Meta-analysis of human connection to nature and proenvironmental behavior. *Conserv. Biol.* 34 (1), 180–193. doi:10.1111/cobi.13381

White, M. P., Alcock, I., Grellier, J., Wheeler, B. W., Hartig, T., Warber, S. L., et al. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. *Sci. Rep.* 9 (1), 7730. doi:10.1038/s41598-019-44097-3

White, M. E., Hamlin, I., Butler, C. W., and Richardson, M. (2023). The Joy of birds: the effect of rating for joy or counting garden bird species on wellbeing, anxiety, and nature connection. *Urban Ecosyst.* 26 (3), 755–765. doi:10.1007/s11252-023-01334-y

White, M. P., Hartig, T., Martin, L., Pahl, S., Van Den Berg, A. E., Wells, N. M., et al. (2023). Nature-based biopsychosocial resilience: an integrative theoretical framework for research on nature and health. *Environ. Int.* 181, 108234. doi:10.1016/j.envint.2023.108234

Zsido, A. N., Coelho, C. M., and Polák, J. (2022). Nature relatedness: a protective factor for snake and spider fears and phobias. *People Nat.* 4 (3), 669–682. doi:10.1002/pan3.10303