Journal of Environmental Psychology 85 (2023) 101921

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

BIO-WELL: The development and validation of a human wellbeing scale that measures responses to biodiversity

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ARTICLE INFO

Handling Editor: L. McCunn

Keywords:
Green space
Nature
Sensory
Human health/wellbeing
Psychometric
Green prescribing

ABSTRACT

The evidence linking nature and human wellbeing is compelling. Yet, there is a lack of understanding regarding which aspects of nature contribute to wellbeing and the role biodiversity plays specifically. This knowledge gap hampers our ability to understand and manage natural environments from an ecological perspective to improve human wellbeing. To investigate the impact of biodiversity on wellbeing in a range of contexts, there is a need for a psychometric scale. Here, we present BIO-WELL, a novel, reliable and validated self-reported wellbeing scale designed to investigate the biodiversity-health/wellbeing relationship. We describe the conceptual foundation, empirical development and psychometric evaluation of BIO-WELL. We detail five studies, involving 2962 participants, describing the steps taken in the scale's development: (1) a series of deliberative workshops to identify how people conceptualise biodiversity metrics and attributes, and the impact these have on wellbeing; (2) an in-depth qualitative analysis of biodiversity-focused stem questions and wellbeing response items, assessed through an expert panel, focus groups and cognitive interviewing techniques; (3) combined methods associated with classical test theory (e.g. factor analysis) and more modern measurement approaches drawn from item response theory to develop the scale; (4) a confirmatory factor analysis alongside classical test and item response theories to evaluate the scale; and (5) scale validation including discriminant/convergent, concurrent and predictive. The studies demonstrate that BIO-WELL is a valid and reliable scale with strong psychometric properties. We discuss ways it could be applied in research, policy and practice to further develop our conceptual and empirical understanding of the biodiversity-health relationship and assess the effectiveness of related interventions.

1. Introduction

Across research, policy and practice it is widely accepted that contact with nature can be beneficial to people, promoting physical and mental health, as well as general wellbeing (Bratman et al., 2019; Donovan et al., 2018; Lovell et al., 2018; Marselle et al., 2019; Martin et al., 2020; Shanahan et al., 2016). These benefits have garnered significant interest among health sectors and providers in light of the rising prevalence of, and associated costs of treating, poor mental health and other non-communicable diseases (e.g. cardiovascular disease, diabetes) (World Health Organization, 2014; Foreman et al., 2018). In the UK, for instance, the government's Department of Health cites 'use of nature' as a determinant of public health and estimates that bolstering this could save the National Health Service ~£2 billion per year (DEFRA, 2011; UK Department of Health, 2016). In practical terms, this interest has led to a raft of 'social' or 'green' prescribing initiatives and programmes (Husk et al., 2019; Van den Berg, 2017) that seek to enable and use nature-based activities, such as outdoor walking groups (Irvine et al., 2020, 2022; Marselle et al., 2016), as non-medical interventions (Shanahan et al., 2019) to manage long-term conditions, promote life-long health and wellbeing, and reduce demand on the health and social care system.

While the evidence-base informing the environmental contribution to human health and wellbeing grows, there is still no clear understanding of what constitutes a health-promoting environment for people from an ecological perspective. Within the corpus of nature-health

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https://doi.org/10.1016/j.jenvp.2022.101921
Received 30 March 2022; Received in revised form 28 November 2022; Accepted 29 November 2022
Available online 7 December 2022

scholarship, the natural environment is often still treated as monolithic and uniform (Dallimer et al., 2012). Understanding which aspects of nature contribute to health/wellbeing, and the role of biodiversity specifically in this relationship, remain open questions in the drive to create initiatives that are tailored to maximise health/wellbeing benefits. These questions take on wider critical salience given the scale of biodiversity loss worldwide (IPBES, 2019).

It is against this backdrop that we have developed BIO-WELL – a psychometric scale – that can be used to empirically measure the human health/wellbeing effect from interactions with biodiversity. We describe the conceptual foundation, empirical development and psychometric evaluation of the scale, comprising stem questions about biodiversity and response items focusing on health/wellbeing, achieved over five studies. We argue that BIO-WELL offers a comprehensive yet parsimonious, valid and reliable measure of multiple dimensions of wellbeing to facilitate further development of our conceptual and empirical understanding of the biodiversity-health relationship.

1.1. *Concept overview and measurement challenges*

Numerous studies have examined the effect of nature on health/wellbeing outcomes, informed by various theories (e.g. Attention Restoration Theory [ART]; Kaplan & Kaplan, 1989; Stress Reduction Theory [SRT]; Ulrich, 1983; Ulrich et al., 1991) and conceptual frameworks (e.g. Hartig et al., 2014; Markevych et al., 2017). The development of BIO-WELL, while grounded in this extensive nature-health theoretical/conceptual research, is specifically informed by the growing body of empirical (e.g. Carrus et al., 2015; Fisher et al., 2021; Fuller et al., 2007) and conceptual (Marselle et al., 2021; Pett et al., 2016) work on biodiversity-health/wellbeing. It is therefore an interdisciplinary endeavour, informed by environmental psychology amongst other disciplines that explicitly consider biodiversity.

Broadly, BIO-WELL's focus is on one's self-reported wellbeing associated with interactions with biodiversity. Here we consider that interactions with biodiversity can be intentional (e.g. going to a park to feed birds, drawing trees *in-situ* within a woodland), incidental (e.g. running across a beach and suddenly realising you have been hearing birds calling, kicking up dead leaves as you walk although you are not aware of what you are doing at the time) or indirect (e.g. looking at images of butterflies in a book, watching a television documentary on brown bears, looking through a window to view a fox in the garden) (Keniger et al., 2013). Furthermore, people also have the capacity to draw on mental images of the natural world without being in, or looking at, biodiversity (e.g. being indoors during the winter thinking about the blue carpet that will emerge across a woodland floor when the bluebells flower in spring). This imagining and visualisation is termed 'thereness' (Kaplan, 1978, 1980; Kaplan & Kaplan, 1989), emphasising that knowing that nature is available and accessible is important for self-reported wellbeing independent of actual use (Kaplan, 1991). BIO-WELL's approach is in this regard akin to other self-reported environment-wellbeing scales, such as the Restorative Outcome Scale (ROS) (Korpela et al., 2008). Korpela et al. (2008) have used the ROS approach to examine self-reported restorative experience from favourite urban and green places; Takayama et al. (2014) have utilised the ROS to examine the effect of forests and urban environments. We bring this approach to the development of a scale that facilitates understanding the person-environment interaction in relation to biodiversity.

In the following sections we elaborate the two elements of the self-report BIO-WELL scale – biodiversity and health/wellbeing – by critically engaging with the conceptual framing for, and empirical assessment of, these concepts within the context of the existing biodiversity-health/wellbeing literature.

1.1.1. *Biodiversity*

Biodiversity is a complex and multi-faceted concept. We use the formal, scientific definition as employed by the biological sciences, and which forms the basis of existing frameworks on biodiversity-health/wellbeing relationships (Marselle et al., 2021; Pett et al., 2016). Biodiversity is thus defined as the "variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (United Nations, 1992). This definition explicitly accounts for the living components of an environment, encompassing the details and qualities of those living organisms and ecosystems, moving beyond the widely used generic concepts of nature, green space and blue space in the nature-health literature.

Our focus for BIO-WELL is therefore to develop a set of stem questions that will allow us to investigate how wellbeing is influenced by interaction with: (i) ecological qualities of the environment at the species/community level (e.g. abundance, species diversity), (ii) ecological processes (e.g. intra- and inter-species interactions, decomposition, photosynthesis), and (iii) specific attributes associated with these living components of nature (e.g. colour, shape). This approach reflects conceptual framing within existing biodiversity-health/wellbeing frameworks (Marselle et al., 2021; Pett et al., 2016). The first two – species/community composition and ecological processes – we include for their alignment with metrics that might be used by an ecologist to objectively measure the actual biodiversity present in an environment. Such biodiversity metrics include: abundance (number of individuals within a single species or across multiple species), species diversity (the variety of species present), encounters one might have with species, species interactions (time or frequency of action patterns between species, such as predation, competition or parasitism), and quantification of ecological processes that occur within an ecosystem. Abundance and species diversity are the most common ecological metrics used within existing nature-health research to evaluate biodiversity, assessed both objectively (through technical field-based ecological surveys) and subjectively (through participants' self-report assessments of the perceived number or variety of species) (e.g. Dallimer et al., 2012; White et al., 2017). Incorporating encounters, species interactions and ecological processes, in addition to abundance and species diversity, heeds calls for a "suite of more resolved [ecologically-focused] metrics" (Pett et al., 2016, p. 3) to help unpack the biodiversity-health/wellbeing relationship.

Within a given environment people might also be responding to various attributes of biodiversity (Pett et al., 2016). These attribute types include: (i) morphologies or shapes (e.g. body size, flower structure); (ii) colours (e.g. red plumage, blue flowers, brown leaves); (iii) sounds (e.g. insects buzzing, wind blowing through leaves on trees, screeching owls); (iv) smells (e.g. rotting vegetation, pine sap, mammal faeces, wild garlic); (v) textures (e.g. thorny plants, smooth tree bark, fluffy fur); and/or (vi) behaviours (e.g. biting, mating, predation, wilting leaves). It is unlikely that all sensory experiences of biodiversity will underpin wellbeing equally or in the same way (Franco et al., 2017; Bratman et al., 2019). For example, colourful planting regimes have been shown to enhance enjoyment of an environment (Hoyle et al., 2018) and birdsong can induce calm in people (Hedblom et al., 2017), while the slimy or mucous appearance of some fungi can provoke negative emotions such as disgust (Yamin-Pasternak, 2011). Similarly, bites resulting from the behaviour of mosquitos or allergies from the release of pollen from flowering plants can generate negative effects on human physical health (Rendón et al., 2019). BIO-WELL specifically includes stem questions that will allow us to investigate how interaction with these different attribute types influence health/wellbeing, both positively and negatively.

Within nature- and biodiversity-health frameworks, and indeed more broadly within environmental psychology, there is a useful distinction made between the objective environment and one's contact or interaction with it (Hartig et al., 2014; Markevych et al., 2017; Marselle et al., 2021; Pett et al., 2016), and the importance of understanding this person-environment interaction relationship. The literature on the health/wellbeing effects from biodiversity is mixed as to whether it is actual or perceived that contributes (e.g. Dallimer et al., 2012). Our approach to operationalising biodiversity within the self-report BIO-WELL scale thus aims to facilitate an investigation of wellbeing associated with interactions with various aspects of biodiversity. The resultant scale could then be combined with measurements of actual biodiversity or an individual's perceptions of biodiversity to assess how wellbeing might be related with these.

1.1.2. Wellbeing

Our conceptualisation of health/wellbeing outcomes from biodiversity builds on the World Health Organization's (World Health Organization, 1948) definition of health as: "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (p. 100). This framing emphasises not only the multi-dimensionality of the concept, which is reflected in the biopsychosocial model increasingly used in health/wellbeing sectors (Engel, 1977; Fava & Sonino, 2008), but also the positive and negative, as well as the subjective components of health. These points have been noted as relevant to health/wellbeing in the context of nature/biodiversity (Hartig et al., 2014; Markevych et al., 2017; Marselle et al., 2021; Pett et al., 2016). This conceptual framing is supported by empirical evidence demonstrating that biodiversity can influence physical (e.g. Aerts et al., 2018) and mental (e.g. Fisher et al., 2021) health/wellbeing. Few studies have specifically examined the effect of biodiversity on the social domain, conceptualised as social interaction and social cohesion (Marselle et al., 2016), with mixed results (e.g. Shanahan et al., 2016).

Definitions of mental wellbeing emphasize both an emotional (affective) and cognitive domain (e.g. Linton et al., 2016). This aligns with core theories in environmental psychology about the emotional and cognitive restoration benefits from nature (SRT; Ulrich, 1983; ART; Kaplan & Kaplan, 1989). Myriad research on the emotional and cognitive effects of nature contact exists (e.g. Wolf et al., 2017) with evidence emerging of such effects from contact with biodiversity (see e.g. Marselle et al., 2019 for review).

An additional proposed extension to the conceptualisation of health/wellbeing benefits from biodiversity is to include a spiritual domain (Chuengsatiansup, 2003). A synthesis of nature-based recreation literature (Heintzman, 2016), an empirical study of gardening (Bell-Williams et al., 2021) and one of recreational urban park use (Irvine et al., 2013) identified spiritual health/wellbeing as an outcome of such activities. The domain has also been included in an expanded biopsychosocial-spiritual model of health (McKee & Chappel, 1992), reflecting emerging emphasis on thinking holistically about health/wellbeing (Linton et al., 2016). In an early review of nature-health research, the identified benefits of nature contact were mapped onto this biopsychosocial-spiritual conceptualisation, specifying evidence to support such a holistic framing (Irvine & Warber, 2002). This approach resonates with Pett et al.'s (2016) framework for considering the interaction between people and biodiversity and previous calls for a holistic framing of health/wellbeing outcomes (Irvine et al., 2013). For BIO-WELL, we therefore argue that a conceptualisation of wellbeing from biodiversity should include five domains: physical (bio), emotional (psycho), cognitive (psycho), social and spiritual (Box 1).

To date, self-reported health/wellbeing assessments within a nature context have predominantly been achieved by applying scales developed in the health sector (e.g. Harvey et al., 2020; Lovell et al., 2018; Marselle et al., 2016; Maund et al., 2019; Wood et al., 2017). Although widely applied, the health/wellbeing assessments currently available have several limitations. Most scales in nature-health research focus on a single wellbeing domain. For example, the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), Profile of Mood States (POMS; Curran et al., 1995) and Generalized Anxiety Disorder 7 (GAD-7; Spitzer et al., 2006) focus on emotional wellbeing. While a few scales do incorporate multiple wellbeing domains, these can have a large number of response items (e.g. 317 items for Self-evaluated Quality of Life; Ventegodt et al., 2003), placing an undue burden on participants and reducing usability. Additionally, multi-domain scales have often been developed within the health sector for specific conditions or for health-promoting interventions (e.g. Ritenbaugh et al., 2011; Thompson et al., 2011; see Linton et al., 2016 for review), and can contain response items that are neither relevant to the population as a whole (e.g. requirement for medication, feeling defined by one's disease) nor likely to be directly applicable to interactions with biodiversity. Where scales have been developed specifically for nature-health research, they frequently consist of single wellbeing response items rather than a validated scale (e.g. Corley et al., 2021). Single items are difficult to validate from a psychometric perspective and open to significantly greater levels of bias, which can impact the reliability of results (Diamantopoulos et al., 2012).

1.2. Study aim

Our aim was to develop a psychometrically valid and reliable wellbeing scale that can be used in studies considering the wellbeing effects from biodiversity. Given the increasing interest in this relationship across multiple sectors, we determined that the scale should provide a measure of an individual's self-reported wellbeing across multiple domains, both positive and negative from interaction with various aspects of biodiversity. We envisioned a scale that could be aligned with objective measures of actual biodiversity or subjective assessments of perceived biodiversity, and that could be adapted for use in different environments.

1.3. General methods

We undertook three phases of scale development (Boateng et al., 2018) – item identification, scale development and scale evaluation – across five studies, following best practice that underpins the construction of self-report scales (Boateng et al., 2018; Clark & Watson, 1995; DeVellis, 2003; Morgado et al., 2018; Nunnally, 1967, 1978; Simms, 2008). Our approach combined participatory deliberative processes to generate items, as well as methods associated with classical test

Box 1
Proposed domains of human health/wellbeing for BIO-WELL[21]

Physical wellbeing: related to the functioning of the physical body and how one feels physically, including recovery from stress..

Emotional wellbeing: the experience of positive and negative emotions and mood.

Cognitive wellbeing: an individual's thoughts about their life and cognitive capacity to direct attention.

Social wellbeing: how an individual perceives their connections with others.

Spiritual wellbeing: concerned with meaning and connection to something greater than oneself.

theory (e.g. factor analysis) and more modern measurement approaches drawn from item response theory to facilitate scale development, and tests of scale dimensionality, reliability and validation.

To identify and confirm relevance of biodiversity and wellbeing domains as outlined in the earlier conceptual framing (Section 1.1), we used deliberative workshops incorporating both *in situ* and *ex situ* facilitated activities and discussion, conducted with the target population (British adults, aged 18 years old or older). Workshop outputs provided a rich and deep understanding of how people conceptualise biodiversity metrics and attributes, and how biodiversity affected their wellbeing. The initial set of biodiversity stem questions and wellbeing response items for inclusion in the scale, developed from the workshop material and a review of existing scales, were assessed for content validity and clarity through several steps. An interdisciplinary expert panel examined the extent to which these were relevant to, and representative of, the biodiversity metric/attribute or wellbeing domain of interest. The resulting set was then reviewed through focus groups with the target population for further refinement, evaluating both the stem questions and the wellbeing response items for interpretation in relation to biodiversity and the applicability of stem questions to a variety of different environment types. We then created a draft scale from the reduced set of stem questions and wellbeing response items and used cognitive interviewing techniques to facilitate further refinement of the scale and format. This resulted in an initial scale with 17 biodiversity stem questions and eight wellbeing response items.

We administered this initial scale to a large sample of the target population for reduction and extraction of factors. We combined methodological techniques associated with classical test theory and item response theory to analyse the psychometric quality of the wellbeing response items to reduce them to one per wellbeing domain. The same analyses were conducted for each individual biodiversity stem question. The complementarity of classical test theory and item response theory for scale development has been argued elsewhere (e.g. Riemer & Kearns, 2010). Broadly, classical test theory provides information on individual items, while item response theory examines how well individual items measure underlying latent traits, thereby increasing the reliability of information and validity of the scale as a whole (DeVellis, 2003). Classical test theory underpinned how we examined the relationship among wellbeing items, reliability and dimensionality. The performance and fit of the individual items were informed by item response theory. A refined scale with five wellbeing response items was then administered to another sample of participants to confirm dimensionality, item performance and fit, and reliability. These analyses were conducted for each individual stem question. Following identification of this parsimonious set of five wellbeing items with 17 biodiversity stem questions, we undertook further scale evaluation with a separate sample. We combined BIO-WELL with several existing scale to examine discriminant and convergent validity, examined concurrent validity through inclusion of questions to differentiate between participant sub-groups hypothesised to differ on the wellbeing effect from interactions with biodiversity (e.g. differing levels of use of nature), and the ability to predict BIO-WELL scores on outcomes of interest (i.e. predictive validity).

As biodiversity can influence wellbeing both positively and negatively, we decided to use a Visual Analogue Scale (VAS) response format, which can facilitate measurement along an entire continuum (Hayes & Patterson, 1921). VAS formats have been used extensively, from measuring the intensity or frequency of symptoms (e.g. pain, anxiety) through to overall health (EuroQol Group, 1990). The Gothenburg Well-Being scale for children (Erling et al., 2002) and adolescents (Hitz et al., 2018) use VAS scales to measure the continuum between negative and positive aspects of wellbeing (e.g. "Tense/Relaxed", "Sad/Happy"). The placement of the negative valence anchor can be either on the left (e.g. Hitz et al., 2018) or right (e.g. Datema et al., 2008) side of the continuous line. VAS formats are considered easy to understand, quick to complete (e.g. Gracely, 1990), robust when administered online (Delgado et al., 2018) and produce continuous data, thereby increasing the sensitivity of the scale and addressing the limitations of ordinal scale (e.g. Likert) responses (Bishop & Herron, 2015; Reips & Funke, 2008). In the VAS format developed for BIO-WELL, responses are indicated along a continuous line, labelled at each end with a descriptive anchor representing linguistic opposites. Participants are asked to place a mark at the point on the scale that corresponds to their wellbeing in relation to the pair of anchors; they can express that there is no impact on their wellbeing by leaving their mark equidistant between the anchors.

The same social research company (Qa Research) recruited participants for all five studies; participants were compensated financially for their time and travel on completion of the workshop. Ethical approval was gained from the University of Kent's School of Anthropology and Conservation Research Ethics Committee (Ref: 009-ST-19); participants provided informed written consent.

2. Study 1

Here we investigated how people conceptualise biodiversity and what aspects of wellbeing might be influenced by it. We focused on identifying the scope of relevant biodiversity metrics and attributes, plus the applicability of different wellbeing domains.

2.1. Method

2.1.1. Participants

Participants were recruited via a social research company, being purposively oversampled to obtain a diversity of backgrounds and perspectives (rather than a representative sample; Fischer et al., 2018). Our sample quotas were: a balance of gender across people who identify as male or female; age balance across three brackets (18–29 years; 30–59 years; 60+ years old); a mix of White British and other ethnicities (>20%); a mix of individuals from different socioeconomic groups (ABC1 - higher income; C2DE - lower income based on employment of chief income earner); a diversity of people resident in different government regions of England, plus individuals from Wales and Scotland; and a mix of urban and rural (>20%) dwellers. A total of 194 individuals (Table S1) attended one of four workshops.

2.1.2. Study system

Woodlands were used as a study system to develop the scale content. Representing 13% of landcover (Forest Research, 2020), they occur across Britain in both rural and urban areas, and are the most visited environments in Britain behind urban parks and paths, cycleways and bridleways (Natural England, 2019a). Woodlands, from young thicket copses to old growth woodlands with mature trees, present a wide range of ecological conditions and support different complementary aspects of biodiversity (Reid et al., 2021). Due to this widespread availability to residents across the urban-rural spectrum and their biodiversity value, woodlands are an ideal study system.

2.1.3. Procedure

The four deliberative workshops in 2019 were timed to align with each season (winter, February; spring, April; summer, June; autumn, October). Each workshop followed the same process design, consisting of a range of *in situ* (within woodland) and *ex situ* (indoor) activities. These included an *in situ* 'woodland scavenger hunt' where participants were invited to write down and photograph elements of woodland biodiversity they noticed, and *ex situ* image elicitation exercises using image-based Q methodology (see Austen et al., 2021). Most activities involved facilitated *ex situ* discussions to prompt further insight about participant experiences of woodland biodiversity across all senses (e.g. visual, olfactory). While the public are now more aware of nature's

[2] Definitions drawn from: Ulrich, 1983; Kaplan & Kaplan, 1989; Ulrich et al., 1991; Irvine et al., 2013; Linton et al., 2016.

contribution to human wellbeing (e.g. Natural England, 2019b), the research team took care not to indicate that we were interested in wellbeing during the workshop activities.

2.1.4. Data analysis

The activities and discussions were audio recorded, transcribed verbatim by an external transcription service, and anonymised. Transcripts were imported to, and coded within, NVivo (Version 12, QSR International Pty Ltd, 2018). We carried out a thematic analysis (Braun & Clarke, 2006) to identify the biodiversity metrics (e.g. abundance, species diversity) and attributes (e.g. smell, texture, shape) of woodlands that participants associated with wellbeing, based on the five wellbeing domains that make up the biopsychosocial-spiritual model of health (section 1.1.2). We additionally examined whether the experiences of wellbeing mentioned were described as positive or negative.

2.2. Results

Wellbeing outcomes fell within physical, emotional, cognitive, social and spiritual domains. We therefore considered it appropriate to develop a scale measuring the effect of biodiversity on human wellbeing representing these five domains. Across all four seasons, spiritual wellbeing was particularly prominent in the discussions, followed closely by emotional wellbeing. Both positive and negative wellbeing outcomes were associated with biodiversity. The experience of positive wellbeing was captured in sentiments such as:

> I sat down for a couple of minutes and I shut my eyes to listen to what was about […] although you've got all the sounds of all the birds, and I could hear the bees but never seen them, [it is …] just so nice and peaceful, even though you've got all these things.

While negative wellbeing from woodland biodiversity occurred across all domains, it was commonly mentioned in relation to emotional wellbeing. For instance, one participant described their negative emotions associated with the colours and texture of lichen:

> … some of the colours I picked that I didn't like was [*sic*] the … pale sickly green of the lichen on the trees. There was [*sic*] some trees that were just completely covered in like this thin film of lichen'y, like sickly, creepy, like they'd almost glow in the dark … So that just unsettled me a little bit.

There was limited discussion of social wellbeing in relation to biodiversity. Although this result may suggest that social wellbeing is not heavily influenced by biodiversity, it is possible that our study design did not lend itself to this domain. For example, some of the activities (e.g. scavenger hunt) were completed individually by participants, meaning that possibilities for social interactions and building connections, which can facilitate social wellbeing, may have been considered less frequently. We chose to retain social wellbeing as a domain because it could be pertinent in other contexts where BIO-WELL could be applied, such as the evaluation of green prescriptions or other interventions utilising the natural environment to improve health and wellbeing (e.g. group outdoor health walks).

Although humans are highly visual species (Kass & Balaram, 2014), participants readily offered rich descriptions of their experiences of woodland biodiversity across multiple senses during discussions. For example, participants spoke of the visual appearance of texture (e.g. rough tree bark), in addition to how things felt when touched (e.g. slimy coating). Wellbeing responses related to biodiversity attributes included colours, smells, textures, sounds, shapes and behaviour, with behaviour being mentioned a great deal. One participant attributed her sense of positive wellbeing to the behaviour (growth) of plants: "There will be little shoots growing here and there next to these like old dead trees and whatever. So it's kind of a continuation of everything isn't it? And that made you feel quite hopeful". Another noted the negative effect of colour: "some of the birch trees … had really red bits on the trunk … orangey red. It actually made me a bit sad because I thought that was a disease".

References to biodiversity metrics, such as abundance or species diversity, were limited. For example, one participant noted, "I think it's good to have a variety of things to look at. Not everybody wants to look just at trees." The influence of pollen production on physical wellbeing was described as "I had all swelling around my eyes. So I just instantly think of bad memories with that". Another participant mentioned the positive effect of interactions between living things on their emotional wellbeing:

> There is a park near us that has a lot of deer […] it's just going into rutting season … so there is a lot of activity going on. So that makes autumnal walks quite nice and pleasant and just seeing activity, seeing their movements, them interacting with each other and things is really cool.

These findings lend support to our argument that we must go beyond just biodiversity metrics and include biodiversity attributes to understand biodiversity-wellbeing relationships. They additionally emphasize the positive, negative and neutral wellbeing associated with interactions with biodiversity.

3. Study 2

The aim of this study was to generate, evaluate for content validity and pre-test a set of biodiversity-related stem questions and wellbeing response items for use in a preliminary BIO-WELL scale.

3.1. Method

3.1.1. Content analysis and scale review

An initial list of stem questions was generated through a content analysis of the aspects of biodiversity highlighted by Study 1 workshop participants. Informed by a review of existing scales, stem questions were phrased to suit the VAS response format and encompassed biodiversity metrics (e.g. "The abundance of living things in this woodland makes me feel …") and specific biodiversity attributes (e.g. "The woody smells make me feel …"). We additionally generated an initial pool of linguistically opposite positive and negative descriptive anchors for the wellbeing response items for use in the VAS. Response items were developed to represent the physical, emotional, cognitive, social and spiritual wellbeing domains. Wording was primarily drawn from the language used by Study 1 participants (e.g. "Relaxed/Tense"; "Satisfied/Dissatisfied"), as well as from existing scales where pairs of positive and negative anchors were not clearly identified from the participants.

3.1.2. Expert review

An expert review was conducted to assess linguistic clarity and content validity of the biodiversity stem questions and wellbeing response items (Hardesty & Bearden, 2004). The review was undertaken individually and then as a group by a subset of the authors (KNI, PRB, GEA, MD, RF, ZGD) representing expertise from the disciplines of human geography, environmental psychology and ecology. Assessment criteria for linguistic clarity included whether the wording was clear, interpretable and unambiguous. Criteria for content validity considered the extent to which a stem question or response item was relevant to, and representative of, the biodiversity metric/attribute or wellbeing domain it was presumed to measure. Stem questions and response items were only retained if the panel unanimously agreed on their inclusion. The resulting reduced set was then subjected to evaluation by the target population through focus groups and cognitive interviews.

3.1.3. Focus groups (Study 2a)

Focus groups provided a further opportunity to examine content validity (Haynes et al., 1995) and refine the stem questions and response items for clarity. Nine, hour-long, online focus groups were conducted, with seven individuals invited to each session. In total, 59 individuals participated (Table S1), recruited by the social research company and adhering to the participant characteristics detailed in Study 1.

The first two focus groups reviewed the reduced set of wellbeing response items. Participants were prompted to discuss their interpretation of the items, particularly in relation to biodiversity, and identify any items they would remove, providing reasons why. The next six focus groups assessed the reduced set of biodiversity stem questions, following an iterative process where wording was refined between each focus group. This process was crucial for the biodiversity metric stem questions, ensuring that the metrics captured by each stem question were interpreted correctly by non-ecologists. The stem questions were also evaluated in relation to each of the wellbeing response items to eliminate ambiguity and redundancy. Applicability of the biodiversity stem questions to environments other than woodlands (e.g. urban parks) was also explored, as was stem question order. The final focus group discussed the remaining biodiversity stem questions and wellbeing response items, and additionally considered the introductory text that asks participants to figuratively place themselves in a nearby woodland and think about biodiversity. This approach draws on previous scenario-based research investigating nature-health/wellbeing (Herzog et al., 1997; Staats et al., 2003).

3.1.4. *Cognitive interviews (Study 2b)*

We used cognitive interviewing, a method to facilitate scale development whereby questions are pre-tested to assess participants' comprehension and response to the scale, generating information to facilitate modification and improvement (Boateng et al., 2018; Willis, 2005). A draft BIO-WELL scale was created using the reduced set of biodiversity stem questions and wellbeing response items, with all response items presented for each stem question. This was hosted on Qualtrics, an online questionnaire platform (https://qualtrics.com). To construct the VAS responses, the negative (e.g. "Physically tense") and positive (e.g. "Physically relaxed") wellbeing item anchors were positioned on the left and right of the continuous line respectively, following formats used in other wellbeing scales (e.g. Hitz et al., 2018). A 100 mm line was placed between the anchors, with a movable counter in the centre that participants were directed to position to indicate their level of wellbeing.

We conducted 1 h, one-to-one, online cognitive interviews with nine individuals (Table S1), recruited by the social research company and adhering to the participant characteristics detailed in Study 1. Cognitive interviews were conducted by asking participants to complete the scale online in the presence of an interviewer. Participants were prompted by the interviewer to verbalize their experience as they completed BIO-WELL. We explored participants' interpretation of each stem question and wellbeing response item in the scale, which wellbeing response item pairs they would keep, the introductory text and use of the VAS slider format. The interviewer noted participant responses and any observations about the completion process. These were reviewed after each interview to identify any potential emerging problems to be addressed and modifications were made iteratively as required.

3.2. *Results*

Before the expert review, there were 75 potential biodiversity stem questions (Table S2) and 68 potential wellbeing response items (Table S3); the reason for removal at each stage of Study 2 are provided in Tables S2 and S3. After review, these were reduced to 43 and 47 respectively. The predominant reasons for removing stem questions were that they: (i) were not specific enough to biodiversity (e.g. "damp smells", as rain/water is abiotic) (ii) were too specific to a particular taxon (e.g. squawking); or specifying, for example, individual colours (e.g. blue, red); (iii) were not applicable to environments, such as coasts or grasslands beyond woodlands; or (iv) had specific positive or negative connotations (e.g. "The sliminess of living things in this woodland makes me feel …" evoked negative reactions due to popular cultural associations with the word "slimy"). Removal of response items was mainly due to ambiguity or because they were not considered as relevant to all biodiversity metrics and attributes (e.g. "Easier to breathe/Harder to breathe").

During Study 2a, the biodiversity stem questions (Table S2) and wellbeing response items (Table S3) were reduced to a pool of 18 and 10 respectively. Many of the stem questions were removed due to participants considering them as not relevant to biodiversity. Stem questions were also eliminated if participants could not understand the wording, could not imagine what in the environment would fit the given description (e.g. "The rubberiness of living things in this woodland makes me feel …") or had negative connotations (e.g. "Decomposing in the woodland makes me feel …"). Wellbeing response items were removed due to ambiguity, perceived lack of relevance to biodiversity, or not associating it with the *a priori* intended wellbeing domain. The language of stem questions and response items was also modified to improve clarity and resonance for the participants. For example, the biodiversity metric stem question "The diversity of species in this woodland makes me feel …" was changed to "The diversity of living things in this woodland makes me feel …". The introductory text was also altered as focus group participants conflated domesticated animals with biodiversity. To address this specifically, we modified the text to become "Please think about the living things, including the plants, fungi and animals (but not pets, horses, cows, sheep), in that woodland" to ensure participants conceptualised biodiversity as intended. Biodiversity metric stem questions were placed before the biodiversity attribute stem questions.

Focus group discussions revealed incidences of both positive and negative wellbeing from biodiversity. Positive wellbeing examples include emotional ("happy" and "glad") from species abundance, "earthy smells" and from pollination as a species interaction. Negative wellbeing responses include emotional ("depressing") from textures such as "mulch", or negative physical responses including allergies to pollen. Across the five wellbeing domains, social wellbeing response items generated the most discussion amongst participants, with comments such as "odd" and "why would biodiversity influence this" (e.g. "Easy to speak to people/Hard to speak to people") made throughout the focus groups. When asked to identify which response items, if any, participants would remove from the scale, social wellbeing items were identified most often. This finding reiterated the recognised difficulties of quantifying social wellbeing in relation to nature (e.g. Warber et al., 2015), despite qualitative evidence of its importance (e.g. Fish & Saratsi, 2015). Given the theoretical relevance and empirical evidence of social wellbeing, the iterative focus group process identified alternative phrasings and endpoints for the wellbeing anchor pairs to be taken forward.

Only a few further modifications were made in Study 2b (Tables S2 and S3). To improve the clarity and conceptualisation of biodiversity metric stem questions in participants' minds, "The abundance of living things …" was changed to "The number of living things …", and "The diversity of living things …" was altered to "The variety of living things …". One biodiversity attribute stem question was removed due to misinterpretation. The wellbeing response items were also reduced. The response item "Constrained/Free" was removed due to ambiguity, while "Pessimistic/Optimistic" was also discarded as participants considered the item as a personality trait rather than a wellbeing reaction to biodiversity. Structurally, after three cognitive interviews, it was clear that having the positive anchors on the right side of the VAS format encouraged individuals to move the marker completely to the right rather than being more discerning in their choice of placement. In contrast, having the positive anchors on the left made individuals consider their placement of the moveable counter more carefully. Therefore, we decided to present the VAS format like this in the remaining interviews (following Datema et al., 2008).

The completion of Study 2 generated 17 biodiversity stem questions

Table 1
Biodiversity stem questions (N = 17) developed by the end of Study 2 to explore the contribution of metrics (e.g. abundance, species diversity; n = 5) and attributes (e.g. smells, colours, shapes, n = 12) of biodiversity to human wellbeing.

Aspect of biodiversity	Biodiversity stem question
Biodiversity metrics	
Encountering	Encountering the living things (e.g. plants, fungi and animals) in this woodland makes me feel …
Abundance	The number of living things (e.g. plants, fungi and animals) in this woodland makes me feel …
Species diversity	The variety of living things (e.g. plants, fungi and animals) in this woodland makes me feel …
Species interactions	The interactions between plants, fungi and animals (e.g. pollination, predator-prey) in this woodland make me feel …
Ecological processes	The living processes (e.g. decomposing, growing) that happen in this woodland make me feel …
Biodiversity attributes	
Sound	The variety of sounds in this woodland makes me feel …
	The distinctive sounds in this woodland make me feel …
Colour	The variety of colours in this woodland makes me feel …
	The vivid colours in this woodland make me feel …
Shape	The variety of shapes in this woodland makes me feel …
	The maturity of living things (e.g. plants, fungi and animals) in this woodland makes me feel …
Texture	The variety of textures in this woodland makes me feel …
	The sponginess of living things (e.g. plants, fungi and animals) in this woodland makes me feel …
Smell	The variety of smells in this woodland makes me feel …
	The woody smells in this woodland make me feel …
Behaviour	Changes in this season make me feel …
	The presence of animals in this woodland makes me feel …

Note. Participants were first asked to imagine themselves in a woodland setting and to think about the biodiversity, using the wording, "For each of the following questions, imagine yourself in a nearby woodland at this time of year. Please think about the living things, including the plants, fungi and animals (but not pets, horses, cows, sheep), in that woodland."

Table 2
Wellbeing response items[a] (N = 8) developed by the end of Study 2 reflecting physical, emotional, cognitive, social or spiritual wellbeing.

Wellbeing domain	Positive anchor	Negative anchor
Physical	Physically relaxed	Physically tense
	Physically comfortable[b]	Physically uncomfortable[b]
Emotional	Joyful	Sad
Cognitive	Clear minded	Muddled
Social	Open to people	Closed to people
	Connected to people[b]	Lonely[b]
Spiritual	Part of something bigger than myself	Not part of something bigger than myself
	Connected to nature[b]	Disconnected from nature[b]

[a] Responses made on a Visual Analogue Scale with positive and negative linguistic anchor placed either side of a 100 mm line, allowing participants to indicate their wellbeing along the line.
[b] Removed as a result of Study 3.

(Table 1) and eight wellbeing response items (Table 2) using a VAS format. The resultant set emphasises language that reflects the characteristic of the attribute (e.g. distinctive sounds), rather than the attribute of a specific taxon (e.g. squawking), to minimize the likelihood of a stem question eliciting a solely negative or positive wellbeing response, and to facilitate applicability across multiple types of environment. The physical, social and spiritual wellbeing domains were each represented by two response items, whereas emotional and cognitive by a single item.

4. Study 3

Study 3 focused on evaluating and identifying a parsimonious set of wellbeing response items by administering the preliminary BIO-WELL scale to the target population via an online questionnaire.

4.1. Method

4.1.1. Participants and online questionnaire

A sample (N = 600; Table S1) was recruited by the social research company, using the participant characteristics detailed in Study 1, following recommendations that scale items are tested on "a sample that reflects and captures the range of the target population" (Boateng et al., 2018, p. 149). The sample size was determined according to best practices for scale development (Boateng et al., 2018; Comrey & Lee, 1992), such as ensuring at least 10 participants per scale response item to reliably compare patterns (Nunnally, 1978; Guadagnoli & Velicer, 1988). The questionnaire was hosted on Qualtrics.

Participants were asked to respond to 17 biodiversity stem questions (Table 1) using eight wellbeing response items (Table 2). At the end of the online questionnaire, participants were asked to: (i) identify which of the two candidate wellbeing response items for physical, social and spiritual wellbeing resonated with them most as a measure of the domain; and (ii) give open-ended feedback on the content or structure of BIO-WELL. Participants also completed sociodemographic questions (Table S1).

4.1.2. Data analysis

All analyses were conducted in R (R Core Team, 2021) for each biodiversity stem question individually. Scores for wellbeing response items were quantified according to where participants positioned the counter on the VAS (0–100). Low scores (0–49) indicated a positive wellbeing response, high scores (51–100) a negative response and a score of 50 was considered neutral. Scores were then inverted to aid interpretability (0–49 = negative wellbeing; 51–100 = positive wellbeing). BIO-WELL scores were then calculated as the mean of all wellbeing response items for each biodiversity stem question.

To assess the functionality of the wellbeing response items, using methods associated with classical test theory we analysed the interrelationships using Pearson's product-moment correlations between items and explored scale dimensionality using exploratory factor analysis. To support the item reduction process, we computed a parallel analysis (comparing the eigenvalues generated from the data matrix to the eigenvalues generated from a Monte-Carlo simulated matrix created from a random data of the same size; Sakaluk & Short, 2017), a scree plot (to visualise the eigenvalues and number of factors) and principal axis factoring with oblique rotation (oblimin with Kaiser Normalization) per stem question (Tabachnick & Fidell, 2013). Model fit statistics were compared for a 1-factor, 2-factor and 3-factor model. We examined coefficient alpha (Cronbach, 1951) for each stem question overall (using a threshold of >0.7 to indicate acceptable reliability; Nunnally, 1978), factor loadings (using a threshold of >0.3; Boateng et al., 2018) and calculated corrected item-total correlations between individual items (using a threshold of >0.3; Boateng et al., 2018) for a hypothesised 1-factor solution to facilitate further item refinement. These steps ensured that only parsimonious, functional and internally consistent items were taken forward (Boateng et al., 2018).

We then used approaches associated with item response theory to assess the strength and performance of each response item to identify those that contributed more to biopsychosocial-spiritual wellbeing that underlies BIO-WELL. We compared three models (graded response model, rating scale model, generalized partial credit model; Nima et al., 2020) and evaluated fit using five indices: log-likelihood, Bayesian information criterion, Akaike information criterion (AIC), AIC for small sample sizes (AICc) and Root Mean Square Error of Approximation (RMSEA). To guide the elimination of less informative response items, we used: (i) item discrimination ratings to examine how well items discriminate between people that experience high or low wellbeing (Baker & Kim, 2017); (ii) difficulty ratings to determine how precisely an item estimates wellbeing (Immekus et al., 2019); and (iii) model statistics to examine item fit (infit and outfit mean square; Alisat & Riemer, 2015). Removal was based on statistical properties; retention was guided by item discrimination ratings, using specified thresholds (Lameijer et al., 2020).

4.2. Results

Inter-item correlation was moderate to high across the biodiversity stem questions for physical wellbeing (0.71–0.81), social wellbeing (0.53–0.73) and spiritual wellbeing (0.52–0.65), highlighting the need to remove one of the two items due to similarity. When examining the parallel analysis, scree plot and principal axis factoring together, we found no clear pattern in the number of factors emerging. Parallel analyses indicated a 2- or 3-factor structure across our stem questions, while scree plots suggested 1- or 2-factor structures. Using principal axis factoring, we compared 1-factor, 2-factor, and 3-factor solutions. However, when we examined the loadings and model fit statistics together, we found statistical support for the number of factors differed for each biodiversity stem question. Factor loadings and corrected item-total correlations (Table S4) showed that all items appeared to be worthy of retention (see Boateng et al., 2018).

The graded response model had the best model fit (Table S5). Evaluation of item discrimination values, model fit statistics and infit and outfit values from the graded response model (Table S4) suggested eliminating "Physically comfortable/Physically uncomfortable", "Connected to people/Lonely" and "Connected to nature/Disconnected to nature" in the physical, social and spiritual wellbeing domains respectively (Table 2). Removal of the "Physically comfortable/Physically uncomfortable" and "Connected to people/Lonely" items was further supported by less variability in responses across the stem questions. Indeed, some of the Study 2 participants reported positive connotations associated with the word "lonely", suggesting it was not an appropriate negative linguistic opposite for the wellbeing response item. For the "Connected to nature/Disconnected from nature" item, there was little variability in responses, whereas "Part of something bigger than myself/Not part of something bigger than myself" was more sensitive and elicited a wider spread of responses. Moreover, despite our Study 1 and 2a participants referring to "Connection to nature" as a wellbeing outcome, it has been proposed as a pathway to wellbeing in the literature rather than a wellbeing outcome in its own right (Pritchard et al., 2020). Our empirical findings, combined with theoretical and pragmatic considerations, identified a parsimonious set of five single items, each measuring a distinct domain of wellbeing that, when combined, can contribute to an overarching measure of biopsychosocial-spiritual wellbeing.

5. Study 4

Study 4 was designed to confirm the unidimensional structure of BIO-WELL. We therefore evaluated the version of BIO-WELL comprising five wellbeing response items, through a combination of confirmatory factor analysis, classical test theory and item response theory approaches, with a new sample of participants.

5.1. Method

5.1.1. Participants and online questionnaire

A new sample (N = 600; Table S1) was recruited by the social research company, following the participant characteristics detailed in Study 1. The online questionnaire was structured and delivered as in Study 3, apart from having five rather than eight wellbeing response items per biodiversity stem question (Table 2).

5.1.2. Data analysis

Analyses were conducted in R (R Core Team, 2021) for each biodiversity stem question individually. Scores for wellbeing response items were calculated as in Study 3. We used confirmatory factor analysis to evaluate the proposed unidimensional structure of the BIO-WELL scale. A 1-factor model for the five response items (representing physical, emotional, cognitive, social and spiritual domains of wellbeing) was specified for each of the biodiversity stem questions. Models were run using a maximum likelihood estimator to correct for non-normality. We examined whether the models for each stem question fitted our hypothesis, following threshold values for fair model fit (relative $X^2 < 2$ or 3, comparative fit index >0.95, RMSEA: and 90% confidence intervals <0.8, standardized root mean square residual <0.08; Byrne, 1994; Hu & Bentler, 1995; Stevens, 2002; Kline, 2010). We confirmed model fit with the data through comparison with alternative models (e.g. a 2-factor solution). We used the graded response model to assess discrimination ratings, difficulty ratings and model fit statistics for each of the five wellbeing items. We examined reliability of the BIO-WELL scale for each stem question through an assessment of item-total correlation (corrected) (threshold >0.3, Boateng et al., 2018) and internal consistency using coefficient alpha (Cronbach, 1951; threshold >0.7, Nunnally, 1978).

5.2. Results

The proposed 1-factor model suggested a relatively good fit for the data (Table S6). Each of the biodiversity stem questions met thresholds for fair model fit for most of the model fit statistics. Cronbach's (1951) coefficient alpha for each biodiversity stem question was high and item-total correlations moderate to strong (Table S7), confirming that BIO-WELL represents a biopsychosocial-spiritual model of wellbeing. Factor means were 69–73 across the 17 biodiversity stem questions (Table S7) with a range from 0 to 100 for each stem question. The full VAS scale was therefore being used to represent negative and positive wellbeing effects from the various biodiversity metrics and attributes. The results of the graded response model additionally support the proposed scale structure (Table S7). Overall, these findings demonstrate that BIO-WELL offers a reliable scale to interrogate self-reported biopsychosocial-spiritual wellbeing in relation to 17 individual stem questions focusing on biodiversity metrics and attributes using a VAS format (Fig. 1).

6. Study 5

Study 5 involved assessing discriminant and convergent validity (comparing BIO-WELL with other scales), concurrent validity (appropriate differentiation between participant sub-groups) and predictive validity (whether the scale predicts outcomes of interest).

6.1. Method

6.1.1. Participants and online questionnaire

A new sample (N = 1500; Table S1) was recruited through the social research company using the same participant characteristics and sample size considerations as for Study 3. The online questionnaire was structured and delivered as in Study 4.

6.1.1.1. Discriminant and convergent validity measures. Five established measures of constructs considered as either theoretically dissimilar or similar to the BIO-WELL wellbeing construct measure were used to test for discriminant and convergent validity respectively (Table 3). We hypothesised resilience, self-esteem, affect and mental wellbeing to be conceptually distinct. To evaluate convergent validity, we used the Restorative Outcome Scale (ROS) which is a place-based measure of emotional and cognitive restoration from an environment (Korpela et al., 2008, 2010). We hypothesised that this would converge with BIO-WELL, given that they are both place-based and focus on two of the same wellbeing domains. We adapted the ROS stem question to include

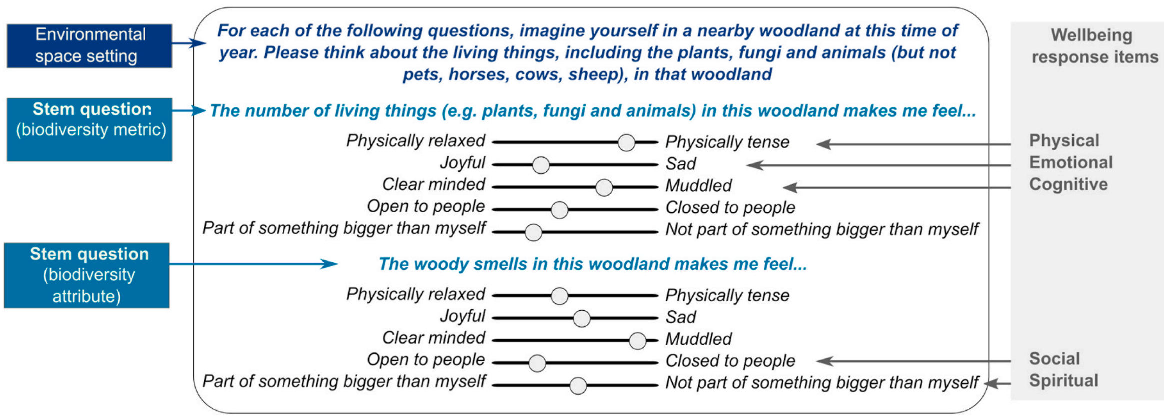

Fig. 1. The biodiversity-wellbeing scale, BIO-WELL. Through an introductory statement, participants are invited to figuratively place themselves in a nearby woodland and to think about the biodiversity. Stem questions asked about biodiversity metrics (e.g. abundance, species diversity), as well as biodiversity attributes (e.g. smells, colours, shapes). Wellbeing response items reflected either physical, emotional, cognitive, social or spiritual wellbeing, following a biopsychosocial-spiritual model of health. They were in Visual Analogue Scale format, with a positive and negative linguistic anchor either side of a 100 mm line, allowing participants to indicate their wellbeing along the line. Two of the seventeen biodiversity stem questions are included here for illustrative purposes.

a statement aligned with BIO-WELL, whereby participants were asked to "imagine yourself in a nearby woodland at this time of year".

6.1.1.2. Concurrent and predictive validity questions. A series of new questions were included in our online questionnaire to assess concurrent validity (differentiating between participant sub-groups hypothesised to diverge in their overall BIO-WELL scores) and predictive validity (predicting BIO-WELL scores on three outcomes of interest). To test concurrent validity, three questions were drawn from existing UK national surveys that examine public use of the outdoors (Natural England, 2019a). Two questions explored whether participants "spent a lot of time in woodland or forests" as a child (<13 years old) and as a teenager (13–18 years old). A third question assessed whether "spending time out of doors is an important part of my life". All responses were made on a 5-point scale (1 = strongly agree; 5 = strongly disagree). We hypothesised that individuals who spent more time in woodlands as children/teenagers and thought that time spent out of doors was important would have higher overall BIO-WELL scores, because time spent in nature early in life can influence health outcomes, pro-environmental behaviour, and subsequent continued time spent in nature (Engemann et al., 2019; Evans et al., 2018). We also used importance of use of the outdoors as a criterion measure for predictive validity.

Given the multi-sensory experience of biodiversity (Franco et al., 2017), a key sub-group of interest was people with sensory impairments. Participants were asked to indicate any sensory impairment (e.g. poor hearing, smell, or sight), which could bias their experience of sounds, smells or colours associated with woodland biodiversity. Responses were binary (yes/no). We hypothesised that people without impairments in these senses would report higher overall BIO-WELL scores because they are better able to sense these biodiversity attributes.

We also included a single question drawn from the Intentional Nature Exposure Scale (Katmitsis & Francis, 2013; Wood et al., 2019), which asked participants to indicate "how much you notice the natural environment in your everyday life" on a 5-point scale (1 = not much; 5 = great deal). Additionally, we used the Nature in Self Scale (Schultz, 2002; Schultz & Tabanico, 2007). Participants were asked to select from among seven pictures of two circles (self, nature) depicting varying degrees of overlap the one that "best describes your relationship with the natural environment". We hypothesised that people who notice natural environments more, and consider themselves as more a part of nature, would have higher overall BIO-WELL scores. These two scales were also used as criterion measures for predictive validity.

6.1.2. Data analysis

All analyses were conducted in R (R Core Team, 2021). The overall BIO-WELL score was quantified as the mean of all wellbeing response items across all biodiversity stem questions for each individual participant. To test discriminant and convergent validity we calculated Pearson's product-moment coefficients. We used the following values (positive or negative) as thresholds for interpretation guided by available literature: weak: $r \leq 0.49$; moderate: $r = 0.5$–0.69; strong: $r \geq 0.7$ (Campbell & Fiske, 1959; Abma et al., 2016; Vaingankar et al., 2017). For concurrent validity, we used ANOVAs to compare overall BIO-WELL scores with woodland use, importance of spending time out of doors, noticing nature and identification with nature. We used Welch two-sample *t*-tests to compare overall BIO-WELL scores with people who did and did not have sensory impairments.

Using hierarchical regression models, we explored predictive validity by determining the proportion of variance explained by BIO-WELL for three dependent variables. We expected that people who experience increased wellbeing from biodiversity would consider spending time outdoors as important, would notice nature more and identify more closely with nature. The hierarchical models were constructed initially using only sociodemographic variables (age, gender, urbanicity, ethnicity, socioeconomic group) (step 1) and then with the overall BIO-WELL scores added as another independent variable (step 2). Differences in model performance before and after the addition of overall BIO-WELL scores were assessed by adjusted F statistic, ΔR^2, ΔAIC and *p* value.

6.2. Results

Correlations supported our hypotheses regarding discriminant and convergent validity (Table 4). We expected overall BIO-WELL mean scores would be related to, but distinct from, the mean score for resilience, self-esteem and affect measures although negative affect was more correlated than the others. This raises a fruitful direction for future research to explore distinction between affective states and BIO-WELL's biopsychosocial-spiritual wellbeing construct. The significant and positive moderate correlation between overall BIO-WELL scores and restorativeness supports convergent validity.

Concurrent validity was supported through differentiation between participant sub-groups. Those who had experienced woodlands a lot as a child (Fig. 2a), a teenager (Fig. 2b), or who felt that visiting the outdoors was important (Fig. 2c) reported significantly higher overall BIO-WELL scores.

Moreover, we found that those who had difficulty with their hearing (Fig. 3a), sense of smell (Fig. 3b) or sight (Fig. 3c) reported significantly

Table 3
Comparator scales to test for discriminant and convergent validity with BIO-WELL and hypotheses for correlations tested.

Discriminant and convergent validity measure	Description	Hypothesis[a]
Brief Resilience Scale (BRS) (Smith et al., 2008)	The unidimensional 6-item scale measures resilience defined as the ability to bounce back from stress. Participants indicate their agreement (1 = strongly disagree; 5 = strongly agree); responses are summed across the six items (range from 6 to 30) with higher scores indicating greater resilience.	Discriminant validity indicated by no correlation or a weak positive correlation
Rosenberg Self-Esteem (RSE) (Rosenberg, 1965)	The 10-item scale measures global self-esteem (0 = strongly disagree; 3 = strongly agree) in response to statements dealing with general feelings about oneself. After reverse scoring of some statements, items are summed (range 0–30) with higher values indicating greater self-esteem.	Discriminant validity indicated by no correlation or a weak positive correlation
Positive and Negative Affect Scale (PANAS) (Watson et al., 1988)	The 20-item multi-dimensional scale measures positive and negative trait affect, respectively. Responses are made on a 5-point scale (1 = very slightly or not at all; 5 = extremely). Scales are summed for each sub-scale (10 items reflecting positive affect, 10 items reflecting negative affect); higher scores represent more positive or negative affect, respectively.	Discriminant validity indicated by no correlation or a weak positive correlation with PANAS Positive, and no correlation or a weak negative correlation with PANAS Negative
Warwick Edinburgh Mental Wellbeing Scale - Short Form (SWEMWBS) (Stewart-Brown et al., 2009; Vaingankar et al., 2017)	This 7-item mental wellbeing scale asks about an individual's experience of different feelings and thoughts over the past two weeks (1 = none of the time; 5 = all of the time). Responses are summed (raw score range 7–35) and transformed with greater mental wellbeing indicated by higher values.	Discriminant validity indicated by no correlation or a weak positive correlation
Restorative Outcome Scale (ROS) (Korpela et al., 2008, 2010)	This 6-item scale measures how restored one is from being in a given environment with higher scores indicating greater restorativeness. Participants are asked to indicate how well a statement describes how they feel in relation to a particular place (1 = not at all; 7 = totally). A mean score is calculated to identify the degree of restoration with higher values indicating more restoration.	Convergent validity indicated by a moderate to strong positive correlation

[a] Validity criterion: strength of correlations: weak ($r \leq 0.49$), moderate (r = 0.5–0.69), or strong ($r \geq 0.7$).

Table 4
Correlations for the overall BIO-WELL score with discriminant and convergent validity measures.

Discriminant/convergent measures[a]	r	p value
Brief Resilience Scale (BRS)	0.32	<0.001
Rosenburg Self-Esteem Scale (RSE)	0.39	<0.001
Positive Affect Schedule (PANAS positive)	0.25	<0.001
Negative Affect Schedule (PANAS negative)	−0.46	<0.001
Warwick-Edinburgh Mental Wellbeing Scale – short form (SWEMWBS)	0.39	<0.001
Restorative Outcome Scale (ROS)	0.64	<0.001

Note: r = Pearson's product-moment coefficients. Strength of correlations: no/weak ($r \leq 0.49$), moderate (r = 0.5–0.69), strong ($r \geq 0.7$).
[a] Cronbach's (1951) alpha in the present study (total sample, containing all participants): BRS (0.82), RSE (0.77), PANAS positive (0.92), PANAS negative (0.94), SWEMWBS (0.90).

lower BIO-WELL scores. Lastly, people who notice natural environments in their everyday life (Fig. 4a), and those who see more of an overlap between self and nature (Fig. 4b), had significantly higher BIO-WELL scores.

BIO-WELL accounted for a significant increase in the proportion of the variance explained in three dependent variables, after controlling for the sociodemographic covariates (Table 5). We expected people who gain more wellbeing from biodiversity to consider spending time outdoors as important, notice nature more and identify more closely with nature.

7. Discussion and conclusion

Scale development is a critical component of the interdisciplinary need to assess the contribution biodiversity makes to human wellbeing. BIO-WELL was created because, while policy and practice increasingly position human interactions with nature as the panacea for a litany of escalating health and wellbeing problems, our understanding of this contribution remains limited. If we are to cultivate and enable the environmental basis of wellbeing in ways that synergise with wider efforts to protect and enhance biodiversity, we will need a richer understanding of how attributes of nature translate into benefits to wellbeing for people.

BIO-WELL was developed to offer a psychometrically valid and reliable self-report wellbeing scale that can facilitate deepening our understanding of these relationships through two innovations. Foremost, BIO-WELL is the first scale of its kind to incorporate stem questions that specifically ask participants to consider their wellbeing in relation to interaction with different elements of biodiversity, namely metrics associated with the species/community (e.g. species diversity) and ecological processes (e.g. decomposition), as well as attributes (e.g. sounds). Given that contact with nature/biodiversity is not single-sensory, BIO-WELL was designed to capture the holistic experience of biodiversity. To facilitate this, it uses an introductory scenario to cognitively situate the participant within a particular natural environment (i.e. a nearby woodland). Secondly, by incorporating response items that cover multiple health/wellbeing domains, asked against each of the biodiversity-focused stem questions, BIO-WELL tests the applicability of a biopsychosocial-spiritual model of holistic wellbeing (Engel, 1977; Fava & Sonino, 2008; McKee & Chappel, 1992) to our understanding of biodiversity's effect on health/wellbeing. Conceptually, the inclusion of the spiritual domain extends the Marselle et al. (2021) biodiversity-health framework beyond the WHO biopsychosocial model that dominates the nature/biodiversity-health literature.

The derivation of wellbeing response items from participants addresses previous calls by Pinder et al. (2009) to gain insights regarding

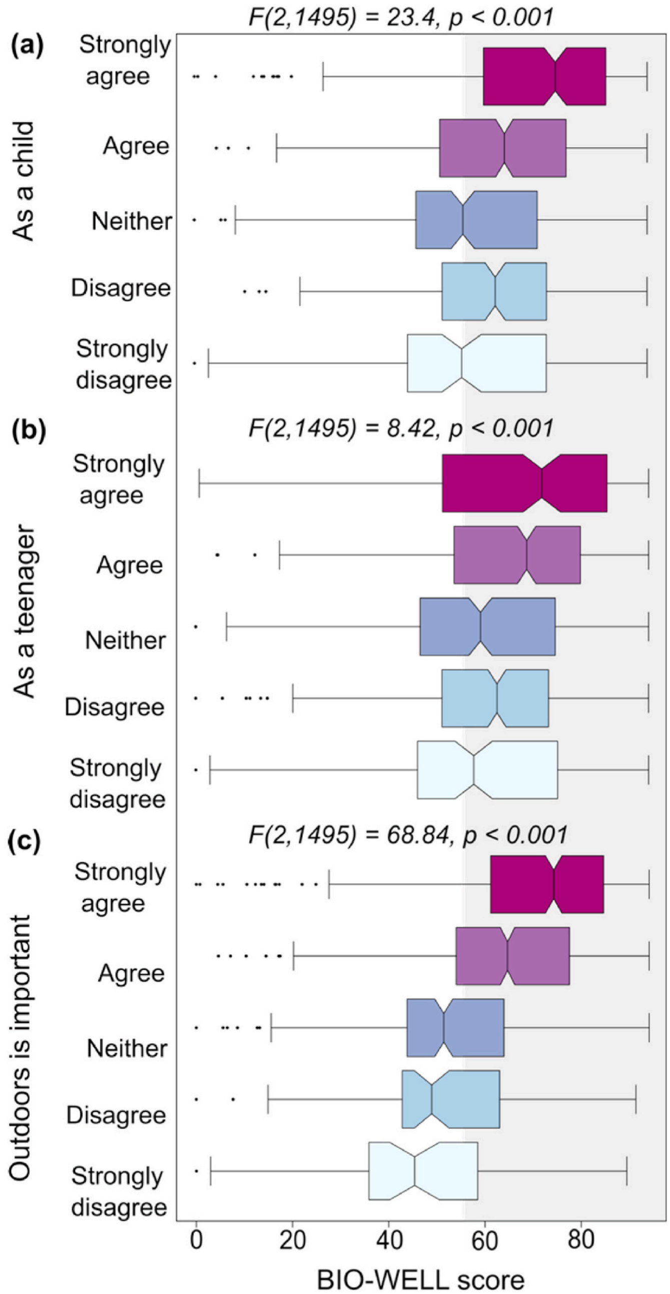

Fig. 2. Participant responses to BIO-WELL when asked to indicate how much they agree that they spent a lot of time in woodlands of forests (a) as a child, (b) as a teenager and (c) whether they believe that time spent out of doors is an important part of their life, with statistics representing results of one-way ANOVA. Grey box indicates threshold at which wellbeing is positive (>50). BIO-WELL scores are calculated as the mean across all wellbeing response items across all biodiversity stem questions.

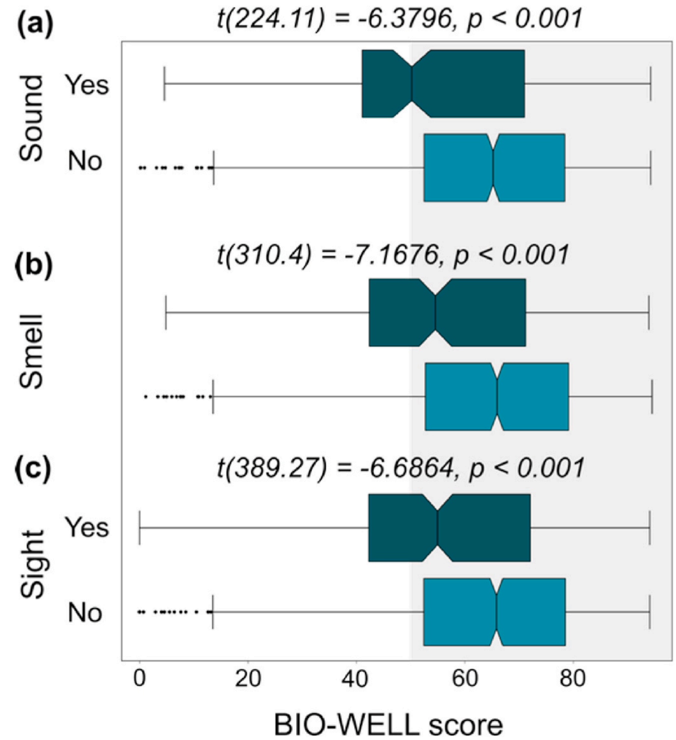

Fig. 3. Participant responses to BIO-WELL when asked to indicate whether they had any difficulties being able to (a) hear, (b) smell and (c) see, with statistics representing results of Welch two-sample *t*-tests. Grey box indicates threshold at which BIO-WELL is positive (>50). BIO-WELL scores are calculated as the mean across all wellbeing response items across all biodiversity stem questions.

how wellbeing is underpinned by nature from people who use outdoor spaces. By applying this "bottom-up" approach to understanding the wellbeing effect from interactions with biodiversity, we provide an instrument reflective of participants' own experiences, knowledge and memories. Our novel integration of *in situ* and *ex situ* participatory approaches combined with facilitated discussion, focus groups and cognitive interviewing enabled the development of a robust preliminary set of participant-generated terms. Participant descriptions were often richly nuanced, yet the item development process necessitated an extraction of essential meaning and needed to use language that could be comprehended across the entire target population. To counteract this limitation and ensure that the terms that could be widely endorsed, they underwent further participant-informed revision via implementation of the preliminary BIO-WELL scale. The final set of wellbeing items thus helps bypass challenges associated with adapting measures from other fields, where wellbeing responses may not be relevant or directly applicable to interactions with biodiversity.

By combining measures about the environment and wellbeing into a single scale, BIO-WELL offers a scale similar to restorative environment measures (e.g. ROS; Korpela et al., 2008). To date, most studies utilise separate measures about the environment (objective or perceived) and separate measures to assess often single domains of wellbeing. In BIO-WELL, participants are asked to specifically consider their wellbeing in relation to interactions with biodiversity thereby opening up several novel future research opportunities.

First, depending on the research questions and required outcomes, BIO-WELL could be used in its entirety (all 17 stem questions) to gain a holistic understanding of the influence of interaction with biodiversity on wellbeing, as demonstrated here. As we also illustrate through our concurrent validation, individuals with, for example, sensory impairment (e.g. difficulty hearing), may score lower in overall wellbeing because they cannot interact with biodiversity through that particular sense. Given the scale properties for each individual biodiversity stem question have been tested thoroughly, the stem questions can be applied independently or as a subset to focus on selected biodiversity metrics or attributes. Thus, for example, one could use a subset of stem questions to understand the wellbeing effect of a specific biodiversity attribute type, such as sound, through a controlled, *ex situ* laboratory or virtual reality study.

Second, future studies could adapt BIO-WELL to allow researchers to quantify the influence of interaction with biodiversity on wellbeing across different environment types (e.g. wetlands, coasts, public parks). While BIO-WELL has been developed and validated based on woodlands, the stem questions and wellbeing response items were extensively

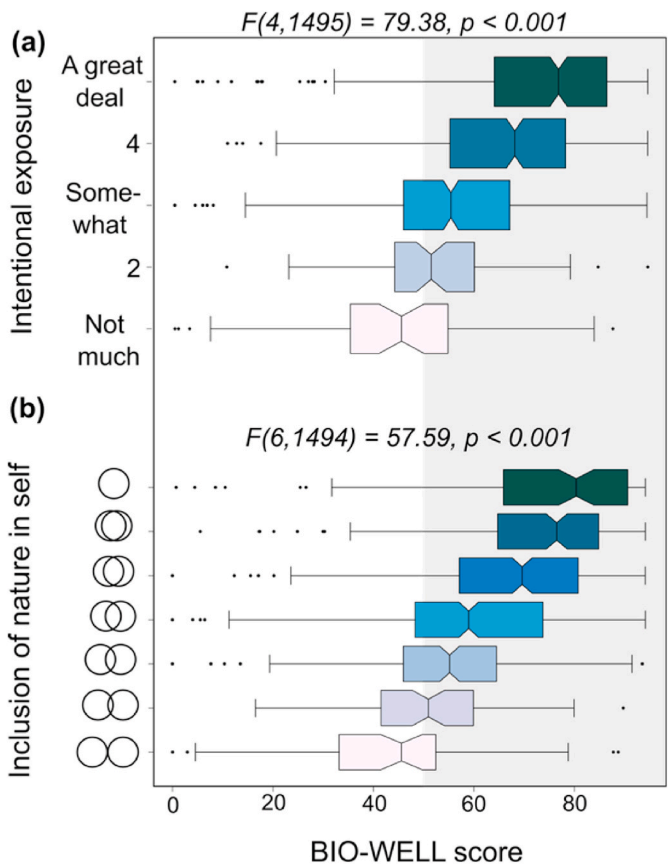

Fig. 4. Participant responses to BIO-WELL when asked to (a) indicate how much they notice natural environments in their everyday life (Intentional Nature Exposure Scale), and (b) select the picture that best describes their relationship with the natural environment (Identity of Nature in Self Scale), with statistics representing results of one-way ANOVA. Grey box indicates threshold at which BIO-WELL is positive (>50). BIO-WELL scores are calculated as the mean across all wellbeing response items across all biodiversity stem questions.

Table 5
Hierarchical regression analysis comparing models with and without BIO-WELL as a predictor for three dependent variables (N = 1500).

Dependent variable	F statistic	ΔR^2 (adjusted)	ΔAIC	*p* value
Outdoors is important	25.46	14.10	232.67	<0.001
Intentional exposure	6.850	11.10	63.59	<0.001
Identity of nature in self	28.90	15.40	259.92	<0.001

Note. ΔAIC = delta Akaike information criterion.

examined for their relevance to other environment types through our focus groups and cognitive interviewing. To utilise the scale in other environments and contexts, adaptation of stem questions could occur through either direct modification (e.g. change "woody smells" to "grassy smells" for urban parks) or through additional empirical work (e.g. focus groups) to identify relevant attributes. Such studies could fruitfully broaden our understanding of how biodiversity underpins wellbeing in previously unexplored environments (e.g. deserts, peatlands). These applications would also allow a specific examination of whether the psychometric properties of BIO-WELL remain valid in a variety of environmental (e.g. wetlands) and cross-cultural (e.g. another country) contexts.

The scale was validated for *ex situ* application, using a scenario-based approach. While this is a common methodology to investigate the effect of an environment on a particular wellbeing outcome (e.g. cognitive restoration; Korpela et al., 2008), BIO-WELL could also be useful *in situ*, opening up a third avenue for future research. Through its inclusion of biodiversity metric stem questions, BIO-WELL could be used in studies considering the wellbeing implications from actual biodiversity present in an environment. This combination of BIO-WELL with measures of actual biodiversity could further develop our understanding of the biodiversity-health relationship. Measures of perceived biodiversity could also be incorporated to further elaborate this relationship. Such an approach offers substantive opportunity for innovative interdisciplinary research between ecology (generating measures of actual biodiversity present in the environment) and social sciences (measuring perceived biodiversity). These types of studies could provide additional opportunity to assess the validity of BIO-WELL in terms of sensitivity to actual and perceived environmental qualities. Additionally, future studies that combine BIO-WELL with measures of actual and perceived biodiversity, could incorporate variables such as ecological knowledge or exposure (frequency, duration of contact) to further unpack the influences between biodiversity and human health/wellbeing.

Few scales combine multiple domains of wellbeing, meaning that conclusions about the links between biodiversity and wellbeing are currently limited to a subset of human wellbeing – physical, mental, social (Marselle et al., 2021). BIO-WELL can facilitate more detailed exploration of if and how biodiversity influences an expanded set of wellbeing outcomes, represented by the physical, emotional, cognitive, social and spiritual, opening up a fourth direction of research. For example, BIO-WELL could be used to monitor change over time in wellbeing effect following implementation of management strategies to increase biodiversity. There is increased interest in utilising the natural environment for health promotion and therapeutic effect (Husk et al., 2019; UK Department of Health, 2016). Future research could incorporate BIOWELL into interdisciplinary *in situ* evaluations of interventions that seek to modify the environment to promote biodiversity and wellbeing through pre-post design to examine the effectiveness of such changes.

While the sample means of all biodiversity metrics or attributes incorporated into BIO-WELL tended toward positive responses, our studies revealed heterogeneity in wellbeing effects amongst participants, with negative and neutral effects also reported. Although the aim of this study was not to interrogate the relative contributions of biodiversity attributes to wellbeing, our findings suggest BIO-WELL could be a suitable tool to understand such research questions. These insights could then be used by decision-makers to refine the ecological quality of environments to maximise their contribution to human wellbeing. BIO-WELL could, for example, enable comparisons between similar environments, such as two wetlands with differing levels of biodiversity attributes, to understand their effect on wellbeing.

In conclusion, to address two critical challenges of our time, biodiversity loss and a growing prevalence of poor mental health and non-communicable diseases, we must shift our view of how the natural world and human health and wellbeing are interconnected. Achieving this requires a deeper, more nuanced understanding of how biodiversity influences wellbeing. Yet the currently available measures for quantifying this relationship are limited. BIO-WELL offers a novel, valid and reliable scale to assess the contribution of biodiversity to wellbeing that has been developed with input at all stages from the target population, adults. This strong focus on non-expert scale development is not only unusual, but critical to its practical utility as a data gathering instrument (Morgado et al., 2018). BIO-WELL also overcomes the limitations of current scales by spanning multiple domains of wellbeing using a small number of response items, thereby minimising participant burden. Furthermore, BIO-WELL has been developed explicitly for use in studies seeking to capture the impact of biodiversity on wellbeing. As such, it can account for the multi-sensory aspects of biodiversity, providing a method to quantify the relative contribution of different types of biodiversity attribute. This has not been possible to do to-date. BIO-WELL's strong qualitative underpinning and psychometric properties suggest it could be suitable for incorporation into studies looking to interrogate the relationship between biodiversity and wellbeing across different environment types, research designs and contexts.

Author contribution statement

Conceptualisation, K.N.I., Z.G.D. and M.D; Methodology, K.N.I., J.C. F., P.R.B., M.N., Z.G.D. and M.D.; Formal Analysis, J.C.F., M.N., P.R.B, K. N.I. and Z.G.D; Investigation, all authors; Data Curation, J.C. F., P.R.B., M.N., and G.E.A.; Writing – Original Draft, K.N.I., J.C.F., P.R.B., M.N. and Z.G.D; Writing – Review & Editing, all authors; Supervision, K.N.I. and Z.G.D.; Project Administration, G.E.A. and Z.G.D.; Funding Acquisition, Z.G.D., K.N.I., M.D., R.F.

Declaration of competing interest

The authors declare no competing interests.

Acknowledgements

This research was funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Consolidator Grant No. 726104). K.N.I was additionally supported by Scottish Government under the Rural & Environment Science & Analytical Services Division (RESAS) Strategic Research Programme 2022–27. The authors would like to thank the participants who took part in the five studies. Additional thanks to the anonymous reviewer, to Kathryn Colley for comments on a previous version, Melissa Marselle and Sara Warber for being 'critical friends'.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2022.101921.

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