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Testing the BIO-WELL scale *in situ*: measuring human wellbeing responses to biodiversity within forests

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ABSTRACT

The benefits of nature for human health and wellbeing are well documented. However, nature is not homogenous, and there remains a gap in our understanding of the role biodiversity (the diversity within species, between species, and of ecosystems) plays specifically. BIO-WELL, a psychometric scale, asks people to consider themselves in a forest (*ex situ*), measuring human wellbeing across five domains for 17 biodiversity metric and attribute stem questions. Here, we adapt and validate BIO-WELL for use *in situ* with 510 participants in British forests during spring and summer. We found good internal consistency, and exploratory and confirmatory factor analyses reaffirmed 1-factor structures for most stem questions (construct validity); variability in model fit statistics for some of the biodiversity stem questions indicates uncertainty in how they were conceived by participants. We found strong concurrent validity, meaning the scale is suitable and reliable for use *in situ*. Perceived variety of sounds, smells, and colours were positively associated with BIO-WELL scores. People who felt visiting the outdoors was an important of their life also scored higher. Participants reported higher BIO-WELL scores in relation to the diversity of, and interactions between, species in spring compared to summer, which is perhaps attributable to seasonal differences in ecological processes. There was no difference in BIO-WELL scores between people who reported sensory impairments. The scale can be deployed to generate empirical evidence to support policy and practice decision-making for planning and managing natural environments for both biodiversity conservation and human wellbeing.

1. Introduction

The beneficial effects of nature on human health and wellbeing are well documented. They include reduced stress, improved immune function, physiological improvements, better psychological wellbeing and facilitated social interactions (e.g. Bratman et al., 2019; Fisher et al., 2023). Such benefits have the potential to counter modern health crises. Nature has been shown to reduce non-communicable diseases (e.g. cardiovascular disease, obesity, diabetes), including mental health difficulties such as chronic depression (e.g. Engemann et al., 2019). The role of nature in improving health and wellbeing is of interest to decision-makers, as its integration into management and care could ease the operative and financial burden on health services (e.g. Grellier et al., 2024). For instance, in 2021, OECD member countries (Organization for Economic Co-operation and Development) allocated 60 % of all health spending on curative care, while preventative care accounted for just under 5 % (OECD, 2023). This imbalance highlights the need for investment in cost-effective, preventative strategies to reduce the long-term burden of disease. One such pathway includes healthcare professionals prescribing contact with nature (Van den Berg, 2017). These ‘green prescription’ programs aim to utilise, and encourage further development of, nature-based activities (e.g. (Marselle et al., 2016; Maund et al., 2019) as preventative interventions to address long-term medical conditions and promote wellbeing (Bragg & Atkins,

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2016).

When examining the evidence base underpinning the nature-health connection, the word 'nature' is often used as an umbrella term that encompasses biodiversity, as well as the abiotic components, of natural environments (e.g. Patwary et al., 2024). However, biodiversity is complex, defined by the Convention on Biological Diversity as '*the diversity within species, between species, and of ecosystems* (CBD, 2022). Recent frameworks (e.g. Marselle et al., 2021) coupled with a growing body of research have sought to expand our theoretical and empirical understanding of the biodiversity-health linkage.

Within the biodiversity-health literature, biodiversity has been examined through classification into 'high' and 'low' categories or broad habitat classes (e.g. coniferous and broadleaved forest) (e.g. high biodiversity forests are associated with greater wellbeing; Carrus et al., 2015), single objective measures of biodiversity within an *ex situ* context (e.g. higher species richness associated with increased health and wellbeing benefits; Johansson et al., 2014; Cracknell et al., 2016), or *in situ* objective (e.g. species richness) and subjective measures (e.g. perceived variety of species) (e.g. perceived species richness is associated with higher wellbeing; Dallimer et al., 2012). Several recent studies have used mixed methods research designs to examine how heterogeneity in the biodiversity people experience influences health and wellbeing outcomes (e.g. Methorst et al., 2020), including linkages between specific traits associated with species (e.g. colours, smells, sounds, textures, behaviours) on different types of positive and negative wellbeing (Fisher et al., 2023). Instruments used to measure the relationship between biodiversity, health and wellbeing have predominantly been developed within the health sector, a practice mirroring the approach within the broader nature-health literature (Lovell et al., 2018). For example, researchers have shown positive associations between life satisfaction and bird species richness (Methorst et al., 2020), less depression, anxiety and stress with higher neighbourhood bird abundance (Cox et al., 2017), and higher positive and lower negative affect and anxiety with greater perceived bird species richness (Fisher et al., 2021). While some scales include wellbeing response items related specifically to nature exposure, few focus on the contribution made by biodiversity. The Restorative Outcome Scale (ROS), for example, is a place-based measure of restoration in an environment, based on six emotional and cognitive scale items, and has been validated in forest settings (Korpela et al., 2008; Takayama et al., 2014).

Irvine et al. (2023) recently developed a scale to complement existing measures for understanding the interactions between people, environment and health, focusing specifically on biodiversity. Their aim was to develop a psychometrically valid and reliable scale for use in studies considering the human wellbeing derived from biodiversity, seeking to include stem questions aligned with various details and qualities of biodiversity in a particular environmental setting and a multi-domain framing of health/wellbeing. Using an exploratory sequential mixed methods design (Creswell & Clark, 2017), BIO-WELL (https://research.kent.ac.uk/bio-well/) is validated for use *ex situ*, asking participants to imagine themselves in a nearby forest, and self-report the effects of 17 stem questions comprising biodiversity metrics (e.g. species diversity), ecological processes (e.g. decomposition), and specific attributes (e.g. smells, texture) on five domains of wellbeing (physical, emotional, cognitive, social, and spiritual) on a visual analogue scale (a positive to negative continuum).

However, real-world experiences of biodiversity are likely to differ from *ex situ* imaginings, calling for validation of BIO-WELL *in situ*. Consequently, in this study we examine the psychometric properties of BIO-WELL *in situ* within four British forests in spring and summer. We evaluate the dimensionality, reliability, and validity of the scale following best practice guidelines (Boateng et al., 2018). As with any new tool, understanding how scales like BIO-WELL perform across different contexts and populations requires on-going validation to test and refine the claims made through the original development process (Boateng et al., 2018).

2. Materials and methods

2.1. Study system

This study focused on forests, one of the world's most productive land-based ecosystems and essential to life on Earth, with the potential to provide 'triple wins' for climate change, biodiversity and human wellbeing (Pritchard, 2021). In Britain, forests cover 13 % of the total land area, with national targets in place to increase forest cover to 19 % to meet net zero emissions by 2050 (Committee on Climate Change, 2018). As one of the most nature-depleted countries in the world, improving the ecological quality of both existing and newly created forests has important implications for the conservation of Britain's declining biodiversity (Reid et al., 2021). While forest restoration/creation can deliver co-benefits for health and wellbeing, people's preferences for forest biodiversity are largely ignored, thus threatening the success of such initiatives which require public support to succeed (Austen et al., 2023; Pritchard, 2021).

Forests in Britain are the most visited natural environment besides urban paths, parks, bridleways and cycle paths (Natural England, 2019), with 51 % of UK forests being coniferous and 49 % broadleaf (Reid et al., 2021). This study took place across three forest sites in southern England (Epping Forest, Thornden Woods, Ashdown Forest) and one site in Wales (Penllergare Valley) (Fig. 1). These forests were chosen as they were located in areas with a high human population density to maximise the quantity, and socioeconomic and demographic background, of participants. Additionally, the four forest sites are biodiverse broadleaf and ancient woodland ecosystems, maximising the biodiversity that visitors may have a chance of experiencing.

2.2. Participant recruitment

During April to June 2023, members of the public who were visiting one of the four forest sites were invited to complete a questionnaire exploring people's experience of the forest (Penllergare Valley, $n = 119$; Thornden Woods, $n = 236$; Ashdown Forest, $n = 27$; Epping Forest, $n = 128$). We did not mention that we were interested in exploring wellbeing specifically, to minimise the likelihood of biased or socially desirable responses from participants (King & Bruner, 2000). A participation incentive was provided to anyone who completed the questionnaire, comprising an entry to a prize-draw to win one of three £50 multi-retail gift cards. A total of 510 participants were recruited across the four forest sites, across all times of the day and days of the week (e.g. morning

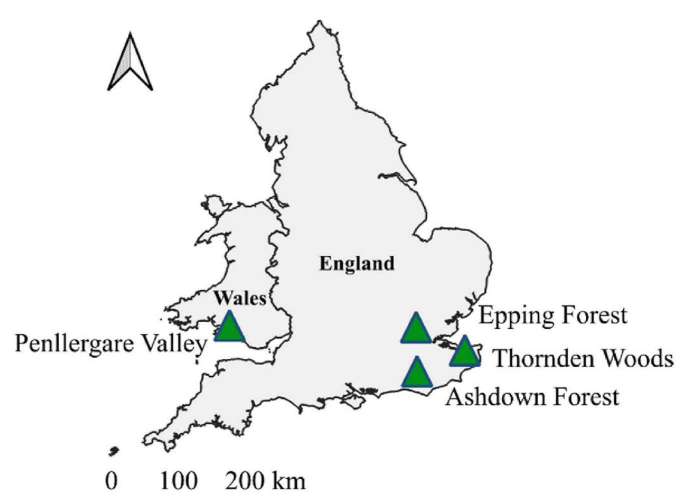

Fig. 1. Forest study sites in England and Wales. BIO-WELL was delivered to 510 participants in Epping Forest, Thorden Woods, Ashdown Forest (in England), and Penllergare Valley (in Wales) as part of a larger questionnaire.

to evening, weekday and weekends). This variation in timing of data collection helped to further maximise participation from different sectors of society, such as those with different work schedules, recreation patterns, or caring responsibilities.

2.3. Ethics

Participation was limited to those who were over 18 years of age and provided informed consent. Ethical approval was obtained from the University of Kent's School of Anthropology and Conservation Research Ethics Committee (REF: 20231680027029271).

2.4. Questionnaire development and delivery

The questionnaire was conducted face-to-face at different places within each of the forests to increase encounters with potential new participants. Tablets were used to deliver the questionnaire, hosted on the Qualtrics Offline app (Qualtrics, 2023). Paper copies of the same questionnaire were available if required by participants (e.g. for individuals limited computer literacy skills). QR codes were also made available for people wishing to complete the questionnaire on their own mobile devices.

BIO-WELL consists of 17 biodiversity stem questions, each with the same set of five wellbeing response items (Fig. 2; Table 1). The scale was developed using an exploratory sequential design and followed best practice for the construction of self-report scales (e.g. Boateng et al., 2018). The exploratory phase comprised a series of participatory and quantitative studies, examining how people interact with and experience biodiversity in forest settings (see Irvine et al., 2023 for details). Analysis identified not only the ways in which participants conceptualised biodiversity, but also how this related to their wellbeing. In this way, the scale is grounded in the everyday language of a range of participants from across Britain.

The original scale, developed for use *ex situ*, asks participants to '*imagine yourself in a nearby woodland…*'. We use the term 'woodland', rather than 'forest', as it is more commonly used and widely understood in England and Wales. For the scale to be conducted *in situ*, we amended this statement to *'think of the woodland you are in…*'. Participants were then asked to '*think about the living things, including the plants, fungi and animals (but not pets, horses, cows, sheep), in this woodland*', and to place a slider/mark at the point on a visual analogue scale (which represents a range of 1–100) that corresponds to their wellbeing in relation to a pair of anchor terms (Fig. 2). The five domains of wellbeing included physical wellbeing (functioning of the physical body and how one feels physically), emotional wellbeing (positive and negative emotion and mood), cognitive wellbeing (individual's thoughts about life and cognitive capacity to direct attention), social wellbeing (how individuals perceive connections with others) and spiritual wellbeing (meaning and connection to something greater than one's self) (Irvine et al., 2013; Kaplan & Kaplan, 1989; Linton et al., 2016; Ulrich, 1983; Ulrich et al., 1991).

Sociodemographic questions (gender, age, ethnicity, country of residence, urbanicity, gross annual household income, and level of education) were positioned at the start of the questionnaire. We also asked whether participants had been a member of any wildlife conservation or natural heritage organisations in the last five years (hereafter 'conservation membership').

Table 1
Biodiversity stem questions used within BIO-WELL scale. Stem questions ($n = 17$) investigate biodiversity metrics ($n = 5$) and attributes ($n = 12$) and their contribution to human wellbeing. Adapted from Irvine et al. (2023). All stem questions can be used independently or combined as needed.

Biodiversity stem questions	
Biodiversity metrics	
Encountering	1. *Encountering living things (e.g. plants, fungi and animals) in this woodland makes me feel …*
Abundance	2. *The number of living things (e.g. plants, fungi and animals) in this woodland makes me feel …*
Species diversity	3. *The variety of living things (e.g. plants, fungi and animals) in this woodland makes me feel …*
Species interactions	4. *The interactions between plants, fungi and animals (e.g. pollination, predator-prey) in this woodland make me feel …*
Ecological processes	5. *The living processes (e.g. decomposing, growing) that happen in this woodland make me feel …*
Biodiversity attributes	
Sound	6. *The variety of sounds in this woodland makes me feel …*
	7. *The distinctive sounds in this woodland make me feel …*
Colour	8. *The variety of colours in this woodland makes me feel …*
	9. *The vivid colours in this woodland make me feel …*
Shape	10. *The variety of shapes in this woodland makes me feel …*
	11. *The maturity of living things (e.g. plants, fungi and animals) in this woodland makes me feel …*
Texture	12. *The variety of textures in this woodland makes me feel …*
	13. *The sponginess of living things (e.g. plants, fungi and animals) in this woodland makes me feel …*
Smell	14. *The variety of smells in this woodland makes me feel …*
	15. *The woody smells in this woodland makes me feel …*
Behaviour	16. *Changes in this season make me feel …*
	17. *The presence of animals in this woodland makes me feel …*

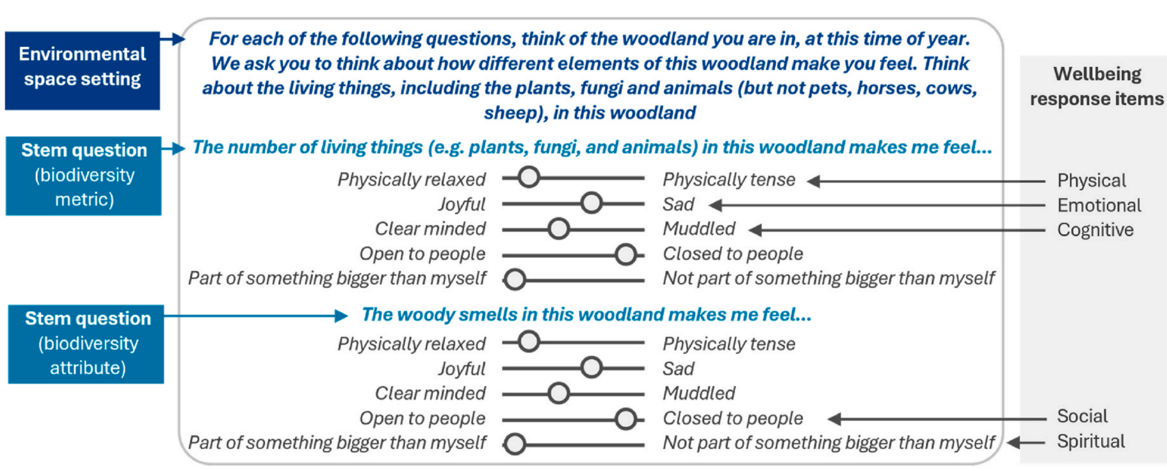

Fig. 2. BIO-WELL structure. Participants were asked to think about the woodland they were in and the biodiversity present at that place and time. The biodiversity stem questions ask about biodiversity metrics (e.g. abundance, species diversity) and attributes (e.g. smells, colours, shapes). Each stem question has five wellbeing response items reflecting physical, emotional, cognitive, social and spiritual wellbeing, presented in a visual analogue scale format between 1 and 100. Adapted from Irvine et al. (2023). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Concurrent validity (the extent to which scale scores have a relationship with other measurements taken at the same time; Boateng et al., 2018) was explored in several ways. First, participants were asked about their perceptions of forest biodiversity: '*What is this woodland like? Indicate the level of each* [biodiversity] *element you believe this woodland contains at this time of year*'. They were asked about three biodiversity elements: '*variety of sounds*', '*variety of smells*', and '*variety of colours*'. For each, responses were on a scale of 1 = high to 100 = low, with scores reversed for analysis. We also compared BIO-WELL scores between seasons, dividing the dataset into either spring (data collected in April) or summer (data collected in June), following Austen et al., (2023). We asked participants if they had any hearing, smell or sight impairments, each with a binary response option (yes/no). We hypothesised that those with impaired sensory systems would score lower on BIO-WELL, due to a reduced sensory experience of biodiversity *in situ*.

Participants were also asked three questions about time spent in nature, modified from an existing national survey (Natural England, 2019). These comprised of whether participants: (i) '*spent a lot of time visiting forests as a child*'; (ii) '*spent a lot of time visiting forests as a teenager*'; and, (iii) '*felt that spending time outdoors was an important part of their adult life*'. The response to each statement was a 5-point scale, from 1 = strongly disagree to 5 = strongly agree. Following Irvine et al. (2023), we hypothesised that those who spent more time in forests as a child or teenager, and felt that visiting outdoors was important to them, would score higher on BIO-WELL, as spending time in nature early in life enhances health outcomes and supports continued engagement with nature as an adult (Engemann et al., 2019; Evans et al., 2018). Finally, we tested whether those with an impaired sense would have higher BIO-WELL scores for other sensory attribute, due to compensatory mechanisms (e.g. Huber et al., 2019; Mediastika et al., 2020). For example, individuals with impaired vision may score higher for stem questions relating to the variety of sounds.

2.5. Analysis

All statistical analyses were conducted in R version 4.3.1 (R Core Team, 2023). We first calculated BIO-WELL scores for each participant, by taking a mean of all wellbeing response items for all biodiversity stem questions, giving an overall score between 1 and 100. These raw scores were then inverted, so that 50 was considered a neutral response to biodiversity, scores below 50 indicate a negative response, and scores above 50 denote a positive response.

Our total sample size comprised 510 participants (Table 2). We ensured that the sample size was determined according to best practices for scale development (Boateng et al., 2018; Comrey & Lee, 2013), such as having at least 10 participants per scale response item to reliably compare patterns (Guadagnoli & Velicer, 1988; Nunnally, 1975) (see Irvine et al., 2023 for details), and a minimum of 10 observations per independent variable used in statistical modelling (Austin & Steyerberg, 2015). We used a one-way ANOVA to test for differences in participant BIO-WELL scores between the four forest sites where the questionnaire was delivered, to confirm that it was appropriate to combine all the data together.

To understand how BIO-WELL scores varied among sociodemographic groups, we first conducted exploratory analyses and tested for differences in BIO-WELL scores between different levels within each sociodemographic group (gender, age, ethnicity, country of residence, urbanicity, gross annual household income, level of education, and conservation membership). We used two-sample t-tests for binary categorical variables, and one-way ANOVAs for those with more than two levels. Where sample sizes were small, we aggregated levels to maximise overall statistical power: age levels ([30–39 and 40–49] and [50–59, 60–69, and 70+]); ethnicities (White (Other), Asian (any), Black (any) and Other); country of residence (Wales and Scotland); gross annual household income levels ([<£5199, £5200-£10399, £10400-£15599, and £15600-£20799], [£20800-£25999, £26000-£31199, £31200-£36399, and £36400-£51999]; education levels ([No qualifications, 1–4 O Levels/CSEs/GCSEs, NVQ Level 1, 2+ A Levels, NVQ Level 3, BTEC National Diploma, Other qualifications (vocational/work related, foreign qualifications or level unknown), and 5+ O Levels/CSEs/GCSEs, NVQ Level 2, AS Levels, Higher Diploma, Diploma Apprenticeship], [Degree, Higher Degree, NVQ level 4–5, BTEC Higher Level, professional

Table 2
Sociodemographic characteristics of participants. Participants completed a questionnaire ($n = 510$) delivered *in situ* in four UK forests. BIO-WELL values > 50 indicate that participants derive positive wellbeing benefits from biodiversity, BIO-WELL values < 50 indicate that participants derive negative wellbeing benefits from biodiversity. Statistics indicate results of a *t*-test for variables with two levels, and a one-way ANOVA for those with more than two levels. The five participants who reported 'prefer not to say' for gender, and 85 who reported 'prefer not to say' for gross annual household income, were removed from each respective test.

Factor	n	%	BIO-WELL mean	BIO-WELL SD
Gender				
Woman	293	0.58	79.68	14.65
Man	212	0.42	76.40	15.77
$t(434) = 2.51, p = 0.02$				
Age				
18–29	184	0.36	78.10	13.99
30–49	180	0.36	79.17	14.90
50+	141	0.28	77.47	17.04
$F(2,502) = 0.52, p = 0.60$				
Ethnicity				
White - British	405	0.80	78.35	15.36
Other	100	0.20	78.09	14.59
$t(151) = -0.16, p = 0.90$				
Country of residence				
England	405	0.80	77.87	15.43
Scotland and Wales	100	0.20	80.08	14.19
$t(162) = -1.40, p = 0.20$				
Urbanicity				
Urban	327	64.75	78.45	14.70
Rural	183	36.24	77.85	15.97
$t(344) = -0.33, p = 0.70$				

Factor	N	%	BIO-WELL mean	BIO-WELL SD
Gross annual household income				
Low (Up to £20,799)	82	19.40	75.85	17.17
Middle (£20,800 to £51,999)	186	44.00	80.38	13.50
High (£52,000 and above)	155	36.60	78.98	13.53
$F(2,420) = 2.85, p = 0.06$				
Forest				
Ashdown Forest	27	5.35	80.03	11.82
Epping Forest	126	25.00	77.49	15.80
Penllergare Valley	118	23.34	80.51	13.98
Thornden Woods	234	46.30	77.43	15.76
$F(3,501) = 1.33, p = 0.26$				
Conservation membership				
Yes	169	33.47	77.53	16.10
No	336	66.53	79.85	13.15
$t(151) = -0.16, p = 0.90$				
Level of education				
Secondary/Other	222	43.96	77.11	16.57
Higher	283	56.04	79.24	13.99
$t(402) = -1.70, p = 0.08$				

qualifications (e.g. teaching, nursing, accountancy)]. Given that the total number of participants also reflects the time and resources available to collect responses from people who were encountered when visiting forests, we undertook a series of post-hoc power analyses. These analyses were conducted in the pwr package in R (Champely et al., 2020), assuming a medium effect size (Cohen's f = 0.25) and α = 0.05. All the power analyses indicate a high level of statistical power (≥0.99) (Supplementary Information Table S1), so the sample sizes were sufficient to detect differences within the sociodemographic groups (Cohen, 1988; Faul et al., 2007).

2.5.1. Reliability

We tested how reliable BIO-WELL was *in situ* through a measure of corrected item-total correlation, for each set of five wellbeing items per biodiversity metric or attribute stem question. This detects how well each item 'agrees' with the stem question (threshold >0.3; Boateng et al., 2018). Reliability was also measured using Cronbach's α, testing homogeneity amongst the response items for each stem question as an indication of how closely related these items are when considered as a group. This internal consistency is considered appropriate when values fall above a threshold of 0.7 (Cronbach, 1951; Nunnally, 1978). We used a parallel analysis, scree plots (visualising eigenvalues generated from the data matrix), and exploratory factor analysis to understand how wellbeing responses items loaded onto each stem question (Boateng et al., 2018). We examined these for a 1- and 2-factor structure per stem question.

2.5.2. Construct validity

To examine the dimensionality of the scale, we used a confirmatory factor analysis. This harnessed structural equation modelling to test whether our *in situ* data met the proposed 1-factor structure that was confirmed when BIO-WELL was developed and validated for an *ex situ* context (i.e. each biodiversity stem question demonstrates a 1-factor structure across five wellbeing domains) (Irvine et al., 2023). We employed maximum likelihood estimation with Santorra-Bentler scaled statistics, to ensure they are as robust as possible (Boateng et al., 2018). Model fit statistics were used to evaluate performance and adequacy. We report the Relative χ^2 (χ^2/degrees of freedom) ratio, given that χ^2 can reject well-fitting models in larger samples (Alavi et al., 2020). We interpreted these statistics as follows: Relative χ^2 (<5 is acceptable, <3 is good, <2 excellent); Comparative Fit Index (CFI) (≥0.95); Root Mean Squared Error of Approximation (RMSEA) and Confidence Intervals (CI) (<0.08 = acceptable, ≤0.06 = excellent); Standardised Root Mean square Residual (SRMR) (<0.08) (Browne & Cudeck, 1992; Hu & Bentler, 1999; Marsh & Hocevar, 1985). These statistical thresholds are considered together and in the context of our other findings, in light of recent criticisms of fixed cutoffs for model (mis)specification, particularly for 1-factor structures (Groskurth et al., 2024).

2.5.3. Concurrent validity

We used a general linear model with a negative binomial error structure to relate people's perceptions of the variety of sounds, smells, and colours associated with the biodiversity in the forest they were visiting, to the respective BIO-WELL stem questions, and calculated the 95 % confidence intervals. To examine whether BIO-WELL scores differed between seasons, we ran general linear models with a negative binomial error structure for each biodiversity stem question, with season as a predictor and forest site as a covariate (given that the forests were visited sequentially during the data collection period). To test whether BIO-WELL scores were associated with time spent in forests/outdoors as a child, teenager, and adult, respectively, we used one-way ANOVAs and Tukey's post-hoc tests. Finally, we used t-tests to explore differences in BIO-WELL scores between those with and without sensory impairments, and for the presence of compensatory sensory mechanisms.

3. Results

3.1. Participant overview

The questionnaire took approximately 20 minutes to complete on average. There were no statistical differences in BIO-WELL scores reported in each forest (Table 2), so it was appropriate to combine all the data together. Participants were roughly evenly spread across genders and ages, and were predominantly white British. They mostly lived in England, particularly urban areas, and were from middle income households. Participants reported a wide range of wellbeing responses to biodiversity (13.7–100), although positive on average (BIO-WELL scale mean = 78.23, where >50 is deemed positive). BIO-WELL scores were significantly higher for participants who were women, but there were no statistical differences for age, ethnicity, country of residence, urbanicity, gross annual household income, level of education, or conservation membership (Table 2).

3.2. Reliability

Corrected item-total correlations for all items were between $r = 0.54$ and 0.94, meeting the acceptable threshold. Across stem questions, values of Cronbach's α ranged between 0.88 and 0.93, with a mean of 0.91, well above the recommended threshold for internal consistency (Supplementary Information Table S2). This shows that BIO-WELL can be reliably used *in situ*, using the set of five wellbeing response items for each stem question. Our scree plots and parallel analyses suggested a 1-factor structure was appropriate for each stem question. However, the factor loadings for the living processes stem question were not statistically different from zero, indicating possible conceptual issues with this construct when considered by participants *in situ*. Factor loadings indicated that all items were retained for all stem questions.

3.3. Construct validity

The confirmatory factor analysis indicated that the 1-factor structure of each BIO-WELL stem question was partially supported (Table 3). Nearly all models achieved high CFI and SRMR values within the required thresholds for good fit, indicating unidimensionality. However, for some stem questions, model statistics deviated from acceptable fit, indicating possible heterogeneity in wellbeing responses to particular biodiversity stem questions *in situ*. The most stable biodiversity metric and attribute stem questions across multiple model fit statistics included encountering living things, number of living things, interactions between living things, and sponginess of living things. Following the exploratory factor analysis, the stem question for living processes exhibited perfect fit, indicating the items did not form a meaningful factor. Across the remaining stem questions, when considered alongside the factor loadings from the exploratory factor analysis (Supplementary Information Table S2), the confirmatory factor analysis supports the retention of a unidimensional structure across all wellbeing domains for theoretical parsimony and comparability.

3.4. Concurrent validity

Participants who perceived a high variety of sounds, smells, and colours associated with the biodiversity in the forest they were visiting reported higher BIO-WELL scores in response to the stem questions about the variety of sounds, variety of smells, and variety of colours, respectively (sounds: $\beta = 0.39$, 95 % CI [0.26, 0.52], $t(508) = 5.92$, $p < 0.001$; smells: $\beta = 0.21$, 95 % CI [0.09, 0.32], $t(508) = 3.48$, $p < 0.001$; colours: $\beta = 0.37$, 95 % CI [0.24, 0.51], $t(508) = 5.61$, $p < 0.001$) (Fig. 3).

When comparing BIO-WELL scores between seasons, we found two differences for the stem questions on the variety of living things and interactions between living things, with participants reporting

Table 3

Confirmatory factor analyses for BIO-WELL. Confirmatory factor analysis of a proposed 1-factor structure for five wellbeing response items for each of the 17 biodiversity stem questions that comprise BIO-WELL for use *in situ* (n = 510 participant responses). Each model is run using a maximum likelihood estimator, with reported scaled values. Good model fit is indicated where: Relative χ^2 is < 2, comparative fit index (CFI) is > 0.95, Root Mean Squared Error of Approximation (RMSEA) and confidence intervals (CI) are each <0.06, and Standardised Root Mean square Residual (SRMR) is < 0.08.

Biodiversity stem question	χ^2/df	CFI	RMSEA	RMSEA 10 % CI	RMSEA 90 % CI	SRMR
1. Encountering living things	1.661	0.994	0.036	0.000	0.067	0.023
2. Number of living things	2.818	0.986	0.060	0.033	0.088	0.024
3. Variety of living things	5.901	0.964	0.098	0.075	0.123	0.032
4. Interactions between living things	3.089	0.989	0.064	0.044	0.085	0.027
5. Living processes	0.292	1.000	0.000	0.000	0.000	0.005
6. Variety of sounds	5.645	0.964	0.095	0.071	0.122	0.031
7. Distinctive sounds	5.941	0.961	0.098	0.072	0.127	0.028
8. Variety of colours	5.899	0.965	0.098	0.078	0.119	0.036
9. Vivid colours	5.806	0.962	0.097	0.076	0.119	0.040
10. Variety of shapes	3.242	0.987	0.066	0.045	0.089	0.023
11. Maturity of living things	3.250	0.986	0.066	0.040	0.095	0.021
12. Variety of textures	6.153	0.979	0.101	0.079	0.124	0.035
13. Sponginess of living things	2.734	0.995	0.058	0.037	0.080	0.026
14. Variety of smells	8.580	0.963	0.122	0.097	0.149	0.041
15. Woody smells	7.124	0.961	0.110	0.084	0.137	0.037
16. Changes in this season	3.697	0.983	0.073	0.050	0.097	0.029
17. Presence of animals	8.287	0.959	0.120	0.094	0.146	0.029

statistically higher scores in spring compared to summer (Fig. 4). Participants who reported that spending time outdoors was an important part of their lives had significantly higher BIO-WELL scores (Fig. 5).

Most participants had no sensory impairments related to their hearing (n = 493, 97 %), smell (n = 493, 86 %), or sight (n = 475, 93 %). The BIO-WELL scores for individuals who had impairments did not differ from those who did not (Fig. 6). Moreover, those with impairments to their sense of smell did not report higher BIO-WELL scores in response to the variety of colours stem question (t(91.694) = -0.119, p = 0.905) or the variety of sounds (t(94) = -0.28, p = 0.800), those with an impaired sense of sound did not report higher BIO-WELL scores for the variety of smells (t(17.696) = -0.055, p = 0.957) or the variety of colours (t(18) = 1.3, p = 0.2), and those with sight impairments did not report higher BIO-WELL scores for the variety of sounds (t(36.513) = -1.410, p = 0.167) or the variety of smells (t(38) = -1.3, p = 0.200).

4. Discussion

To enhance beneficial interactions with nature to support human health and wellbeing, we need a deeper understanding of the role played by biodiversity (Bartkowski et al., 2015; Sandifer et al., 2015). This is crucial at a time when there are increasingly urgent calls to create, protect, and restore biodiverse natural environments in the face of global environmental change (Keck et al., 2025). To help align efforts to conserve biodiversity and improve public health, we sought to understand the performance of BIO-WELL, a self-report biodiversity-wellbeing psychometric scale (https://research.kent.ac.uk/bio-well/; Irvine et al., 2023) *in situ* within four British forests.

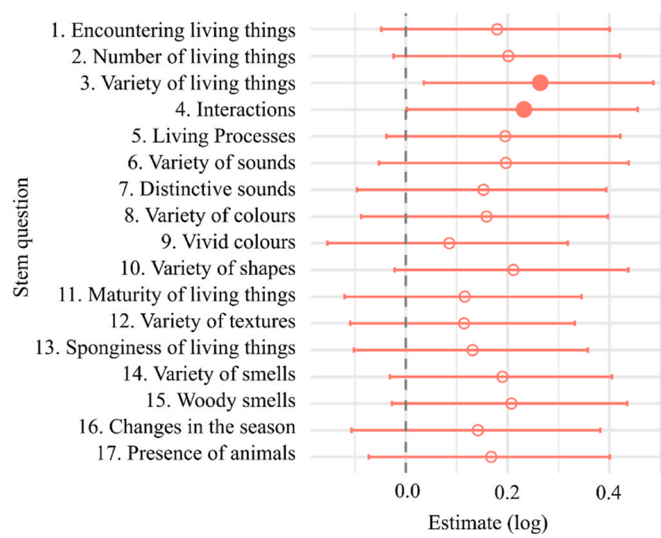

Fig. 4. BIO-WELL scores in spring compared to summer. Parameter estimates and 95 % confidence intervals for the 17 biodiversity stem question models investigating whether season influences BIO-WELL scores. Plot represents scores for spring, when compared with summer as the reference category. Centre circle is the estimate, which is considered significant if the confidence intervals do not cross zero (centre circle filled). The association is determined to be negative if the confidence intervals fall below 0, and positive if above.

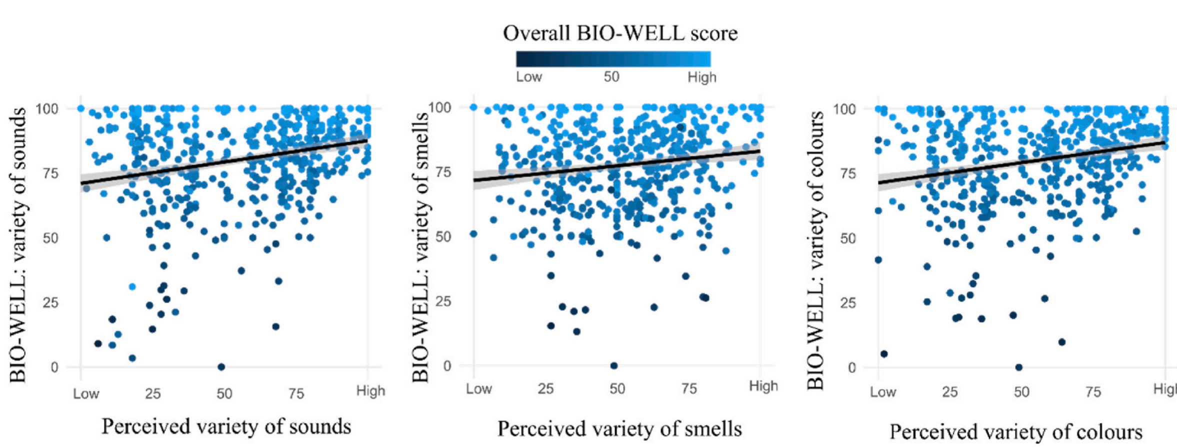

Fig. 3. Associations between perceptions of forest biodiversity and three BIO-WELL stem questions. Participants were asked about the variety of sounds, smells, and colours they perceived to be associated with the biodiversity in the forest they were visiting, which were related to the respective BIO-WELL stem questions. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

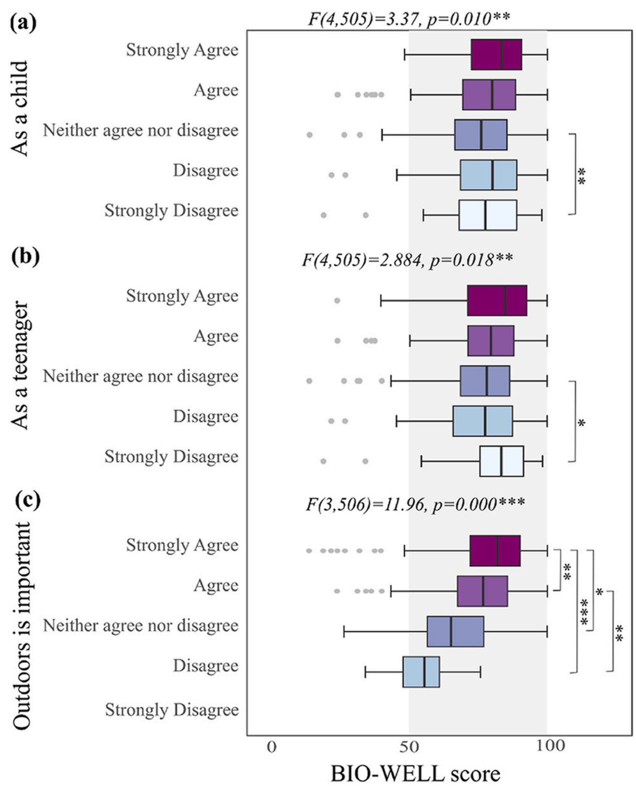

Fig. 5. BIO-WELL scores in relation to time visiting forests growing up and time outdoors being important. BIO-WELL scores according to participant responses ($n = 510$) when asked whether they spent a lot of time visiting forests (a) as a child, (b) as a teenager, and (c) whether they feel that spending time outdoors is an important part of their life. No participants indicated that they 'strongly disagree' in response to (c). Asterisks indicate the level of statistical significance as determined a Tukey's post-hoc test (*** $= p < 0.001$, ** $= p < 0.01$, * $= p < 0.05$). Shaded right hand side indicates where BIO-WELL scores are >50, the threshold at which responses to biodiversity are deemed positive.

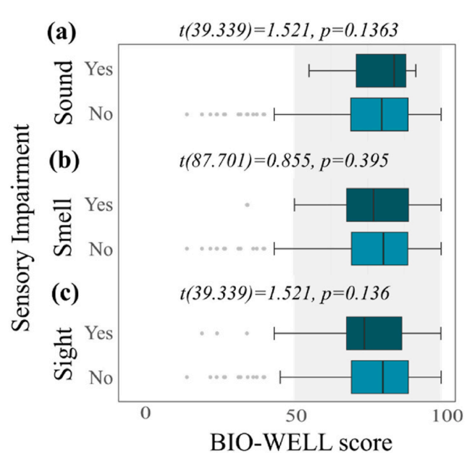

Fig. 6. BIO-WELL scores in relation to sensory impairments. BIO-WELL scores according to participant responses ($n = 510$) when asked whether they had any impairments to their sense of (a) sound, (b) smell, or (c) sight. Grey box indicates where BIO-WELL scores are >50, the threshold at which responses to biodiversity are deemed positive.

BIO-WELL demonstrated internal consistency, good construct validity and strong concurrent validity, reflecting reliable performance *in situ*. The varying results in dimensionality between stem questions indicate possible heterogeneity in how individuals conceive some forest biodiversity metrics and attributes experienced *in situ*, compared to *ex situ* (Irvine et al., 2023). However, other metrics and attributes of biodiversity (encountering living things, number of living things, interactions between living things, and sponginess of living things) resonated more consistently across participants in forest settings *in situ*, highlighting the strength of the scale in detecting real-world conditions. Future applications of BIO-WELL *in situ*, in a context other than forests, may benefit from researchers/practitioners undertaking cognitive interviews and piloting the scale before deployment, to identify which stem questions are most salient to participants. As all the BIO-WELL stem questions can be used independently or combined as needed (see Irvine et al., 2023 for details), this would potentially allow the number of stem questions to be reduced as necessary (e.g. if any appear redundant) to reduce participant burden.

Participants who felt that spending time outdoors was important to them reported significantly greater BIO-WELL scores in response to biodiversity *in situ*, reflecting findings when the scale was conducted *ex situ* (Irvine et al., 2023). These differences between participant sub-groups supported concurrent validity, indicating the scale behaves as hypothesised based on theoretical and empirical evidence (Boateng et al., 2018). Longitudinal research suggests that early-life experiences outdoors, such as in green spaces, can lead to positive psychological benefits as an adult (Engemann et al., 2019), with subsequent impacts such as increased pro-environmental behaviour (Evans et al., 2018). Collecting BIO-WELL data across the life course, focusing on the same environmental setting, could further reveal whether the wellbeing people derive from nature-based experiences increases with age, with implications for decision-makers seeking to enhance contact with biodiversity starting early in life. However, it is important to note that the sample of those who participated in our study may not be representative of the wider population, given they were already visiting a forest environment when they completed the questionnaire. Additionally, they may also be aware of the health and wellbeing benefits of spending time in nature. This is corroborated by an absence of participants reporting that they '*strongly disagree*' when asked whether spending time outdoors is an important part of their adult life.

We found no differences in BIO-WELL scores between individuals who did and did not have sensory impairments. These findings contrast with those of the *ex situ* validation of BIO-WELL, where those with sensory impairments scored significantly lower (Irvine et al., 2023). We also found no evidence for compensatory mechanisms between senses, whereby some may intensify where another is impaired (e.g. Huber et al., 2019; Mediastika et al., 2020). It may be that the participants visiting the forests were less likely to have sensory impairments, given that such an experience may return diminished wellbeing benefits (e.g. Boucherit et al., 2023). In addition, despite the extensive participatory qualitative work that underpinned the development of BIO-WELL, participants may have experienced sensory attributes of the forest that were different from those represented by the stem questions. A greater understanding of how sensory experiences of biodiversity impact the wellbeing of people with sensory impairments would be particularly valuable for informing how to optimise nature-based interventions to improve health and wellbeing outcomes (e.g. designing a 'wellbeing garden', Harries et al., 2023).

For two BIO-WELL stem questions, about species diversity and species interactions, we found statistically higher BIO-WELL scores in spring compared to summer, indicating differences in seasonal experiences of biodiversity *in situ*. This is could be because of greater biodiversity activity in spring (Li et al., 2024; Newson et al., 2016), such as migratory bird species returning to the UK or more understory wildflowers and, consequently, pollination. Given that our four forest sites were biodiverse broadleaf and ancient woodland ecosystems, this result may not have been apparent if the study had been conducted in just coniferous forests, which would be characterised by a different ecological community (Richardson et al., 2010).

Our findings support the use of BIO-WELL for providing insights into how biodiversity can influence wellbeing across physical, emotional, cognitive, social and spiritual domains. For instance, there is increasing interest in longitudinal studies to establish the impacts of green prescribing, evaluate the success of nature-based interventions, and exposure to the 'doses' of nature (e.g. hours, weeks, months) needed to deliver health and wellbeing gains (Shanahan et al., 2016; White et al., 2019). In this context, BIO-WELL could be used to measure participant wellbeing pre- and post-intervention to assess effectiveness. Indeed, BIO-WELL could be disaggregated into its constituent individual wellbeing domains (e.g. emotional wellbeing) to investigate the impacts of biodiversity with more specificity. The human wellbeing outcomes of conservation action to improve biodiversity could also be assessed. Trends in objective biodiversity data collected on sites could be examined in association with the BIO-WELL stem questions that reflect ecological metrics (e.g. variety of living things equating to species richness, or the number of living things equating to abundance). This would provide an opportunity to assess how improving biodiversity, either spatially in various locations across a landscape or temporally, could lead to improved human wellbeing. While the BIO-WELL scale was tested *in situ* in forests, the scale is flexible enough to facilitate its adaptation to other environments. This could be straightforward, changing words within the stem questions (e.g., 'woody smells' becomes 'grassy smells' for a grassland ecosystem), although we would recommend undertaking a participatory process to determine the most pertinent words to switch to in the new environmental context.

In conclusion, testing BIO-WELL *in situ* enabled us to evaluate participant experiences of biodiversity in relation to their wellbeing in real time. BIO-WELL therefore complements and extends the existing set of tools for understanding the effect of natural environments on human health and wellbeing, but with a specific focus on biodiversity. BIO-WELL is built upon a strong qualitative and theoretical underpinning (Irvine et al., 2023), and can be used to further explore the relationship between biodiversity and wellbeing both *in situ* and *ex situ*. It can be applied to unpack the influence of ecological knowledge or exposure, determine the effect of interventions to improve public health or enhance the biodiversity in an environment (e.g. nature recovery actions), or compare similar environments (e.g. two wetlands) with differing levels of biodiversity. Gaining a deeper understanding of the interconnectedness between biodiversity conservation and human health and wellbeing is an important step in addressing global environmental change and its associated impacts on both people and ecosystems. BIO-WELL is one scale that can be used to quantify this relationship, offering a valid and reliable metric that is flexible and easy to use. It is the first self-reported psychometric scale that has been validated for use *ex situ* and *in situ*, accounting for standard metrics of biodiversity (e.g. species richness, abundance) as well as the sensory components of people's experiences (e.g. sounds, smells, colours), across multiple domains of human wellbeing. We encourage researchers and practitioners to use BIO-WELL, alongside other such tools, to contribute to the evidence-base that supports the improvement of our ecosystems for biodiversity and people.

CRediT authorship contribution statement

F. Jones: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation. **J.C. Fisher:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Formal analysis. **G.E. Austen:** Writing – review & editing, Supervision, Project administration. **K.N. Irvine:** Writing – review & editing, Supervision, Methodology, Conceptualization. **M. Dallimer:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **L. Croager:** Writing – review & editing, Investigation, Formal analysis, Data curation. **M. Nawrath:** Writing – review & editing, Methodology. **R.D. Fish:** Writing – review & editing, Funding acquisition. **Z.G. Davies:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interests

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2025.102897.

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