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TOPICAL REVIEW

A one health sustainability framework for ecologically mediated nature-based wellbeing

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Abstract

Human health benefits associated with nature exposure are increasingly recognised in public health and environmental policy. However, most evidence linking nature and wellbeing relies on broad anthropogenic exposure proxies, including greenness indices, land-cover categories, and self-reported visit frequency, rather than ecological measures capturing biodiversity, habitat condition, or ecosystem functioning. Consequently, the ecological conditions that mediate health benefits, their exposure–response relationships, and the long-term sustainability of nature-based wellbeing interventions remain poorly understood. Here we examine how current research integrates human health, ecological integrity, and sustainability dimensions within nature-based wellbeing research. A targeted evidence synthesis confirms that most research is conducted in urban or human-modified environments and relies predominantly on coarse spatial proxies or categorical exposure contrasts, with limited incorporation of ecological quality, biodiversity, or environmental pressures. Critically, ecological costs and feedbacks associated with nature use, including habitat disturbance, visitor pressure, and infrastructure expansion, are rarely accounted for in assessments of health outcomes. We propose a one health sustainability framework that conceptualises nature-based wellbeing as an emergent property governed by ecological integrity, biodiversity-mediated pathways, environmental pressures, and long-term sustainability feedbacks. Extending one health beyond its traditional focus on zoonotic disease, this framework links human wellbeing outcomes to ecological condition and sustainability constraints, enabling assessment of exposure efficiency and the capacity of ecosystems to sustain health benefits under increasing demand. Embedding ecological integrity and sustainability dynamics within nature-based wellbeing research provides a basis for developing integrated indicators that can evaluate not only whether nature exposure benefits health, but also under what ecological conditions such benefits remain equitable and durable over time.

1. Introduction

The intentional use of natural environments to promote human health and wellbeing is rapidly gaining global interest, as health systems, public health agencies, and emerging wellbeing economies seek preventive, low-cost, and non-pharmacological interventions (Bratman *et al* 2019, Martin *et al* 2020). Nature-based social prescribing, green care, forest therapy, and blue space interventions increasingly position nature exposure as a modular and value-accruing strategy for improving mental, physical, and social health (Müller-Riemenschneider *et al* 2020). At the same time, accelerating urbanisation, biodiversity loss, climate-related stressors, and rising burdens of non-communicable disease have intensified interest in understanding how interactions with nature contribute to human resilience and wellbeing (Marselle

et al 2021, Pascual *et al* 2023). Despite rapidly growing scientific and policy attention, the evidence base supporting nature-based health interventions still remains fragmented, and difficult to translate into ecologically robust and sustainable practice.

A major limitation is that uncertainty persists regarding the types, durations, frequencies, and ecological qualities of nature exposure required to yield measurable health outcomes (Barton and Pretty 2010, Shanahan *et al* 2015, White *et al* 2019). Most studies rely on coarse proxies of exposure such as greenness indices, land-cover classifications, park proximity, or self-reported visits, rather than ecological metrics reflecting biodiversity, habitat condition, ecological integrity, or ecosystem functioning (Cardinale *et al* 2012, Southon *et al* 2018, Twohig-Bennett and Jones 2018, Bratman *et al* 2019). In this context, ecological integrity refers to the extent to which ecosystems retain native biodiversity, ecological structure, functional processes, and characteristics of relative 'naturalness' despite anthropogenic pressures. Although such proxies capture general vegetation presence or access to green and blue spaces, they provide limited insight into the ecological systems and processes that may mediate health outcomes. As a result, existing evidence remains insufficient to determine whether health outcomes vary systematically across ecological gradients, biodiversity levels, or habitat conditions, or whether different forms of nature exposure produce distinct physiological, psychological, or social responses. More fundamentally, this highlights an unresolved conceptual challenge: the health benefits derived from nature are not determined solely by the presence of exposure, but by the efficiency of that exposure, namely the extent to which ecological conditions translate into measurable health gains under different levels of environmental quality, biodiversity, and human demand. From this perspective, nature cannot be treated as a uniform or unlimited health intervention. Rather, it should be understood as a constrained socio-ecological system in which health outcomes are shaped by ecological integrity, exposure characteristics, and broader system pressures. Despite the importance of this perspective, empirical research has not yet systematically conceptualised, quantified, or modelled these exposure-efficiency relationships within a sustainability framework.

Emerging evidence suggests that ecological quality may influence human wellbeing through multiple interacting pathways, including sensory richness, biodiversity perception, microbial and environmental exposure, thermal regulation, opportunities for physical activity, social cohesion, and restorative experiences (Weinstein *et al* 2018, Roslund *et al* 2020, Marselle *et al* 2021). For example, bird diversity and birdsong have been associated with psychological restoration and positive affect, while vegetation complexity, flower diversity, and habitat heterogeneity may influence perceived wellbeing and restorative experiences. Ecological exposure may also shape human health through physiological and immunological pathways linked to environmental microbial interactions and dietary diversity that contribute to immune regulation and resilience (Mills *et al* 2017, Hanley-Cook *et al* 2025). At the same time, interactions with biodiverse environments may also involve ecological hazards, including allergens, pathogens, parasites, or vector-borne disease risks, highlighting the need to understand nature-health relationships as complex, context-dependent socio-ecological processes rather than uniformly beneficial exposures.

This complexity is increasingly relevant because the institutionalisation of nature-based wellbeing interventions introduces a sustainability challenge. Nature-based health initiatives are frequently promoted as simultaneously benefitting human wellbeing and environmental stewardship by encouraging engagement with natural environments. However, as demand for recreational, therapeutic, and prescribed nature exposure increases, ecological systems may experience cumulative pressures including habitat disturbance, infrastructure expansion, visitor congestion, wildlife disruption, and resource degradation. These pressures may erode ecological integrity and reduce the very environmental conditions that generate health benefits, creating a potential sustainability paradox in which short-term wellbeing gains contribute to long-term ecosystem decline.

This challenge aligns with broader concerns in planetary health regarding the interdependence of human wellbeing and environmental stability (Whitmee *et al* 2015). Related frameworks, including one health, socio-ecological systems theory, ecosystem services, nature's contributions to people, and nature-based solutions, have each advanced understanding of coupled human–environment systems (Díaz *et al* 2018, Seddon *et al* 2020). However, most have not sufficiently integrated exposure–response relationships in nature-based wellbeing with ecological integrity and sustainability constraints.

Here, we extend one health in a socio-ecological sense that emphasises the interdependence between human health, ecological integrity, biodiversity, environmental processes, and long-term system resilience, rather than focusing narrowly on zoonotic disease (One Health High-Level Expert *et al* 2022). Within this framing, nature-based wellbeing emerges from coupled human–nature systems shaped by ecological conditions, biodiversity-mediated pathways, and environmental pressures. Ecological degradation and biodiversity loss may therefore not only reduce the availability of nature exposure but also alter the quality and efficiency with which health benefits are generated.

Despite growing recognition of these interdependencies, current research remains fragmented, with limited capacity to link ecological conditions, exposure characteristics, health outcomes, and

sustainability constraints within a unified analytical structure. In particular, there is currently no coherent framework for evaluating how efficiently nature exposure produces health benefits under varying ecological conditions and levels of human demand, or how these relationships change as ecosystems experience increasing pressure.

We propose a one health sustainability framework for nature-based wellbeing that integrates human health outcomes, ecological integrity, biodiversity-mediated exposure pathways, environmental pressures, and sustainability dynamics. We first draw on a targeted evidence synthesis to identify commonly used exposure approaches and health and wellbeing measures. We then introduce a conceptual framework designed to integrate exposure efficiency, ecological condition, and sustainability constraints, providing a basis for evaluating not only whether nature exposure benefits health, but also under what ecological conditions such benefits can be maintained, and equitably distributed over time. We argue that nature-based wellbeing should be understood not as a universally standardisable public health intervention, but as a sustainability-constrained socio-ecological process whose effectiveness depends on ecological integrity, biodiversity-mediated pathways, and the capacity of ecosystems to sustain increasing human demand.

2. Insights from a targeted evidence synthesis

To examine how current research integrates human health, ecological, and sustainability dimensions of nature-based wellbeing, we conducted a targeted evidence synthesis (Garritty *et al* 2024) of influential studies at the human–nature interface. Using a structured Web of Science search (2015–2025) combined with citation-rate-based prioritisation, we selected 54 peer-reviewed articles spanning public health, ecology, environmental science, and sustainability. This exploratory synthesis was intended to identify dominant conceptual and methodological patterns in influential studies and to inform development of the proposed framework, rather than provide a comprehensive or systematic mapping of the field. Eligible studies were selected based on relevance to nature exposure and measurable human health outcomes. Data were extracted using a structured AI-assisted template and subsequently verified and refined manually. The included studies were then synthesised using standardised taxonomies covering health outcomes, environmental context, and exposure characteristics, enabling cross-domain comparison of ecological quality, environmental pressures, and sustainability considerations (supporting information).

Most research on health-nature relationships has been conducted in urban, managed, or otherwise human-modified settings rather than across ecosystems characterised by clearly defined gradients of ecological integrity, habitat condition, and anthropogenic disturbance (supporting information, table S2). Exposure assessments were dominated by anthropocentric, landscape-scale indicators such as the normalised difference vegetation index (NDVI), land-cover percentages, proximity-based metrics or self-reported visit frequency (Wheeler *et al* 2015, Martin *et al* 2020), rather than by ecological metrics that capture biodiversity, habitat condition, or ecosystem function. While such proxies capture broad vegetation patterns or access to green space, they do not adequately reflect gradients in ecological integrity, biodiversity, habitat condition, or ecosystem functioning, and therefore provide limited insight into the ecological systems and processes hypothesised to generate health benefits. Using our dose-response evidence taxonomy, we found that most studies relied on spatial proxies or categorical contrasts, and only rarely reported interpretable exposure–response functions (supporting information, table S3). Although dose-response terminology is widely used within nature-health research, we primarily adopt the broader term exposure–response throughout this paper to reflect the multidimensional and context-dependent character of nature exposure, including variation in ecological quality, biodiversity, environmental conditions, and patterns of human engagement. Few studies identified threshold or plateau patterns, or used longitudinal or quasi-experimental designs that enable stronger causal or prescribable inferences. Reported effects primarily quantified exposure quantity (for example NDVI increments, green space proximity or visit frequency), but almost none assessed whether associations vary with ecosystem integrity, biodiversity or socio-demographic context. Consequently, the evidence base remains too limited to evaluate how exposure–response relationships depend on ecological integrity or to inform robust, transferable guidance for nature-based health interventions.

Ecological costs and trade-offs were also rarely examined. Well-documented consequences of anthropogenic pressure such as habitat disturbance, visitor impacts, wildlife disruption, trampling, resource extraction or pollution were rarely incorporated into analyses, despite their importance for long-term ecosystem stability (Buckley 2011, Balmford *et al* 2015). This lack of attention to environmental impacts limits our ability to determine whether health-promoting interventions are ecologically sustainable or whether they risk degrading the ecosystems on which future human health depends.

3. Reframing nature-based wellbeing through a one health sustainability perspective

Much of the evidence linking nature exposure with improved mental, physical, and social wellbeing remains based on broad exposure proxies such as greenness indices, park proximity, or self-reported visitation. Although these measures have enabled large-scale epidemiological research, they provide limited insight into the ecological characteristics, biodiversity, and ecosystem processes that may shape variation in health outcomes across environmental gradients. This limitation is increasingly important in highly urbanised societies where direct interactions with biodiverse and ecologically intact environments are often reduced. While many forms of green exposure may still generate psychological or physiological benefits, nature–health relationships are unlikely to depend solely on vegetation presence or recreational access. Simplified or heavily managed greenspaces may differ substantially from more biodiverse and ecologically functional environments in habitat complexity, sensory diversity, ecological functioning, microbial exposure, and restorative potential. Biodiversity, vegetation structure, birdsong, environmental microbiomes, and ecosystem functioning may all contribute to psychological restoration, immune regulation, social wellbeing, and resilience through multiple interacting ecological and socio-environmental pathways.

At the same time, ecological degradation may progressively alter both the quality of available nature exposure and societal perceptions of what constitutes 'natural' or healthy environments. As urbanisation and environmental simplification intensify, there is a risk that increasingly depauperate or fragmented forms of greenspace become normalised as adequate substitutes for more ecologically intact environments, potentially obscuring relationships between ecological integrity and long-term wellbeing outcomes. Ecological exposures may also involve hazards and trade-offs, including allergens, pathogens, parasites, or vector-borne disease risks shaped by wildlife communities, ecosystem condition, and landscape change.

Nature–health relationships are therefore context dependent rather than uniformly beneficial, and both positive and negative exposure pathways may vary across ecological gradients and socio-environmental conditions. Understanding these coupled dynamics is critical not only for clarifying exposure–response relationships, but also for determining where, how, and under which ecological conditions nature-based wellbeing interventions can maximise long-term health benefits while remaining ecologically sustainable.

These questions become even more significant as nature-based interventions are increasingly institutionalised through social prescribing, recreation, ecotourism, therapeutic landscapes, and commercial wellbeing sectors. Although such initiatives are often promoted as simultaneously benefitting human wellbeing and environmental stewardship, growing demand for nature-based experiences may also intensify pressures on ecosystems through habitat disturbance, infrastructure development, transport emissions, and increasing visitor density. If wellbeing benefits depend partly on ecological integrity or biodiversity-mediated experiences, then ecological degradation may progressively undermine the quality and sustainability of the very health benefits being promoted. Conversely, stronger recognition of the ecological foundations of wellbeing could create incentives for restoration, conservation, and equitable access to high-quality environments.

Although one health has traditionally focused on the interconnections between human, animal, and environmental health, its broader systems-oriented perspective provides a useful basis for reframing nature–health relationships as coupled socio-ecological processes shaped by biodiversity, ecological integrity, and environmental change rather than simple exposure effects alone. However, these interconnected human-biodiversity-environment feedbacks have rarely been integrated within frameworks capable of simultaneously evaluating ecological integrity, biodiversity-mediated exposure pathways, dose-response relationships, environmental pressures, and long-term sustainability constraints in nature-based wellbeing research. Addressing this gap requires a more integrative perspective capable of linking human wellbeing outcomes with the ecological systems and sustainability dynamics that support them. We therefore propose a one health sustainability framework for nature-based wellbeing that conceptualises health benefits from nature exposure as emerging from coupled socio-ecological systems shaped by ecological integrity, environmental pressures, biodiversity-mediated pathways, and sustainability feedbacks.

4. Towards a one health sustainability framework for nature-based wellbeing

Taken together, these insights reveal not only important evidence gaps but also broader disciplinary limitations in the ways nature-health relationships have traditionally been conceptualised and measured. Human health outcomes of exposure to nature are increasingly well documented, yet the ecological conditions underpinning these outcomes and the sustainability of nature-based wellbeing interventions remain insufficiently measured (Robinson *et al* 2024). In an era of accelerating biodiversity loss, fragmented landscapes, and climate-driven hazards (Rockström *et al* 2023), as well as

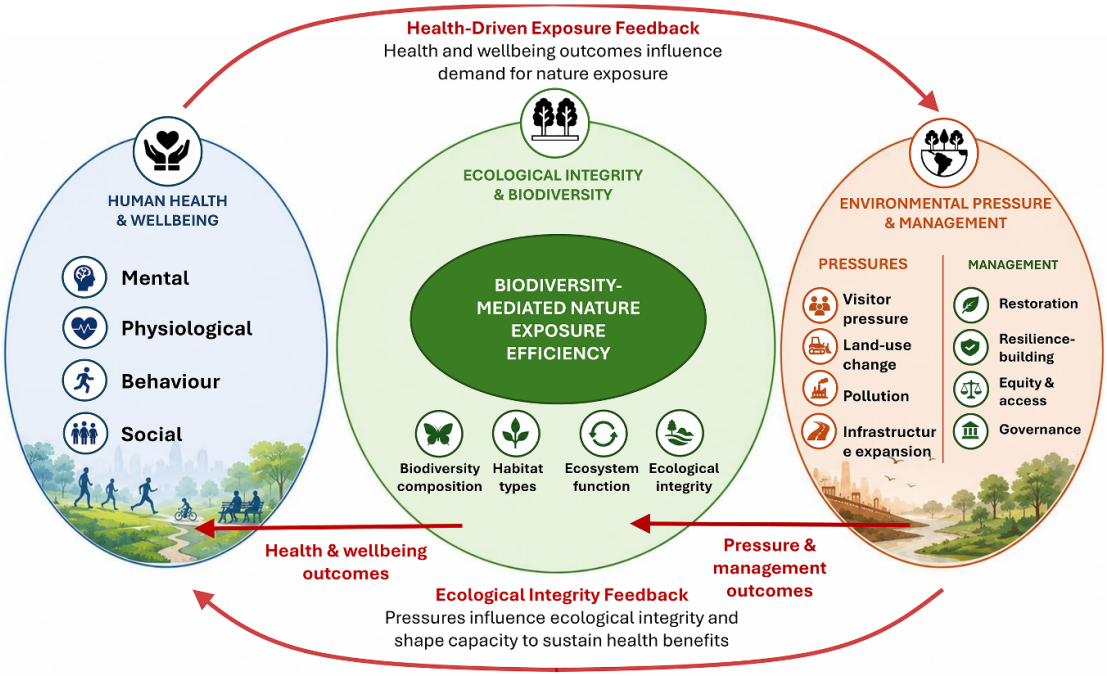

Figure 1. A one health sustainability framework for nature-based wellbeing. Human health and wellbeing outcomes are conceptualised as emerging from coupled socio-ecological systems shaped by ecological integrity, biodiversity, environmental pressures, and sustainability feedbacks. Ecological integrity and biodiversity influence the efficiency with which nature exposure generates mental, physiological, behavioural, and social wellbeing outcomes through biodiversity-mediated exposure pathways. Environmental pressures including visitor intensity, land-use change, pollution, and infrastructure expansion, together with management outcomes such as restoration, resilience-building, equitable access, and governance shape ecosystem condition and influence the long-term capacity of environments to sustain health benefits. Feedbacks between wellbeing outcomes, increasing demand for nature exposure, and environmental pressure and management outcomes highlight the dynamic and potentially self-limiting nature of nature-based wellbeing systems.

rising demand for nature-based wellbeing services (Haukeland *et al* 2023), this gap is increasingly untenable.

To address this, we propose a unifying one health sustainability framework that explicitly integrates four interlinked domains:

(1) Human health outcomes and modes of exposure and engagement with natural environments,

(2) Local habitat condition and ecological integrity,

(3) Landscape-level environmental pressures and hazards, and

(4) Sustainability, restoration, and human equity and justice considerations.

The framework conceptualises nature-based wellbeing as an emergent property of coupled socio-ecological systems in which human health benefits both depend upon and potentially influence ecological integrity and long-term sustainability dynamics. By linking these dimensions, the framework provides a structured approach for synthesising ecological and health evidence, identifying meaningful indicators, guiding interdisciplinary research, and informing policies that ensure nature-based interventions are both effective for human wellbeing and ecologically sustainable (figure 1; table 1).

Although the framework is conceptual, its constituent domains are measurable using existing ecological, health, and socio-environmental monitoring approaches. Ecological integrity can be characterised through indicators of biodiversity, habitat condition, ecosystem functioning, and environmental quality, while health outcomes may be assessed using validated wellbeing scales, physiological markers, behavioural measures, and healthcare data. Environmental pressures can be quantified through metrics such as visitor density, infrastructure footprint, transport emissions, habitat disturbance, and landscape modification. Importantly, many of these indicators are already routinely collected through environmental monitoring, public health surveillance, remote sensing, and biodiversity assessment programmes.

Where indicators can be standardised across locations and scales, they provide a foundation for integrated one health sustainability assessment. Rather than evaluating health outcomes or ecological conditions in isolation, multi-domain indicator systems could be used to identify, compare, and

Table 1. A one health sustainability indicator framework for evaluating nature-based wellbeing across coupled socio-ecological systems. The table outlines candidate indicator domains, their analytical relevance, and potential measurement and assessment approaches to support future multi-domain assessments of human wellbeing, ecological integrity, environmental pressures, and sustainability outcomes. Although illustrative rather than prescriptive, these indicators demonstrate how one health sustainability concepts could be operationalised and integrated within future monitoring, research, and landscape-planning frameworks.

Indicator domain	Candidate indicators	Analytical relevance	Potential measurement and assessment approaches
Human health and wellbeing	Wellbeing and mood; psychological restoration; sleep quality; physical activity; cardiovascular and neuroendocrine stress markers; morbidity and preventive health indicators; exposure to pollutants, allergens, pathogens, and environmental hazards	Characterising exposure–response relationships; distinguishing perceived and physiological outcomes; evaluating positive and negative health pathways associated with nature exposure	Validated psychometric scales, wearable sensors, cortisol, heart-rate variability, physical activity monitoring, health care records
Ecological integrity and biodiversity	Habitat type and condition; vegetation structure; biodiversity indicators (e.g. plants, animals, microbiomes); soil and water quality; habitat disturbance and ecological degradation metrics	Assessing whether ecological integrity and biodiversity condition modulates wellbeing outcomes; identifying biodiversity-mediated exposure pathways; evaluating ecological thresholds and habitat dependencies	Species surveys, eDNA, acoustic monitoring, vegetation structure assessments, habitat-condition indices, remote sensing
Environmental pressures and ecological costs	Visitor density; trampling and erosion; transport-related emissions; waste generation; wildlife disturbance; infrastructure pressure	Evaluating sustainability trade-offs; identifying low-impact exposure models; assessing whether wellbeing interventions generate ecological degradation	Visitor counters, GPS tracking, infrastructure footprint analysis, transport carbon accounting
Landscape and socio-environmental context	Greenness and land-use gradients; habitat fragmentation; accessibility; urbanisation; noise, light, and chemical pollution; socio-environmental inequality indicators	Situating local exposure within broader socio-ecological systems; evaluating contextual heterogeneity, accessibility, and cumulative environmental pressures	GIS, land-use mapping, accessibility modelling, human density and activity indices, pollution monitoring
Sustainability, restoration, and equity	Ecosystem service indicators; restoration potential; equitable access to high-quality environments; life-cycle and resource-use assessments	Linking wellbeing benefits to long-term ecological resilience and sustainability objectives; evaluating distributional and intergenerational dimensions of nature-based wellbeing	Accessibility metrics, restoration monitoring, ecosystem service assessments
Integrated socio-ecological assessment	Multi-domain indicator systems; cross-domain modelling; integrated sustainability assessments; spatially explicit one health sustainability assessment	Supporting systems-level evaluation of health benefits, ecological integrity, environmental costs, and sustainability trade-offs across coupled human-nature systems	Multi-criteria analysis, structural equation models, Bayesian networks, systems modelling

map socio-ecological patterns of wellbeing, ecological integrity, environmental pressure, and sustainability trade-offs across landscapes. Such approaches could support the development of spatially explicit one health sustainability indicator maps capable of informing landscape planning, restoration prioritisation, public health interventions, and nature-based wellbeing strategies. In this way, the framework offers a pathway for translating broad aspirations for 'healthy people in healthy environments' into operational assessment systems that can evaluate not only where nature-based wellbeing benefits occur, but also whether those benefits are supported by ecologically resilient and sustainable socio-ecological systems.

5. Framing future research and policy for nature-based wellbeing

A one health sustainability perspective provides a conceptual basis for developing more integrated approaches to evaluating nature-based wellbeing interventions across human, ecological, and sustainability dimensions. Such approaches would need to consider not only human health outcomes, but also the ecological conditions that support those benefits, the environmental pressures associated with increasing use, and the broader socio-ecological context within which interventions occur. Although the framework proposed here remains conceptual, it highlights several areas where future research and

policy development may benefit from stronger integration of ecological and health evidence.

One important priority is the establishment of clearer ecological reference conditions and habitat baselines. Without more systematic characterisation of habitat type, biodiversity, ecological integrity, and landscape context, it remains difficult to compare interventions across studies or determine whether health outcomes vary according to ecological quality. More consistent ecological measurement may also help disentangle the effects of specific nature-based interventions from broader environmental and socio-economic gradients that influence population health.

The framework also highlights the need to better understand ecological costs and trade-offs associated with nature-based wellbeing practices. Ecological impacts are likely to vary substantially across exposure types, intensities, and landscape contexts (Shanahan *et al* 2016, Marselle *et al* 2021). Passive engagement within semi-natural environments may impose relatively limited ecological pressures, whereas high visitor densities, infrastructure development, motorised access, or commercialised nature-based activities may contribute to habitat disturbance, wildlife disruption, resource use, and broader environmental degradation. Conversely, greater recognition of the ecological foundations of wellbeing could potentially support incentives for habitat restoration, biodiversity enhancement, and equitable access to high-quality natural environments (Faure *et al* 2024).

Future research would therefore benefit from more systematic integration of ecological metrics, biodiversity indicators, environmental pressures, and sustainability considerations alongside health outcomes. Longitudinal, experimental, and comparative studies across ecological gradients may be particularly important for clarifying how exposure–response relationships vary across different environmental and socio-economic contexts. Greater attention to environmental costs, including transport emissions, visitor pressure, habitat disturbance, and resource demands, may also help evaluate whether nature-based wellbeing interventions remain sustainable under increasing societal demand.

Integrating measures of both human wellbeing and ecological condition could support more context-sensitive approaches capable of balancing health benefits, ecological integrity, accessibility, and sustainability objectives (Nguyen *et al* 2023, Venter *et al* 2023). Although substantial empirical work remains needed to operationalise and test these relationships, a one health sustainability perspective may provide a useful conceptual foundation for future interdisciplinary research at the intersection of biodiversity, public health, and sustainability.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://zenodo.org/records/18891399 (Konstans *et al* 2026).

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Conflict of interest

The authors declare no conflicts of interest.

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