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Perspective Article

Changing landscapes and their effects on non-material benefits: challenges and opportunities for landscape science

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HIGHLIGHTS

- Links between landscape change and non-material benefits remain poorly understood.
- Integrating biophysical data and people's perspectives allows capturing changes.
- People's perceptions are shaped by contextual and personal factors.
- Challenges persist, including scale mismatches, concepts, and capturing perceptions.
- Linking technology and transdisciplinary approaches fosters integrative solutions.

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ABSTRACT

Landscape changes are occurring at unprecedented rate and pace, affecting non-material benefits of human-nature interactions and highlighting the need for better integration of perceptions into decision-making. However, links between landscape changes and impacts on non-material benefits remain poorly understood, despite being core topics in landscape science. This paper aims to provide insights into current approaches to assess landscape changes and related impacts on non-material benefits, highlighting limitations and challenges of research in landscape science. In an interactive workshop setting, experts in landscape science collected and discussed assessment approaches to capture impacts on non-material benefits due to landscape changes as well as factors influencing perceptions of these changes. Current challenges and opportunities of research in landscape science are pointed out applying a Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis. While landscape science as an interdisciplinary and increasingly transdisciplinary research field enables the holistic assessment of human-nature interactions and impacts from landscape changes on non-material benefits, conceptual and methodological issues limit knowledge production and hamper the integration into landscape planning and decision-making. Factors influencing perception of changes are still insufficiently understood, while technological developments can help to develop novel integrative methods. Landscape science has the potential to holistically assess the impacts on human-nature interactions caused by landscapes changes. However, there are several challenges and limitations that still need to be addressed, requiring a steady exchange

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between research and governance, as well as a better integration of the perception of diverse types of users and beneficiaries.

1. Introduction

Over millennia, human activities such as agriculture, forestry, and mining have shaped our landscapes to fulfil people's needs and demands (Ellis, 2021; Tasser et al., 2024). In the last century, the pace and extent of landscape changes have been unprecedented due to environmental changes, socio-economic developments, and alterations in political conditions, leading to changes in land-use and management practices (Li et al., 2023). However, beyond their ecological and economic effects, rapid and extensive landscape changes fundamentally alter human-nature interactions, (Soga and Gaston, 2022), influencing non-material benefits, such as recreational and aesthetic experiences, knowledge and skills, place identity, spirituality, and inspiration (Nowak-Olejnik et al., 2022). Studies indicate mostly negative effects on non-material benefits due to landscape changes (Leite et al., 2024; Schirpke et al., 2024), although they also can be enhanced, e.g., through the restoration of ecosystems (Dou et al., 2022). Since non-material benefits are directly experienced and valued by people, they often act as a motivation to preserve specific landscapes (Riechers et al., 2016). Limited attention on the consequences of landscape changes on non-material benefits therefore undermine the effectiveness of management strategies and policies aiming at preserving biodiversity and the provision of ecosystem services (Satz et al., 2013). Moreover, understanding these dynamics is complicated by shifting baselines, which are changing reference points for what is considered "normal" (Alleway et al., 2023). Hence, the scale and long-term impact of landscape changes are often overlooked due to limited awareness of initial baselines.

Decision-makers and landscape planners need meaningful quantitative and qualitative information to address impacts on non-material benefits due to changing landscapes (Mandle et al., 2021). Landscape science as an interdisciplinary research field can contribute to knowledge on underlying mechanisms, causes and consequences of landscape changes, as it comprises a multitude of concepts and approaches allowing to inform planning, decision-making, and policies (Qiu et al., 2025). However, despite the advances in developing indicators and methods, it remains open how strongly changes in non-material benefits are associated with landscape changes, and whether biophysical indicators measuring landscape change are sufficient to indicate changes in non-material benefits as perceived by people. If people's perceptions of impacts differ from measured changes and further aspects such as socio-economic conditions influence perceived changes in non-material benefits, this poses great challenges for landscape science to support decision-making and fostering sustainable and socially desirable landscapes (Bennett and Reyers, 2024).

While reviews usually synthesize existing knowledge solely on literature analysis, offering limited insight into how diverse perspectives converge in practice, this perspective paper takes a different approach. It is grounded in an interactive, face-to-face workshop that brought together researchers from diverse backgrounds and scientific disciplines, allowing participants to challenge assumptions, co-develop insights, and highlight practical challenges and opportunities that might not emerge from literature reviews alone. The paper therefore reflects collective expertise and dialogue, and the findings presented in the following are not intended to be exhaustive. We aim to provide insights into current approaches to assess landscape changes and related impacts on non-material benefits, highlighting how landscape science can contribute to decision-making and landscape governance to maintain and enhance non-material benefits of changing landscapes (Fig. 1), focusing on three main questions:

(RQ1) How can we measure the effects of changing landscapes on non-material benefits?

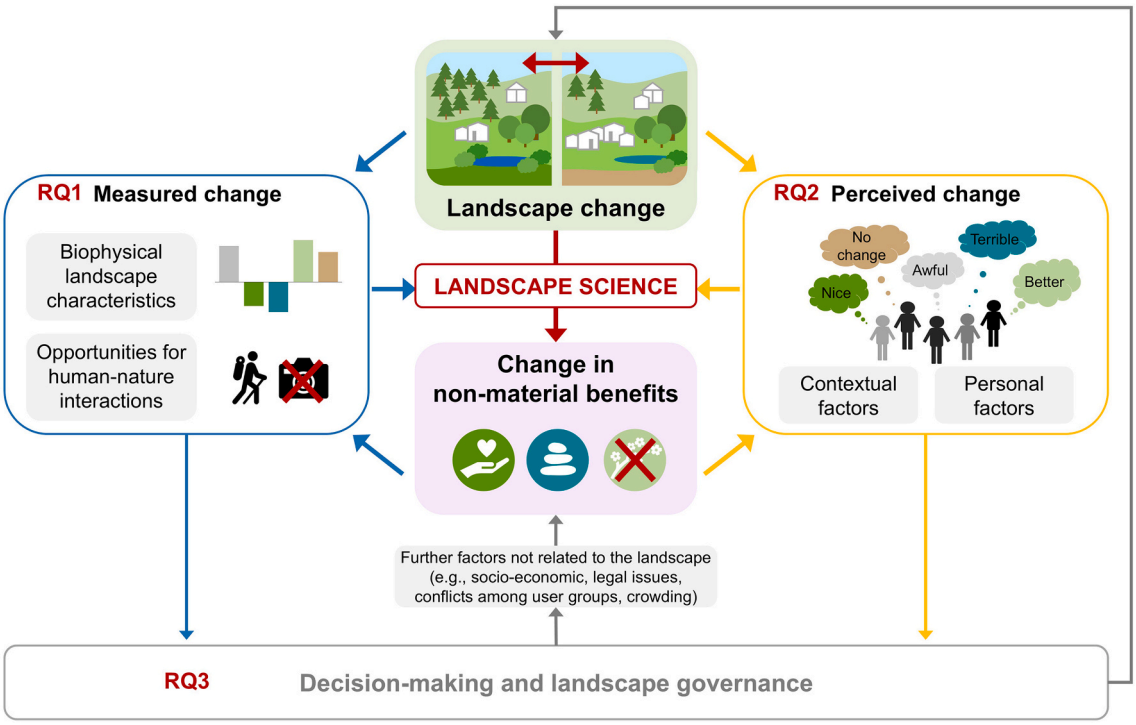

Fig. 1. Conceptual relationships between landscape changes and impacts on non-material benefits; RQ1-RQ3 refer to the main questions discussed during the workshop and post-workshop meeting.

(RQ2) Which factors shape people's perceptions of landscape change and their impacts on non-material benefits?
(RQ3) What key challenges and opportunities exist for landscape science to support decision-making in relation to RQ1 and RQ2?

We understand "non-material benefits" as the intangible contributions that arise from human-nature interactions contributing to human well-being through cultural, psychological, and social dimensions rather than physical or economic outputs. These benefits emerge from relationships between people and their environments and are expressed through experiences, meanings, and values associated with nature (Díaz et al., 2018; Russell et al., 2013). They encompass aspects such as aesthetic enjoyment, recreation, learning, inspiration, cultural identity, heritage, and spiritual fulfilment (Nowak-Olejnik et al., 2022). Unlike material benefits, which are measurable in terms of goods or services, non-material benefits are subjective, context-dependent, and deeply embedded in worldviews, traditions, and cultural practices (Pascual et al., 2023). Although they are often conceptualized as cultural ecosystem services (Fish et al., 2016; Small et al., 2017), we understand "non-material benefits" beyond this concept, as many of such studies still emphasize environmental rather than socio-cultural dimensions, using approaches with limited analytical capacity and inadequate metrics to assess intangible values (Nowak-Olejnik et al., 2022).

2. Workshop setting, participants, and case studies

We addressed the three questions applying a nominal group technique exercise (Hugé and Mukherjee, 2018), comprising three major phases: (1) generating ideas and workshop preparation; (2) sharing, collecting, and discussing ideas during the workshop, and (3) distilling the outputs in a post-workshop meeting. First, we defined the research questions RQ1-RQ3 based on recent literature (Fig. 1). The lead-authors invited experts in landscape science, focusing on landscape changes in various contexts, for example, in urban areas, rural landscapes, or mountain regions. The workshop took place in Bernburg (Germany) in October 2024 during the annual IALE-D conference, where six of the participants shared their experiences from case studies (Table 1) related to one or more research questions in five-minute flash talks. The case studies spanned diverse landscape settings, methodological approaches, concepts, scales, and non-material benefits. In the subsequent 120 min, the six presenters and seven further participants from the audience discussed the first two research questions in two groups. Information was collected on a digital board for sticky notes (https://padlet.com/), which allowed the participants to post their ideas in one place that is easily accessible to everyone. The padlets had been prepared in advance to facilitate collecting the information in a systematic way. After organizing all information related to RQ1 and RQ2, we discussed the third research question (RQ3) in an online workshop (about 90 min) in January 2025. Finally, we systematized the information collected through qualitative approaches to categorize and organize the findings using a combination of narratives, tables, and graphical presentations. To illustrate key arguments and place our discussion results within current scientific debates, in addition to the case studies, we selectively draw on recent and relevant studies without aiming to provide a systematic or exhaustive literature review. By referencing empirical findings and conceptual advances, we aim to support our statements with evidence while maintaining the forward-looking and exploratory nature of a perspective paper. All authors of this article participated in the workshop and the online post-workshop meeting.

3. How can we measure the effects of changing landscapes on non-material benefits?

3.1. Assessment of landscape changes and changes in opportunities for human-nature interactions

Landscape science commonly concerns dynamics and configuration of landscape mosaics, disturbance regimes, species responses across scales, ecosystem functions, and feedback between landscape changes and ecological processes that transform landscape patterns and processes (Turner and Gardner, 2015). Landscape change can be defined as an alteration over time in the composition of ecosystem types, or more broadly land cover types, in a given area due to the conversion to other types or changes in management practices (Brudvig et al., 2017; Plieninger et al., 2015). These include, for example, the conversion of grassland to forest due to the abandonment of grazing and mowing activities (Tasser et al., 2024), the transformation of grassland to agricultural land to meet increasing resource demands (Winkler et al., 2021), or urban sprawl due to population growth, migration, and socio-economic developments (Meyer et al., 2021). Changes in management practices in agriculture and forestry, for example, through changes in fertiliser use or changes in harvesting patterns, lead to changes in the land-use intensity and often to a loss of cultural landscapes (Kuemmerle et al., 2016). In contrast, growing demands for renewable energies, tourism, and nature conservation may create new types of landscapes (García-Ruiz et al., 2020; Spielhofer et al., 2021). In addition, climate change increasingly impacts on the conditions for agricultural use, requiring adaption of cultivation patterns (Schönhart et al., 2016), or on specific landscape elements such as iconic species or glaciers, directly affecting landscape appearance (Inglis and Vukomanovic, 2020; Salim et al., 2021).

Landscape changes are usually assessed through biophysical indicators describing spatial landscape patterns in quantitative terms over time (c.f. C5 in Table 1; Martín et al., 2018), which can be expressed through composition metrics such as number of patches, proportion of each type, or Shannon Evenness index (McGarigal et al., 2012). While these metrics do not account for the spatial arrangement of the individual patches, there are various metrics describing, for example, patch density, mean patch size, and largest patch index (McGarigal et al., 2012). To indicate landscape changes, statistical tests are usually applied to evaluate whether there is a change in the landscape indicators (Kienast et al., 2015). More subtle changes that do not alter the land cover type and that may be related to changes in the management intensity (e.g., mowing frequency of grassland, changes in harvesting practices in forests, change in crop variety, or biodiversity conservation measures (c.f. C5 in Table 1)), lead to changes in species composition and visual qualities of a landscape that may not be captured by metrics due to limitations in thematic resolution of land cover or habitat maps, and may require knowledge of historical dimensions to understand changes (Tappeiner et al., 2020).

Landscape changes often come along with changes in their capacity to support benefits to human well-being that people obtain from interaction with ecosystems (Yee et al., 2021). These benefits are usually quantified under the ecosystem service framework through biophysical indicators that assume empirical or theoretical links between landscape changes and well-being outcomes (Burkhard & Maes, 2017; Turner and Gardner, 2015). For example, changing opportunities for recreational activities can be quantified by changes in length of hiking trails, skiing days per year, water quality for water-based activities, or species richness and abundance for wildlife watching, while landscape indices like shape and diversity reflect on landscape aesthetics (Burkhard & Maes, 2017). However, landscape changes often impact human-nature interactions in ways that are not easily captured by biophysical landscape indices, e.g., when climate-induced landscape changes diminish options for subsistence practices while fundamentally eroding cultural identities, sense of place, and mental health (Crate, 2022; Ellis and Albrecht,

Table 1
Overview of the case studies (C1-6) presented during the workshop.

ID	Topic	Background and aims	RQ1	RQ2	RQ3	References
C1	Incorporating (shifting) baselines into landscape governance at different spatial scales using place-based methods.	Environmental changes are often underestimated or misinterpreted, partly because perceptions of what is "normal" shift over time, making it challenging to define clear baseline states. Despite their importance for conservation, restoration, and biodiversity policies, these shifting baselines are rarely considered in landscape governance. This perspective paper examines place-based approaches for detecting and incorporating shifting baselines, helping landscape governance obtain the insights required for improved decision-making	• Place-based approaches offer complementary tools for understanding landscape baselines across both space and time. • Participatory Mapping engages communities in spatial co-production • Narrative methods inform planning through long-term value shifts	• "Shifting Baseline Syndrome": People assess environmental change relative to what they perceive as "normal" at a given time, which may not reflect historical conditions. • Contextual factors, including environmental (earth system) and societal (politics, culture, economy) systems, and their interactions including links between biodiversity, water, food, health, and climate.	• Identification of (shifting) environmental and societal baselines • Integration of (shifting) baselines across planning scales	Komossa et al. (submitted)
C2	Effects of landscape changes on aesthetic value	This study assessed changes in aesthetic landscape values between 1950 and 2010 in the European Alps, using a spatially explicit modelling approach relating people's preference with landscape characteristics. The results indicate that aesthetic values declined due to changes in agricultural activities, with lowland areas being more affected than higher elevations, suggesting that landscape planners and managers can effectively enhance non-material benefits by preventing agricultural land abandonment or improving accessibility to areas of high aesthetic value.	• Landscape characteristics quantified through landscape metrics • People's landscape preferences gathered through photo-based questionnaires • Spatio-temporal analysis	• Socio-cultural factors influencing landscape preferences	• Combination of quantitative and qualitative data • Spatio-temporal analysis • Mapping and monitoring • Identification of general mechanisms	Schirpke et al., 2019, 2021
C3	Mountain lakes as indicators of shifts in non-material benefits	Mountain lakes are considered not only iconic elements of mountain landscapes but also important indicators of environmental change. Through stakeholder consultations, surveys, and spatial analyses of social media data, this study has assessed the non-material contributions of mountain lakes. It identified issues related to increasing overcrowding and potential habitat degradation and their negative impacts on non-material benefits and examined how environmental changes could further exacerbate these impacts. The findings show that socio-cultural approaches to assessing non-material benefits can be linked with (landscape) ecological perspectives to better understand the relationships between non-material benefits, and ecosystems in a landscape context.	• Natural assets, non-material benefits, and pressures identified by a mixed methods approach • Differentiated perspectives by user and stakeholder groups gathered • Spatial scale determined by combining methods, taking into account common indicators	• Socio-cultural factors, use intensity, and environmental changes reflected in perceptions	• Combination of quantitative and qualitative data • Complementarity of approaches • Applicability of approaches differs in practical context • Approaches differ in social representation, information content and generalisability	Ebner et al., 2022; Schirpke et al., 2022

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Table 1 (*continued*)

ID	Topic	Background and aims	RQ1	RQ2	RQ3	References
C4	Assessing landscape change and its social implications – the example of „Urban Rewilding“	To tackle the climate and biodiversity crises in cities, diverse nature-based solutions are needed. One approach gaining attention is “urban rewilding,” the deliberate transformation of grey or green spaces into wild urban landscapes. The dynamic and unpredictable character of these landscapes creates new challenges for research and practice, especially for understanding their social implications. This case study in Vienna, using a novel multi-scenario approach, demonstrates that urban rewilding is a socially viable approach that is largely supported by local communities, and its potential landscape outcomes are associated with diverse non-material benefits. However, differences in reactions to urban rewilding emerge among different user groups, people with varying sociodemographic backgrounds and neighbourhood contexts, suggesting the need for context-sensitive applications of restoration approaches.	• Multi-scenario approach used to assess people’s reactions to landscape changes across heterogenous social-ecological contexts • Landscape trajectories and their possible outcomes are holistically depicted from a social-ecological perspective and using both visual and text material • The influence of object-, subject- and context-related factors shaping reactions to landscape change is assessed	• Socio-demographics, individual traits and neighbourhood context influence reactions to landscape change and perceived non-material benefits of emerging landscape outcomes • Positive reactions to landscape change are associated with greater appreciation of non-material benefits	• Multi-scenario approach supports context-sensitive guidance of future landscape change • Allows integrating local communities’ place-based and situated knowledge • Highlights factors that deserve further attention to prevent potential environmental injustices arising from rewilding-driven landscape changes	Zoderer and Wieser, 2025
C5	Impacts of global change on landscapes with geographical indications	Rural landscapes provide cultural ecosystem services such as aesthetic, heritage, and experiential values. Geographical indications (GIs) systems certify and regulate the link between landscapes and products whose unique qualities depend on natural and human factors of their production area. Typically granted by government bodies, GIs influence the provision of cultural ecosystem services. Using examples from GI regulations this case study illustrates these impacts and explore the potential of participatory methods (e.g., Living Labs), historical landscape analysis (e.g., land-use change detection), and crowdsourced data (e.g., social media) to help stakeholders prioritize actions that sustain cultural benefits in rural areas.	• Geospatial indices of historical persistence of landscapes • Participatory scenario planning exercises • Living labs to gather stakeholders’ preferences about changes in rural landscapes	• Socio-cultural-economic factors • Regulatory framework causing changes in management practices	• Support transdisciplinary and participative approaches • Inform transformative pathways for maintaining benefits despite ongoing changes	Candiago et al. 2025, Jaramillo Sanchez and Candiago, 2025, Tscholl et al. 2024
C6	Narrative pathways for implementing European policy targets through value perspectives of the Nature Futures Framework	The Nature Futures Framework (NFF) aims to open up space for plural perspectives on human-nature relationships and to identify visions and pathways for people to navigate towards desirable nature-positive futures. This study aimed to identify scalable actions to operationalise pathway narratives at the	• Target-seeking pathway narratives (linked to EU policy objectives) that can be assessed in modelling to connect landscape changes to quality-of-life / non-material benefits	• Value perspectives (intrinsic / relational / instrumental), so perceived impacts differ depending on whether landscapes are valued for nature itself, cultural relations/identity, or services to society • In “Nature as Culture/One with Nature” perceptions are shaped by cultural	• Challenges: translating plural, value-laden dimensions into quantitative, decision-relevant indicators/models • Opportunities: common structure to explore future trade-offs/synergies of changing landscapes and non-material benefits.	Raymond et al., 2025

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Table 1 (*continued*)

ID	Topic	Background and aims	RQ1	RQ2	RQ3	References
		European scale. Specifically, policy targets of the European Union (EU) emerge from a process including a wide range of actors and describe a comprehensive vision of a nature-positive future for Europe that entails climate regulation and the preservation of biodiversity and cultural landscapes. To reach these targets, three narratives of land system pathways were created, including the multiple values of nature. These narratives can be used to infer model input parameters to quantify alternative NFF-based futures and their impacts on ecosystem services and human-wellbeing. The narratives can also serve as a starting point for the creation of case study specific narratives within Europe, for instance, through participatory processes.		landscapes, traditions, and local meaning		

2017).

3.2. Approaches to assess changes in non-material benefits

There is growing evidence that activities in contact with natural environments have greater beneficial effects on physical and mental health than activities in non-natural settings (Houlden et al., 2018). Accordingly, positive effects are recognised in the context of Shinrin-yoku (forest bathing) (Kotera et al., 2022), or associated with the exposure to blue spaces (White et al., 2021). However, landscapes differ in providing opportunities for human-nature interactions due to their specific social-ecological characteristics, supporting different outcomes in terms of non-material benefits (Bieling et al., 2014). Landscape features such as rivers and lakes positively influence recreational activities (Meyer et al., 2019), while natural or traditionally used, and diverse landscapes offer higher aesthetic, recreational and spiritual values than strongly modified or monotonous landscapes, resulting in differing restorative effects (Deng et al., 2020). Despite the increasing evidence of impacts of landscape change on non-material benefits and their relevance for decision-making (Schirpke et al., 2024), studies still often quantify changes in opportunities or capacities of ecosystems in supporting human-nature interactions using indicators that can be related to landscape characteristics (Stanik et al., 2018). However, socio-economic factors, legal issues, and the level of use by other people, can also alter the accessibility and quality of non-material benefits (Martinez-Harms et al., 2018; Schirpke et al., 2020). For example, crowding is one of the most mentioned pressures on human-nature interactions leading to negative experiences rather than to the expected positively perceived non-material benefits (Kainzinger et al., 2015; Schirpke et al., 2022). This applies also to conflicts among different user groups, e.g., hikers vs bikers, visitors vs locals, or established vs new user groups (Hansen et al., 2023; Komossa et al., 2018). Thus, biophysical indicators are not sufficient to evaluate changes in non-material benefits due to their subjective character (Bryce et al., 2016), exhibiting affective, symbolic, and relational dimensions that do not necessarily follow scientific paradigms (Russell et al., 2013). This makes it fundamental to account for people's perceptions and lived experiences.

There is enormous potential in operationalizing changes in the biophysical environment and their impacts on perceived non-material benefits using place-based methods, which recognize the importance of understanding and addressing the specific context and its (social-ecological) dynamics reflected through place-based data (Bennett et al., 2021). Due to the subjective nature of perceptions, studies typically employ qualitative or quantitative empirical social research methods, such as semi-structured interviews or questionnaire surveys to elicit people's lived experiences, preferences, and perceptions (Cheng et al., 2019). Frequently, these studies include photo-based methods such as the integration of visual stimuli as part of questionnaires (Zoderer et al., 2019a), or the application of photovoice research as part of, e.g., walking interviews, to either simulate or investigate real-life landscape experiences in a holistic way (Huber et al., 2023). While qualitative perception-based methods support an in-depth understanding of people's situated interactions and relationships with specific places, integrating multiple landscape photographs in face-to-face or online questionnaire surveys has the advantage to approach a large survey sample, while still simulating holistic landscape evaluations by inviting people to recall previous experiences, feelings and activities undertaken in landscapes similar to those presented by visual stimuli (Zoderer et al., 2019a). Recent methodological advances highlight the benefits of combining photo-based methods with textual descriptions in questionnaires to holistically represent envisioned landscape changes and their potential outcomes (c.f. C4 in Table 1). As shown by Zoderer and Wieser (2025), this approach is particularly effective for assessing social responses to landscape changes driven by deliberate restoration measures such as urban rewilding. By providing respondents with a robust information base on potential landscape trajectories, shifts in governance and human–nature interactions, and the social–ecological characteristics of possible outcomes, it supports more informed and nuanced responses. Moreover, integrating visual and textual materials into a multi-scenario design enables participants to evaluate these changes and their implications within their specific local contexts.

Despite these advantages, the above-mentioned methods are often limited in spatial coverage and can be time-consuming and costly. To overcome such constraints, studies have related biophysical landscape characteristics to people's perceptions (c.f. C1 in Table 1) derived from interviews or questionnaire survey to either develop biophysical

Table 2
Factors influencing subjective perceptions of landscape changes and impacts on non-material benefits. The factors were deductively categorized based on literature (Gifford and Nilsson, 2014; IPBES, 2022; Swanwick, 2009; Van Riper et al., 2017).

Category		Influencing factor	Explanation
Contextual factors		Social structure	Social structures and organisation of society, e.g. demographics, ethnicity, and social stratification, power relations (Leite et al., 2024; Plieninger et al., 2015)
		Cultural context	Interaction with nature is shaped by shared values, beliefs, traditions, norms, language, knowledge systems and practices of a specific community or population (Cebrián-Piqueras et al., 2020; Crate, 2022; Fish et al., 2016; Small et al., 2017), differing for indigenous communities (Menzies et al., 2022) or people with immigrant status (Buijs et al., 2009), common lifestyle, or living in different milieus (Müller et al., 2008)
		Institutional/legal context	Legal system (formal, informal), land ownership (private, public), access (rights, fees, regulations) (Schirpke et al., 2020)
		Political context	Shifts in governance and political paradigms, or institutional change (Balázsi et al., 2019)
		Information	Accessibility to information sources (e.g., scientific publications, newspaper, radio, TV, internet, social media), as well as type and format (e.g., text, pictures, videos) of information (Adger et al., 2022; Anderson, 2017)
Personal factors	Socio-demographic factors	Age	Intergenerational differences (Furberg et al., 2011; Tran et al., 2021)
		Education	Level of education and field of study (Zheng et al., 2011)
		Gender	Gender identity and role (Bunce et al., 2016; Sang et al., 2022)
		Income	Spendable income determines opportunities for human-nature interactions and behaviour (Zheng et al., 2011)
		Occupation	Type of profession and role, e.g., farmers vs people employed in nature protection, or tourism (Küchen et al., 2023; Thiemann et al., 2022)
	Individual factors	Capabilities	Mental, physical, and intellectual abilities of individuals (Browning et al., 2020; Santana-Santana et al., 2022)
		Nature experiences	Type of interaction (direct − indirect), type of experience (positive – negative), and skills (experienced vs inexperienced user) (Browning et al., 2020; Mourey et al., 2019; Pröbstl-Haider et al., 2016)
	Value orientation	Environmental value orientation	Biocentric versus anthropocentric worldview influences values and perception of impacts (Kaltenborn and Bjerke, 2002; Liordos et al., 2023; Marshall et al., 2019; Wardropper et al., 2020)
		Symbolic value	Iconic entities that feature symbolic value (Curnock et al., 2019)
		Personal interests	Opportunity and interest in diverse types of interaction, frequency in nature visitation (McCreary et al., 2019; Oh et al., 2022)
		Place attachment and identity	Feelings, emotions, and experiences associated with a specific place, shaping knowledge, rituals, traditions, and identity (Crate, 2022; Ellis and Albrecht, 2017; Gobster et al., 2022; Riechers et al., 2022, 2020)
		Emotional responses	Emotional responses to changes, e.g., ecological grief (Cunsolo and Ellis, 2018; Kumar et al., 2021; Rigby et al., 2011)
		Sense of ownership	Possibility to influence, co-create, or participate to change (Riechers et al., 2020; Wu et al., 2024)

indicators for monitoring changes in landscape values or to generate maps indicating the capacity of the landscape in supporting non-material benefits across larger time and spatial scales (Hedblom et al., 2020, Zoderer et al. 2019b). With the development of digital technologies studies increasingly rely on mobile technologies to understand human perceptions and benefits from human-nature interactions (Schirpke et al., 2023). Such data can be either actively collected, for example, through citizen science projects, or passively collected (i.e., crowdsourced) through social media. Particularly, content analysis of user-generated tags, pictures, or videos by applying advanced data science techniques can provide insights into people's perceptions, e.g., to capture the dynamics of nature experiences in different landscapes (Baer et al., 2024; Komossa et al., 2023), or for evaluating the impacts on benefits after the installation of hydropower plants or wind parks (Sherren et al., 2024; Vespa et al., 2022). Digital technologies can also be used to enhance nature experiences through virtual contents or to support role-playing games (Fox et al., 2022). Pointing towards future developments, participatory approaches are increasingly applied to support transdisciplinary learning and to improve the decision-making process guiding collective action to implement possible and desired visions (Hirons et al., 2016; López-Rodríguez et al., 2023).

4. Which factors shape people's perceptions of landscape change and their impacts?

There is still little knowledge on how measured landscape changes align with people's perception of changes. Studies indicate that most people notice the mapped landscape change as well as changes in related benefits, while highlighting differences between individual recognitions of change (Aretano et al., 2013; González-Puente et al., 2014; Leite et al., 2024). People often notice abrupt changes more than transformations occurring over extended periods (Gobster et al., 2022; Miara et al., 2022). Environmental changes may trigger even contrasting perceptions, e.g., returning wildlife, such as wolves and bears, can create positive emotions or provoke fear and distress, preventing people to enjoy contact to nature or carry out recreational activities (Rippa, 2023; Zscheischler and Friedrich, 2022). An increase in natural hazards in mountain regions due to global warming may prevent casual mountain tourists to choose hiking trails that are exposed to rock fall and debris flow, while experienced tourists accept higher risks (Pröbstl-Haider et al., 2016). Although many studies assessed people's preferences and perceptions of landscapes in different contexts, studies usually analysed socio-demographic differences, such as gender, age, and educational level (López-Martínez, 2017; Pinto et al., 2021). However, there is less evidence on the factors shaping people's perceptions of changes, particularly, regarding the role of changing landscapes on impacts of non-material benefits. A better understanding of how changes in non-material benefits are perceived and experienced by diverse groups in society due to differences in contextual factors influenced by environmental (earth system) and societal (politics, culture, economy) systems (c.f. C1 in Table 1) and personal circumstances (c.f. C4 in Table 1) is necessary to manage ecosystems and steer landscape changes in ways that they are socially just (Langemeyer et al., 2024). We therefore attempted to collect contextual and personal factors that influence people's perceptions and may explain differences in perception (Table 2).

While contextual factors represent the broader context in which people live such as the social, cultural, and political context, personal factors refer to the individual's background such as demographic and socio-economic characteristics, experiences, and value orientations (Gifford and Nilsson, 2014; Van Riper et al., 2017). It also needs to be noted that contextual and personal factors are often difficult to separate, as individuals' lives are embedded in the larger social context (Gifford and Nilsson, 2014). The broader context influences people's everyday life, providing the cultural, social, political, and legal framing (Gifford and Nilsson, 2014; Van Riper et al., 2017). Contextual factors can be stable over extended periods, but they can also rapidly change due to shocks such as economic crises, political disruptions, or pandemics,

altering people's perceptions and preferences (Balázsi et al., 2019; Lourenço-Gomes et al., 2020; Morse et al., 2020). Similarly, personal factors evolve over time due to the development of individual capabilities and socio-economic circumstances, life events and experiences, or shifts in value orientations, as conceptualized by the shifting baseline syndrome (c.f. C1 in Table 1; Alleway et al., 2023). Multiple factors can interact, but such linkages are largely unexplored.

5. What challenges and opportunities exist for landscape science to support decision-making?

Landscape science has enormous potential to support planners, managers, decision-makers, and policymakers in developing sustainable and just solutions and strategies that steer landscape changes in ways that they can maintain and enhance non-material benefits for diverse groups in society (Mandle et al., 2021). By providing integrated, spatially explicit knowledge on human–nature interactions and regional trade-offs, it enables more coherent, evidence-based, and long-term land-use and resource-management decisions. However, it is important to acknowledge that such endeavours come with various challenges (Qiu et al., 2025). Reflecting on the previous sections, we used a Strengths–Weaknesses–Opportunities–Threats (SWOT) analysis to point out current challenges and opportunities (Fig. 2) with regard to several goals: (1) to capture and measure the impacts of landscape changes on non-material benefits, (2) to integrate interdisciplinary and transdisciplinary knowledge to align potential mismatches between measured and perceived changes, and (3) to inform planning and decision-making to achieve the establishment of sustainable relationships between landscapes and people. Strengths are the characteristics of landscape science that underpin the ability of the research field in pursuing these goals, while weaknesses are the characteristics that can hamper their achievement if they are not remediated. Strengths and weaknesses can be considered internal features of landscape science arising from its concepts and approaches. Opportunities and threats are external factors representing the context in which research in landscape science is placed, referring to socio-economic, political, technical, and environmental conditions and developments that may facilitate (opportunities) or prevent (threats) the achievement of the goals.

5.1. Strengths

Due to its interdisciplinary character, landscape science comprises a variety of concepts that support the development of integrative approaches and assessment of human-nature interactions (Wu, 2021). It increasingly develops towards a transdisciplinary science, applying collaborative and participatory approaches that allow to explore and integrate local knowledge (Milovanović et al., 2020). Starting from the core strength of landscape science, i.e., describing the relationships between ecological processes and spatial patterns through quantitative metrics, spatially explicit assessments, and mapping approaches (c.f. C2, C3 in Table 1), it is possible to assess the capacity of diverse landscapes in enabling human-nature interactions (Aspinall and Staiano, 2019), such as for biodiversity-supporting interactions like wildlife watching or enhancing aesthetic experiences (Methorst et al., 2020). Biophysical landscape indicators can either be related to people's perceptions or developed by considering the latter (see above), providing a holistic perspective on human-nature interactions and non-material benefits across space and time. While acknowledging that human-nature interactions are highly place-based and context-specific (Hoelting et al., 2024), landscape science aims to assess a multi-scale analysis of social-ecological systems (Willemen et al., 2012). In this way, processes can be integrated that occur at multiple spatial levels, ranging from local to global, and across temporal scales, i.e., slow vs abrupt changes (Runting et al., 2017). Furthermore, long-term monitoring of landscape dynamics typically employed in landscape science allows a more continuous consideration of changes than assessments otherwise done at one point in time (c.f. C2 in Table 1).

5.2. Weaknesses

Despite a growing recognition of the importance to integrate people's perceptions and attempts to integrate the latter in the development of landscape indicators, many landscape science studies still focus on ecological processes and spatial landscape patterns, limiting the assessment of human-nature interactions to indicate the capacity of ecosystems in enabling such interactions. This may be due to limited availability of resources for applying participatory and transdisciplinary approaches, usually requiring a considerable amount of time, sufficient

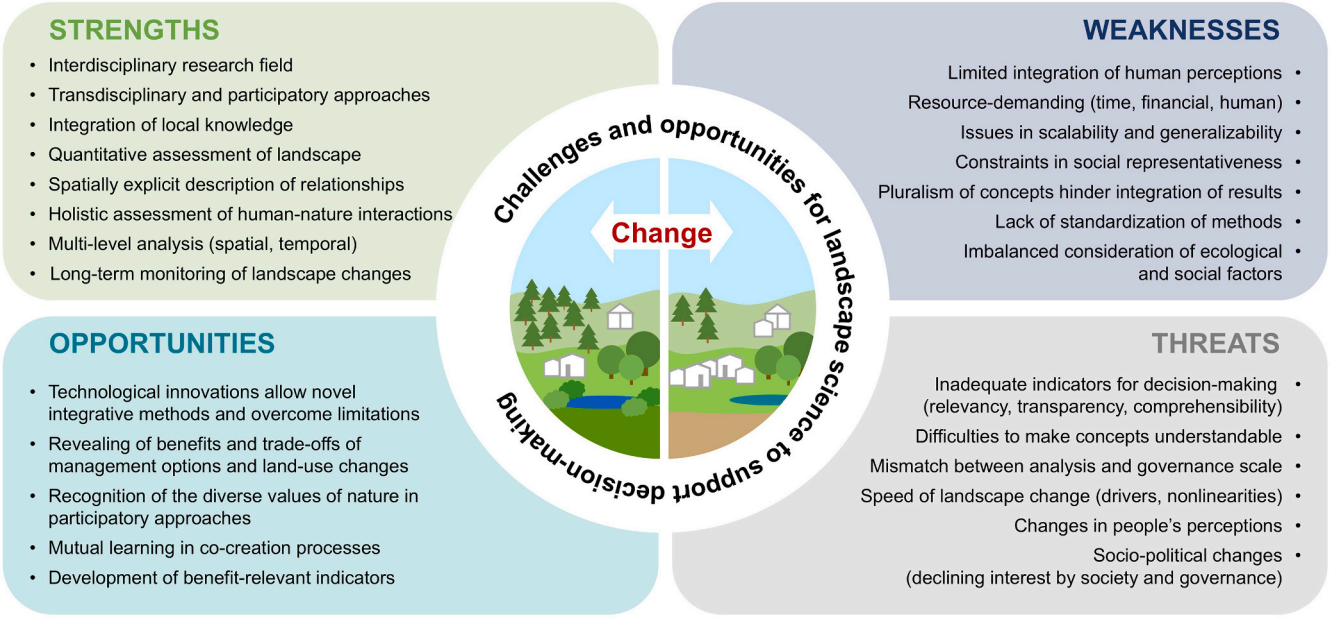

Fig. 2. Strengths, weaknesses, opportunities, and threats (SWOT) of landscape science for supporting decision-making to preserve and enhance non-material benefits under changing landscapes.

financial, and human resources for conceptualisation, data gathering, and analysis, as well as specific expertise and skills for their application (c.f. C3 in Table 1; Small et al., 2017). There may be issues related to software and data requirements, e.g., for analysing big data (Schirpke et al., 2023). Some approaches also come along with difficulties in scalability, i.e., adaptability of the approach to multiple spatial levels or planning contexts, as well as generalizability, i.e., transferability of outcomes to other spatial levels or contexts (Scholte et al., 2015). This can lead to simplified results that neglect heterogeneity of social-cultural systems and contexts across large spatial levels (c.f. C2 and C6 in Table 1). Moreover, an insufficient consideration of the socio-cultural context may limit social representativeness, i.e., groups of users and/or social actors may not be considered (Langemeyer et al., 2024; Scholte et al., 2015). While the integration of multiple concepts can be considered a strength of landscape science, the pluralism of concepts and terminology applied by different studies (e.g., nature's contributions to people, ecosystem services, and human-nature interactions) can result in an insufficient consideration of existing knowledge due to the lack of harmonization (Blouin et al., 2025; Nowak-Olejnik et al., 2022). Similarly, lacking standardization of methods impedes the comparison of changes or indicators across different studies or locations, while there is the risk of applying inadequate methods and tools that depict only some aspects of human-nature interactions but disregard others (Turner and Gardner, 2015). Moreover, imbalanced consideration of ecological and social factors may not reflect the relevance of landscape changes for human-nature interactions. Such issues can decrease the transparency and hamper the acceptance and integration of the results in decision-making processes (Blouin et al., 2025).

5.3. Opportunities

Technological developments improving digital devices and infrastructures, methods to collect, store, process, and visualize data, and new digital data sources offer opportunities to develop novel integrative methods such as participatory mapping and game-based approaches, social media analysis, citizen science, data science methods (e.g., artificial intelligence, machine learning, and data mining), art-based methods, and virtual or augmented reality approaches (Schirpke et al., 2023). Such developments may help to overcome limitations related to insufficient resources, to improve the consideration of the social-ecological context, and to account for diverse drivers at different spatial scales. Co-creation processes, such as living labs (c.f. C5 in Table 1), help decision-makers and stakeholders to define suitable actions as well as to identify potential pitfalls, while co-developing theories and/or solutions is also beneficial to researchers in assessing and evaluating the impacts on human-nature interactions, enabling collective and mutual learning (Qiu et al., 2025; Reed et al., 2023). Moreover, if such processes occur over longer periods, they also allow tracking changes in perceptions and preferences over time and identify differences in interests, opinions, and values of stakeholders, decision-makers, beneficiaries, and the public (c.f. 3 in Table 1). Using scenario analysis in such co-creation process in combination with quantitative landscape science approaches that are usually not applied in planning processes allows to highlight the benefits or trade-offs of management interventions and resulting landscape changes (c.f. C4 in Table 1), facilitating sharing of knowledge, developing common visions, building a strategy for achieving the goals, and supporting acceptance (López-Rodríguez et al., 2023; Reed et al., 2023). Due to the large portfolio of concepts and approaches in landscape science, there is the potential to translate aspects of human-nature interactions into benefit-relevant indicators (quantitative, spatially explicit) that are useable and understandable by decision-makers (Bryce et al., 2016).

5.4. Threats

A major threat to the integration of insights on measured and perceived landscape changes from landscape science studies into decision-making concerns the suitability and relevance of metrics and indicators for management and governance. If indicators and results are not transparent and comprehensible enough for decision-makers and planners, they will hardly uptake such information (Hirons et al., 2016). This applies also to underlying concepts and terminology used in landscape science, if they are not translated into a more common language that can facilitate exchange and co-creation processes with local communities and indigenous populations (Gould and Lincoln, 2017; Stålhammar et al., 2017). Moreover, mismatches between governance scales and assessment scales (C1 in Table 1) (i.e., mapping/quantification of changes) as well as institutional barriers can impede the consideration of impacts on human-nature interactions during the decision-making process (Blouin et al., 2025; Small et al., 2017). Although indicators and mapping approaches in landscape science facilitate the assessment and monitoring of landscape changes and its effects on non-material benefits over time, monitoring schemes may not match the speed of changes or are not sufficient in identifying mechanisms of abrupt changes due to complex interactions among multiple drivers and nonlinear responses to gradual changes in drivers (Ratajczak et al., 2018). Regarding impacts on non-material benefits, we still have a limited understanding of changes in perceptions due to the variety of influencing factors (see previous section; c.f. C2 in Table 1) and non-linear relationships between landscape characteristics and people's perceptions (Schirpke et al., 2019). A further threat can arise from changes in the socio-political landscape, influencing the societal interest in topics and integration opportunities into landscape governance (Blouin et al., 2025), and consequently, the willingness of stakeholders to participate and collaborate, as well as the availability of funding opportunities for research.

6. Conclusions

Landscape science has the potential to holistically assess the impacts of landscape changes on non-material benefits. Due to its quantitative and spatially explicit character, meaningful results can inform planning and decision-making to evaluate management interventions and to develop strategies to preserve and enhance such benefits. Through the application of participatory approaches, novel digital technologies, and new data sources, people's perceptions and interests can be acknowledged. However, there are several challenges that still need to be addressed, including mismatches between assessments and governance scales, conceptual issues, and difficulties in sufficiently capturing and integrating people's perceptions into assessments. Little is known about the discrepancies between measured and perceived changes and the interaction among multiple factors that influence perceptions over time. Such challenges require a steady exchange between research and governance, as well as a better integration of the diverse types of users and beneficiaries to support decision-making with meaningful and relevant information. Combining quantitative, biophysical assessments with qualitative, place-based evaluations can reveal mismatches, trade-offs, and synergies between ecological changes and societal expectations, while scaling these insights through scenario simulations can identify priority areas for management interventions. Interactive tools providing context-aware guidance at multiple governance levels can further support decision-makers and landscape managers. Through such efforts, landscape science can enhance the effectiveness, equity, and sustainability of landscape governance, aligning land use objectives with stakeholder priorities and fostering long-term support for management measures or restoration efforts.

CRediT authorship contribution statement

Uta Schirpke: Writing – original draft, Visualization, Conceptualization. **Sebastian Candiago:** Writing – review & editing. **Konrad Gray:** Writing – review & editing. **Franziska Komossa:** Writing – review &

editing. **Karoline Hemminger:** Writing – review & editing. **Markus Meyer:** Writing – review & editing. **Thomas M. Schmitt:** Writing – review & editing. **Brenda Maria Zoderer:** Writing – review & editing. **Manuel Ebner:** Writing – review & editing, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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