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Research article

Aligning land use with sustainability: Context-sensitive pathways forward

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ABSTRACT

The concept of sustainable development states that economic, social, and technological progress needs to be harmonised with nature. However, with the rate of global environmental deterioration now higher than at any time in human history and an ever-increasing human population, sustainability slips out of reach. One of the central processes and key issues in attaining sustainability is human use of and interaction with land resources. These can be described by two main processes that often go hand in hand: land conversion and land-use intensification. As these two phenomena accelerate, the level of disturbance in the environment increases, transforming natural ecosystems into altered, novel ecosystems or intensively used ecosystems. Depending on the degree of human-induced land alterations, different actions are needed to achieve and maintain sustainability. Conservation and prevention are necessary in natural areas with a low level of anthropogenic pressures. In areas that have already been disturbed by humans, sustainable management allows for a harmonious coexistence between humans and nature. Restoration and mitigation can help address the negative impacts of the most altered habitats. Sustainability, however, is not a fixed target but a dynamic condition shaped by evolving local contexts and global drivers. We advocate for transformative change grounded in flexible, context-sensitive land-use strategies that integrate ecological resilience, participatory governance, and institutional adaptability. With such systemic shifts, land systems can become catalysts for long-term sustainability.

1. Introduction

Along with the unprecedented scale of human-induced environmental issues that have accelerated over the last decades, sustainability, broadly defined as the long-term capacity of natural and human systems to persist without exceeding planetary boundaries (Steffen et al., 2015), has become a central yet contested goal in global discourse. One common approach to achieving this target has been the framework of sustainable development, which seeks to balance the intertwined and mutually reinforced dimensions of economic growth, social equity, and environmental protection. Since its inception at the 1992 Rio Summit (UN, 1992), the concept has gained growing attention and has been integrated and mainstreamed into global agendas and national strategies, with the United Nations 2030 Agenda for Sustainable Development (UN, 2015) and its Sustainable Development Goals (SDGs) being a leading example. However, the vision of sustainable development and sustainability itself has received several criticisms (Spash, 2022). It has been argued that the concept is inherently incompatible, and there is a

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general contradiction between the calls for continued global economic growth and environmental sustainability (Dawes, 2020; Eisenmenger et al., 2020; Hickel, 2019; Hole et al., 2022; Spaiser et al., 2017). Moreover, it has been raised that sustainability is a context-dependent concept rather than a universal, constant, or objective state (Purvis et al., 2019). Its meaning and implications may vary across spatial and temporal scales, cultural settings, and ecological baselines (Cash et al., 2006). Thus, what is deemed sustainable in one context may be harmful or unjust in another, highlighting the limitations of applying uniform indicators to diverse socio-ecological systems (Miller et al., 2014). Recent research further illustrates these complexities, showing associations between biodiversity, socioeconomic status, and environmental injustice in Central and Eastern European villages, underscoring the high socio-ecological value of maintaining landscape complexity (Batáry et al., 2025). As a result, despite establishing detailed blueprints for advancing efforts to address sustainability challenges at the global and national levels, such as the SDGs, progress toward achieving them has been uneven and unsatisfactory (Sachs et al., 2024). This problem has been further exacerbated by external global stressors, including health crises (e.g., the COVID-19 pandemic) and geopolitical conflicts (e.g., the Russo-Ukrainian war) (Naidoo and Fisher, 2020; Sachs et al., 2022; Pereira et al., 2022), leading to a debate about the need for a more context-sensitive approach (Mupepele et al., 2021).

Given these challenges, land systems, being the result of human interactions with the environment, emerge as a central domain and a key focus area for advancing more grounded, adaptive, and effective sustainability strategies (Meyfroidt et al., 2022). These interactions have accompanied human population development, shaping most of terrestrial Earth's surface for millennia and manifesting in land-use and land-cover change (Ellis, 2021). The resulting cultural landscapes, where local societies and ecosystems have coevolved in a close interconnection, have sustained biodiversity and people's livelihoods for thousands of years. However, along with the growth of the global human population and its prosperity, this synergy has been disrupted by the intensified use of land, triggering a cascade of environmental issues. Humanity is estimated to use 173% of the Earth's natural resource capacity (Wackernagel et al., 2021). Under the current consumption trends (such as increased meat consumption, which is already 2.5 to 3 times higher than recommended; Brunori et al., 2020) and projections of the human population to exceed 10 billion by the mid-2080s (Gerland et al., 2014; UN DESA, 2024), even much more of the Earth's resources will be needed to meet growing societal demands (van Dijk et al., 2021). Therefore, the scarcity of the Earth's resources, the most important of which is land, must be more centrally considered in attempts to address the challenges of sustainable development.

Here, in this perspective, we present the concept of sustainable development focusing on its environmental dimension. We highlight land-use and land-cover change as a central process in development and describe how it can interact with other external drivers affecting environmental sustainability. We show how improved land system management can contribute to addressing sustainability challenges and suggest actions needed to achieve more sustainable outcomes under varying levels of land conversion and land-use intensification. Finally, we argue that to make sustainability more attainable, we need more context-specific approaches maintaining a dynamic balance between different dimensions of sustainability in a rapidly changing environment.

2. Land alteration is a central development process and the primary environmental issue

Modifying the land surface for livelihood and welfare gains is one of the processes crucial to how humanity has developed throughout history (Martin et al., 2018; IPBES, 2019). As a result, to date, more than 77% of land on Earth (excluding Antarctica) has been altered by human activity, inflicting severe and often irreversible environmental consequences (Foley et al., 2005; Watson et al., 2018; Zeng et al., 2020). These alterations can be described by two metrics: the level of land conversion (i.e., replacement of one type of land use or land cover with another, along a gradient from natural to man-made habitats) and land-use intensity (i.e., intensity of practices with which land is managed for agriculture or other land uses; Watt, 2020). These processes, and their implications for environmental sustainability, are synthesised in our conceptual framework (Fig. 1). Depending on the direction of these alterations, their impact on environmental sustainability can be either positive or negative. Both the progressive conversion of land into human-disturbed areas and the intensification of land use have been documented as major contributors to habitat loss and ecosystem degradation worldwide, posing increasing threats to global biodiversity (IPBES, 2019; Jaureguiberry et al., 2022; Semenchuk et al., 2022). These impacts are also reflected along the disturbance gradient illustrated in Fig. 1. For example, between 2000 and 2018, about 157 million hectares of tropical forests were lost due to deforestation, mainly for croplands and palm oil plantations (FAO, 2022). During the last three centuries, the global area of natural wetlands has declined by 21% as they were replaced with croplands, forest plantations, urban areas, or pastures (Fluet-Chouinard et al., 2023). Although unmitigated urbanisation is projected to threaten up to 855 plant and animal species by 2050 (Simkin et al., 2022), nearly 10,000 square kilometres of land are converted from non-urban to new urban areas each year worldwide (Liu et al., 2020).

Human-altered landscapes are managed with varying intensities. However, the continued growth of the global human population and its exploding demands have driven a steady increase in land-use intensification, shifting land systems along the gradient shown in Fig. 1 and further accelerating biodiversity decline (Seibold et al., 2019). For example, agricultural intensification for increased crop and livestock production has led to widespread landscape homogenisation and ecosystem simplification, reducing the abundance and diversity of species relying on open and semi-natural habitats (Tscharntke et al., 2005). Similarly, intensification of forest management for timber production, which reduces the amount of dead wood and simplifies forest structure and composition, has been reported to negatively impact several species groups, e.g., saproxylic species (Lassauce et al., 2011). Furthermore, the intensification of urban land use, such as increasing building and road density, entailing the loss and fragmentation of urban green spaces, has been shown to negatively affect urban species communities, e.g., birds, bats, or insects (Batáry et al., 2018; Fenoglio et al., 2021; Villarroya-Villalba et al., 2021). Consequently, anthropogenic land alterations for economic and social benefits affect not only biodiversity and ecosystems, but also the services they provide to societies (Tscharntke and Batáry, 2023). Thus, land-use dynamics can be viewed as a socioeconomic force driving environmental changes. Since it is innately associated with social, economic, and environmental dimensions of development, it plays a crucial role in addressing current and future sustainability challenges (Meyfroidt et al., 2022).

3. Interacting global change drivers threatening and moderating environmental sustainability

Land-use and land-cover change can interact with or have a triggering effect on multiple other global change drivers affecting sustainability (Fig. 1; Brook et al., 2008; Cabrerizo and Marañón, 2022). A synthesis by Jaureguiberry et al. (2022) identifies a hierarchy among the five global change drivers of biodiversity loss in terrestrial ecosystems: (1) land-use change, (2) direct overexploitation, (3) invasive alien species, (4) pollution, and (5) climate change. Land-use change stands at the core of this hierarchy and, as shown in our conceptual framework (Fig. 1), often interacts with or exacerbates the effects of the other four drivers (here referred to as external stressors) on sustainability outcomes. Overexploitation of natural resources, such as unsustainable hunting, logging, mining, or agricultural overuse is commonly associated with land transformations. For instance, in tropical forests, logging

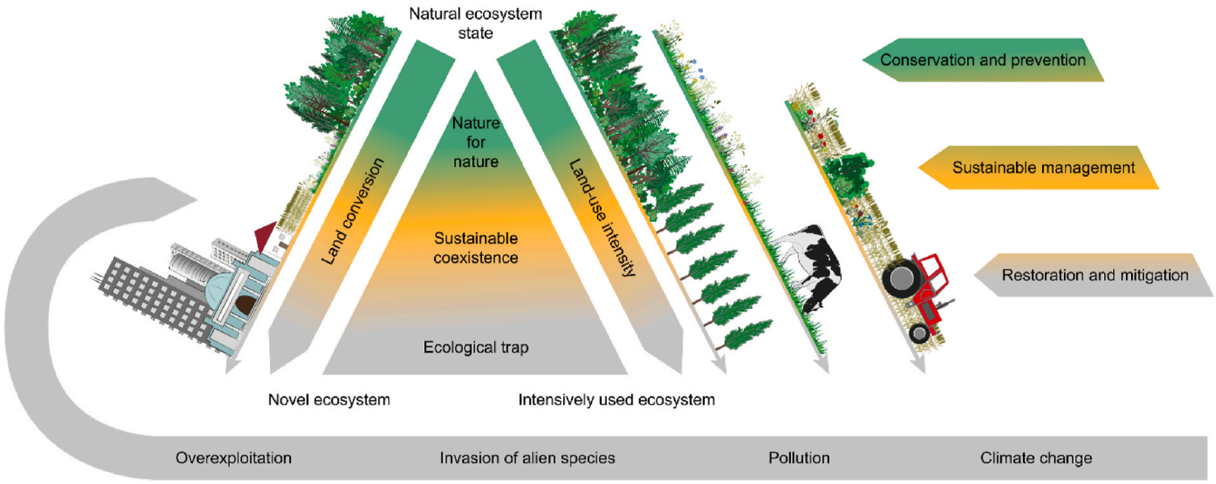

Fig. 1. Conceptual diagram illustrating the role of land-use and land-cover change in environmental sustainability. The left side (triangle) shows a gradient of land conversion and land-use intensification, from natural ecosystems to the most altered, intensively used ecosystems or novel ecosystems, with disturbance in the environment increasing along the gradient. The right side links this gradient to management responses needed to achieve and maintain sustainability, from conservation and prevention in areas where values of nature are of the highest importance, through sustainable management that allows sustainable coexistence between people and nature in moderately altered landscapes, to restoration and mitigation of the negative effects from highly altered habitats that risk functioning as ecological traps. The grey arrow at the bottom illustrates external global stressors: overexploitation, invasions of alien species, pollution, and climate change that interact with land systems dynamics and can shift it away from sustainability. Together, these elements highlight how context-specific strategies are needed to maintain or restore human–nature coexistence across different states of land-system.

not only drives deforestation but also increases human access to wildlife through road construction, intensifying hunting pressure and accelerating biodiversity loss (Laurance et al., 2006, 2011). In western Amazonia, largely illegal gold mining has increased by 400% over 14 years, leading to extensive deforestation and forest degradation (Asner et al., 2013). In arid ecosystems such as the Sahel, overgrazing combined with climate change accelerated desertification (Sivakumar, 2007). Similarly, the excessive use of agricultural soils through agrochemical overuse, the cessation of crop rotation, and monocultures, can lead to soil depletion and reinforce climate-related impacts (Cook et al., 2009).

Land-use modifications can facilitate biological invasions (Lenda et al., 2012), which, by disrupting the stability of native ecosystems, contribute significantly to the global biodiversity decline (IPBES, 2019) and pose serious risks to human well-being (Early et al., 2016; Diagne et al., 2021). Human-induced land surface alterations, like those associated with transportation networks, built-up areas, or agricultural land use, can provide suitable habitats for invasive species (e.g., plants) and serve as potential source pools and pathways for their spread (Vila and Ibáñez, 2011; Cadotte et al., 2017; Kotowska et al., 2022). Increased human activity and mobility associated with infrastructure development, such as roads and expanding settlements, can further accelerate the spread of numerous other invasive species, including pests like the emerald ash borer (*Agrilus planipennis*; Ward et al., 2020). Land-use change can also influence the dynamics of infectious diseases (Plowright et al., 2024). For example, deforestation and settlement expansion have been linked to malaria outbreaks in Africa, Asia, and Latin America (Patz et al., 2004), whereas cropland expansion has been associated with an increased risk of rodent-borne zoonoses (García-Peña et al., 2021).

Pollution is another major stressor that is often exacerbated by intensified land use. Agricultural runoff contributes to water and soil contamination with pesticides, fertilisers, and other pollutants (Houet et al., 2010). Increased urbanisation can result in air pollution, e.g., with particulate matter or nitrogen oxides from industry, energy consumption, and transportation. It can also lead to water and soil contamination with nutrients, plastics, and hazardous chemicals (Ma et al., 2023; Strokal et al., 2021) and results in the introduction of sensory pollutants, such as anthropogenic noise and artificial light (Alberti, 2015). These impacts can extend far beyond their original locations, affecting distant ecosystems and contributing to global environmental challenges (Grimm et al., 2008).

Finally, among the external global stressors, climate change is one of the most pressing issues with far-reaching consequences for the environment, society, and economy (Parmesan and Yohe, 2003). Human-induced greenhouse gas emissions (of which anthropogenically modified land is a major contributor, accounting for about 23% of emissions) have already caused global warming of more than 1.1 °C above pre-industrial levels (IPCC, 2019; IPCC, 2022; He et al., 2024). This has led to alterations in precipitation regimes, rising sea levels, frequent extreme weather events, oxygen depletion, salinisation and acidification of aquatic environments, and increasing soil salinity (Corwin, 2021; Cunillera-Montcusí et al., 2022; Pörtner et al., 2023). Resulting shifts in land productivity and environmental suitability for different types of land use can drive losses in livelihoods, negatively affect food security, commodity production systems, and human health, and may have dramatic effects on biodiversity (Van de Vuurst and Escobar, 2023; Jerneck et al., 2011). Together, these compounding stressors underscore the complexity of land system dynamics. As summarised in Fig. 1, sustainability efforts must therefore be tailored according to the degree of human-induced land-use modifications and take into account the reinforcing influence of external stressors.

4. Balancing coexistence: human–nature interactions across changing land systems

The level of anthropogenic alterations to land through land conversion and land-use intensification reflects the state of the environment, from the most natural and intact ecosystems to the most heavily human-disturbed ones. As illustrated in Fig. 1, this gradient corresponds to different strategies to achieve and maintain environmental sustainability: conservation and prevention in intact ecosystems, sustainable management in moderately altered landscapes, and restoration or mitigation in degraded systems (Table 1).

Natural areas with low level of anthropogenic pressures are of primary importance for buffering the effects of climate change and other human impacts (Alberti, 2015). These wilderness areas provide high-value ecosystem services, are essential refuges for declining species, and can serve as reference sites for observing natural processes

Table 1
Actions to achieve and maintain environmental sustainability, along with their description, examples, and reference to the key synthesis studies.

Actions for sustainability	Description	Examples	References
Conservation and prevention	Safeguarding intact and low-disturbance ecosystems to preserve biodiversity, ecosystem functions, and cultural values; preventing new land conversion or degradation.	Establishing protected areas and wilderness reserves; recognition of indigenous and community-conserved areas; strict protection of old-growth forests and primary ecosystems; legal frameworks to halt deforestation, wetland drainage or mining in sensitive areas; establishing ecological corridors and buffer zones.	IPBES, 2019; Allan et al. (2020); Langhammer et al. (2024)
Sustainable management	Maintaining multifunctional landscapes in moderately altered ecosystems through practices that balance production with ecological resilience; supporting coexistence of people and nature.	Traditional, low-intensity agriculture; "Closer-to-Nature" forest management; agroecology and agroforestry systems; agri-environment schemes.	Batáry et al. (2015); Garibaldi et al. (2017); Vanbergen et al. (2020)
Restoration and mitigation	Reversing or alleviating degradation in heavily altered ecosystems by re-establishing ecological processes, improving habitat quality, or mitigating damage where full recovery is not feasible.	Rewetting of drained peatlands; adoption of paludiculture and regenerative agriculture; rewilding projects; afforestation and reforestation with native species; river and floodplain restoration; removal of invasive species; reintroduction of native or keystone species; restoring ecosystem connectivity; urban green and blue infrastructure.	Benayas et al. (2009); Wortley et al. (2013); Jones et al. (2018)

unimpeded by human influence. They are also home to some indigenous communities with critical traditional knowledge necessary for maintaining environmental sustainability (McElwee et al., 2020). Conserving such intact ecosystems in an unaltered state is, therefore, essential to achieving several SDGs. The urgency of incorporating this goal into global conservation frameworks has been increasingly highlighted (Watson et al., 2018).

In moderately altered systems, relevant land-use practices can positively affect environmental sustainability, maintaining a sustainable coexistence of people and nature. Over at least 12,000 years of human activity shaping the Earth's terrestrial surface, traditional low-intensity land use has created and sustained complex landscapes of high biodiversity and cultural significance (Ellis et al., 2021). For example, in Central Europe, extensive agricultural management has created semi-natural habitats, such as hay meadows, dry grasslands, or wood pastures, with diverse fauna and flora that depend on continued agriculture for survival (Sutcliffe et al., 2015). Thus, maintaining these biodiversity-rich landscapes requires sustainable management (e.g., extensive mowing or grazing) that safeguards the stability of ecosystems and the well-being of communities that depend on them (Báldi et al., 2023; Halada et al., 2011). Similarly, "Closer-to-Nature" forest management practices could harmonise timber production with conservation goals in forests (Larsen et al., 2022). However, these actions should extend beyond individual patches to encompass broader landscape-scale strategies that support ecological connectivity and dynamic land-use mosaics, offering promising pathways for sustaining biodiversity in moderately altered environments (Grass et al., 2021). Notably, even some highly disturbed landscapes, such as military training lands, can support unexpectedly high levels of biodiversity (Svenningsen et al., 2019). This is due to a reduced pressure for land-use intensification and the presence of a disturbance regime that is heterogeneous in size, shape, spatial and temporal distribution, frequency, severity, and duration (Warren et al., 2007). Such complexity underscores the critical importance of spatial and temporal dynamics in shaping habitat heterogeneity and sustaining ecological resilience across disturbed land systems. However, the state of sustainable coexistence in these systems depends not only on internal dynamics but also on broader external stressors (Fig. 1) such as climate change, global pandemics, or military conflicts. In such crises, the balance between human needs and environmental sustainability changes and the point of coexistence may be shifted. Recognizing these dynamics underscores the need for adaptive, context-specific strategies that remain responsive to both internal land-use dynamics and external global pressures.

Such a balanced coexistence can also be disrupted by increased levels of land-use intensification and land conversion, leading to ecosystem deterioration, emergence of novel ecosystems, or creation of large-scale homogeneous landscapes (as exemplified by the Dust Bowl drought in the United States in the 1930s; Cook et al., 2009). Up to a certain level of these land transformations, re-establishment of ecological processes supporting self-sustaining and biodiverse ecosystems is possible through restoration (Palmer and Stewart, 2020). It can involve a range of actions, such as reintroducing native species, removing perturbing factors (e.g., pollutants, invasive species), reducing unsustainable use of ecosystems, and changing land management regimes (e.g., implementing agri-environmental practices). However, in the case of heavily degraded environments, restoration efforts may not be successful (Suding, 2011). Thus, these highly altered habitats can be viewed as ecological traps for humans (Cumming et al., 2014). This term, primarily used in evolutionary and conservation biology (Gates and Gysel, 1978; Schlaepfer et al., 2002; Søgaard Jørgensen et al., 2023), can describe an unsuitable state of the environment in which limited resources are depleted or become unusable without a realistic perspective of their restitution, thereby being detrimental to the species' survival. This can also apply to human development, potentially creating a social-ecological trap, a situation in which self-reinforcing social and ecological interactions lock a system into an undesirable trajectory, threatening ecological sustainability and human well-being (Haber, 2007; Boonstra et al., 2016). In our framework (Fig. 1), these states represent the far end of the gradient, where restoration and mitigation efforts face the greatest challenges.

5. Pathways towards sustainable land systems: integrating solutions with contextual realities

Efforts to achieve and maintain sustainability can be implemented through a range of complementary approaches (broadly outlined in Fig. 1 and described in Table 1), but their effectiveness depends on the context. Turning this framework into practice requires adapting conservation, management, and restoration measures to local ecological and social conditions while remaining responsive to external stressors. Nature-based solutions exemplify such approaches. They offer a way to enhance sustainable land use by harnessing natural processes to support both people and the environment. For instance, the restoration of mangrove forests can safeguard local coastal communities from storm surges and erosion while providing habitats for wildlife, absorbing carbon dioxide and enhancing water quality by filtering pollutants (Lovelock et al., 2024). Agroforestry practices, such as integrating trees and shrubs into crop and animal farming systems can prevent soil erosion, improve water retention and create ecological corridors while providing economic benefits (Castle et al., 2021). Similarly, agroecological farming practices, like crop rotation and intercropping, can increase food production while maintaining soil fertility and reducing the need for chemical inputs (Rosa-Schleich et al., 2019). Urban green and blue infrastructure, including parks, green roofs, community gardens, tree-lined streets, ponds, and wetlands, play a crucial role in stormwater management, reducing urban heat, enhancing air quality, and providing recreational space, thereby contributing to the improvement of residents' well-being (Kowarik et al., 2025). The rewetting of drained peatlands and adoption of paludiculture, which involves cultivating wetland-adapted crops, are gaining recognition as a climate-smart land use strategy that reduces carbon emissions while maintaining economic productivity (Lupascu and Wijedasa, 2021). These examples of diverse individual measures can be integrated into broader management frameworks, such as the Spatial Ecological Network (SEN) approach, which serves as an integrative tool for conservation and land-use planning. This approach focuses on identifying and managing functionally connected ecosystems that support both biodiversity and the sustainable use of natural resources (Gonzalez et al., 2017). By combining ecological principles with social considerations, it facilitates conservation strategies that enhance habitat connectivity, sustain ecosystem services, and improve resilience to environmental change, while also addressing human needs and land-use pressures.

However, the success of these interventions and strategies is highly context-dependent. Despite the growing scientific focus on sustainability science, the concept of sustainability remains subjective, with different interpretations depending on the cultural, economic, institutional, and ecological conditions (Ramsey, 2015; Purvis et al., 2019). As such, the effectiveness of sustainability measures may depend on the historical developments, socio-economic conditions, and governance structures, which vary across space and time (Tappeiner et al., 2021; Diogo et al., 2022). Thus, their impact can also be scale-dependent (Grass et al., 2021; Batáry and Tscharntke, 2022). In regions like Central Europe, where a significant proportion of land has been transformed primarily for agriculture, the success of these measures depends on their alignment within the land-use intensity gradient and the proportion and configuration of different habitat types within the landscape at the scale of interest. Agri-environmental schemes, for example, tend to be more effective in simplified landscapes with a low proportion of semi-natural habitats, such as grasslands, forests, hedgerows, tree lines, or wetlands than in more complex ones (Batáry et al., 2015; Marja et al., 2019). Importantly, the spatial structure of a landscape (including patch size, connectivity, and habitat heterogeneity) plays a critical role in enabling biodiversity persistence at a broader spatial scale (Tscharntke et al., 2012). Thus, even in fragmented or degraded environments, species may survive if landscape elements are functionally connected (both in space and time) and habitat quality is maintained (Auffret et al., 2015). In the Pannonian lowlands of Hungary, for instance, dirt road verges between forest plantations support arthropod communities similar to those in remnant forest-steppe habitats, functioning as semi-natural habitats and corridors that help mitigate fragmentation within the wider landscape (Kaur et al., 2019). Furthermore, the scale at which ecological processes are analysed plays a crucial role in shaping conclusions. At finer spatial scales, local extinctions may appear alarming, yet when considered at a broader landscape or regional scale, these patterns might reflect natural population turnover. Similarly, short-term studies may fail to detect long-term trends driven by climatic variability, land-use change, or ecological succession. Therefore, our framework emphasises that sustainability cannot be considered a fixed target. In a rapidly changing environment where different pressures constantly shift, we argue that flexible, scale-sensitive strategies that account for spatial and temporal dynamics in ecosystems and landscapes are essential for guiding effective sustainability efforts.

6. Conclusions

With land being a primary finite resource and a nexus for societal, economic, and environmental problems, how human communities use and interact with land is critical for addressing sustainability challenges. Given this interdependence, there is an urgent need for transformative change in land use to ensure long-term planetary and human well-being (Díaz et al., 2019). Such transformation requires fundamental system-wide reconfigurations of how societies manage land, produce and consume resources, and value ecological integrity. It involves addressing the underlying causes of unsustainable land use, such as economic incentives that prioritize short-term exploitation over long-term resilience; fragmented governance systems that impede integrated land-use planning; social norms that promote overconsumption, and a significant science–policy gap that hinders evidence-based decision-making and appropriate interventions (Ostrom, 2009; Lambin and Meyfroidt, 2011; Báldi et al., 2023).

Therefore, this change should involve a range of multifaceted and context-sensitive efforts, recognizing that sustainability is not a fixed target, but a dynamic condition. Interventions must be adapted to local ecological, institutional, and socio-cultural contexts, integrating restoration with mitigation, prevention, and conservation to maintain ecological balance before critical thresholds are crossed. Traditional low-intensity land-use practices and local knowledge can guide the development of place-adapted management strategies, subsidy schemes, and conservation measures, especially in landscapes of high biodiversity values (Sutcliffe et al., 2015; Ogar et al., 2020). Also, approaches such as agroforestry, agroecology, regenerative agriculture, and technology-based precision agriculture can facilitate the transition from input-intensive monocultures to diverse, resilient systems that enhance soil health, support biodiversity, and improve resource efficiency (Altieri et al., 2012; Vanbergen et al., 2020). Reducing land-use pressures also requires changes in consumption patterns, including food waste reduction, shifting dietary habits, and shortening supply chains (Willett et al., 2019). This, in turn, calls for tackling the underlying social issues by promoting education and raising awareness to change the perceptions, values, and behaviours among producers and consumers. Equally important is promoting institutional coherence by integrating land governance across sectors and administrative levels and ensuring the meaningful participation of indigenous peoples and local communities in land use decisions. Furthermore, rethinking ineffective incentives and governance systems is essential for achieving sustainability. This involves designing flexible, science-based governance frameworks that can adapt to diverse and changing regional contexts. To keep these systems responsive and effective, closer collaboration and communication between researchers and policymakers are critical. A strengthened science–policy interface would support the implementation of multi-scale monitoring and feedback mechanisms, ensuring that policies evolve in response to environmental dynamics and the continuous advancement of scientific knowledge.

Addressing the complexities of sustainable land use necessitates shifting toward integrated, adaptive, and inclusive approaches that consider ecological realities and governance challenges. Improving institutional coherence, strengthening science–policy interfaces, enabling local adaptation, and incorporating long-term resilience into land use systems are crucial to preventing societies from becoming locked into unsustainable trajectories. Fostering coordinated efforts across different scales and sectors, while remaining responsive to evolving conditions, can transform land management from a driver of environmental degradation into a catalyst for systemic change and long-term sustainability.

CRediT authorship contribution statement

Dorota Kotowska: Writing – review & editing, Writing – original draft, Conceptualization. **András Báldi:** Writing – review & editing, Funding acquisition, Conceptualization. **Péter Dobosy:** Writing – review & editing, Funding acquisition, Conceptualization. **Tamás Felföldi:** Writing – review & editing, Funding acquisition, Conceptualization. **László Zsolt Garamszegi:** Writing – review & editing, Funding acquisition, Conceptualization. **Zsófia Horváth:** Writing – review & editing, Funding acquisition, Conceptualization. **György Kröel-Dulay:**

Writing – review & editing, Funding acquisition, Conceptualization. **Péter Ódor:** Writing – review & editing, Funding acquisition, Conceptualization. **Orsolya Valkó:** Writing – review & editing, Funding acquisition, Conceptualization. **Péter Batáry:** Writing – review & editing, Writing – original draft, Funding acquisition, 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 new data were created or analysed during this study. Data sharing is not applicable to this article.

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