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Opinion

Integrating biodiversity, ecosystem function and human dimensions for sustainable landscape management under environmental change

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Environmental change, driven by human activity and climate variability, is reshaping ecosystems worldwide, affecting biodiversity, ecosystem functioning and the services these systems provide to humanity. Sustainable landscape management requires a holistic understanding of the interplay between ecological processes and human dimensions. This article synthesizes current knowledge on the integration of biodiversity conservation, ecosystem function and socio-ecological dynamics in landscapes experiencing anthropogenic pressures. Key themes include habitat fragmentation, pollination services, soil and microbial mediation, water regulation and climate feedbacks. By combining ecological, social and technological approaches—including remote sensing, participatory management and microbial ecology—landscape managers can design interventions that optimize ecosystem services while supporting human livelihoods. The paper emphasizes adaptive strategies to enhance resilience and sustainability in rapidly changing environmental contexts.

Keywords: Biodiversity, Ecosystem function, Human dimensions, Landscape management, Environmental change, Pollination, Soil microbiome, Resilience, Ecosystem services.

Introduction

Global environmental change—encompassing climate shifts, land-use transformation and habitat degradation—poses significant challenges for ecosystem integrity and human well-being. Biodiversity underpins ecosystem functioning by supporting nutrient cycling, carbon storage, water regulation and pollination. At the same time, human activities such as agriculture, urbanization and infrastructure development modulate ecological patterns and processes. Sustainable landscape management must therefore integrate ecological and social dimensions. This requires understanding how biodiversity and ecosystem function respond to environmental stressors, how human interventions shape these responses and how ecosystem services feed back into human societies. Emerging research highlights that managing for biodiversity alone is insufficient; functional relationships and socio-ecological interactions are equally critical for maintaining resilient landscapes. This explores the integration of biodiversity, ecosystem functioning and human dimensions in landscape management (Battipaglia G, et al, 2013). It examines mechanistic linkages, evaluates management strategies under environmental change and identifies opportunities for enhancing ecosystem resilience and sustainability. Biodiversity provides the foundation for ecosystem stability and productivity. Species richness and functional diversity contribute to redundancy and resilience, allowing ecosystems to withstand perturbations such as droughts, floods and land-use intensification. Insects and other pollinators are sensitive indicators of ecological health. Active and spontaneous restoration of degraded landscapes reveals divergent outcomes in pollination services, highlighting the importance of targeted management strategies.

Description

Soil microbes play critical roles in nutrient cycling, carbon storage and plant health. Environmental stressors, such as drought or chemical exposure, can alter microbial composition, reducing ecosystem resilience. Pre-exposure to stress has been shown to enhance microbial resistance, allowing ecosystems to maintain function under repeated perturbations. Root-associated fungi and ectomycorrhizal networks further mediate plant-soil feedbacks, influencing productivity and recovery in disturbed habitats. Functional traits of plants—including root morphology, leaf area and drought tolerance—determine how vegetation mediates water and nutrient cycles (Carvalho C, et al. 2022). Afforestation and vegetation restoration can alter local microclimates, reduce surface temperatures and enhance carbon sequestration, demonstrating the interconnectedness of biodiversity, ecosystem function and climate feedbacks. Environmental change modifies the structure and function of ecosystems, impacting services that support human livelihoods.

Semi-arid and dryland ecosystems disproportionately contribute to interannual variability in the global carbon cycle. Land-use change, soil degradation and vegetation loss disrupt carbon storage and nutrient availability. Wetlands, by contrast, regulate greenhouse gas fluxes through inundation and vegetation-mediated processes (Craig JM, et al. 2016). Effective management requires understanding the spatiotemporal dynamics of these ecosystems under changing hydrological and climatic conditions. Landscape management influences hydrological cycles, with implications for flood control and water conservation. Spatial-temporal modeling of flood control capacity reveals the sensitivity of ecosystem services to land-use patterns. Restoration practices that increase vegetation cover and enhance soil structure can buffer hydrological extremes, protecting both biodiversity and human communities. Land-use patterns affect pollinator distribution and activity, which in turn regulate agricultural productivity. Large-scale landscape suitability assessments for honeybees demonstrate the importance of maintaining connectivity and habitat diversity to sustain pollination services (Gallant AL, et al. 2014). Ecosystem feedbacks emerge when changes in pollinator activity influence plant community composition, affecting future ecosystem productivity and resilience.

Sustainable landscape management cannot ignore human dimensions. Governance, socio-economic incentives, cultural practices and community participation shape land-use outcomes and conservation success. Engaging local communities in decision-making, for instance through participatory causal loop mapping, enhances adoption of sustainable practices such as organic farming or habitat restoration. Participation ensures that management interventions align with local needs, improving long-term success and ecosystem service delivery. Economic and regulatory frameworks influence land-use decisions (Guo X, et al. 2023). Rank-order incentive structures, subsidies and policy instruments can either reinforce unsustainable exploitation or promote conservation-compatible land use. Integrating ecological insights with policy design is key to aligning human incentives with landscape sustainability. Human health is intrinsically linked to environmental quality. Air pollution, access to natural spaces and ecosystem degradation impact both physical and mental health. Social-ecological frameworks, such as the ecological theater concept, highlight how exposure to healthy ecosystems can promote well-being and inform conservation priorities.

Conclusion

Integrating biodiversity, ecosystem function and human dimensions is essential for sustainable landscape management under environmental change. Land-use practices, habitat restoration and conservation interventions influence biodiversity, soil and microbial dynamics, water regulation, pollination and carbon cycling. These ecological processes interact with human activities and societal well-being through complex feedbacks. Sustainable management requires multi-scale, cross-disciplinary approaches that combine ecological monitoring, restoration ecology, microbial and soil science and socio-economic integration. By aligning conservation goals with human needs, promoting participatory management and leveraging technology and policy, landscapes can be managed to maintain ecosystem services, enhance resilience and support human health and livelihoods in a rapidly changing world. Future research should emphasize integrative, multi-scale approaches combining ecology, social science and technology. Developing predictive models, long-term monitoring frameworks and participatory management strategies will improve our ability to maintain resilient, sustainable landscapes.

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Conflict of Interest

The authors declare no conflict of interest.

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