Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2025, 15(5), 25-27, doi: 10.15421/2025_640

Short Communication

Assessing ecosystem service sustainability under land-use change and restoration

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Received: *02 September, 2025, Manuscript No: UJE-26-178651,* ***Editor assigned:*** *05 September, 2025, PreQC No: P-178651,* ***Reviewed:*** *16 September, 2025, QC No: Q-178651,* ***Revised:*** *23 September, 2025, Manuscript No: R-178651,* ***Published:*** *30 September, 2025*

Land-use change and habitat restoration are pivotal factors influencing the sustainability of ecosystem services. Anthropogenic activities, including agriculture, urbanization and industrial expansion, alter biodiversity, soil health and pollination services, often compromising ecosystem resilience. Conversely, ecological restoration offers opportunities to recover degraded ecosystems and enhance service provision. This article synthesizes current research on the impacts of land-use change and restoration on ecosystem service sustainability, emphasizing pollination, carbon sequestration, water regulation and human health outcomes. By integrating insights from biodiversity, microbial ecology and social-ecological systems, we propose a framework for evaluating and managing ecosystems in a manner that balances human needs with ecological integrity. The analysis underscores the importance of monitoring, adaptive management and stakeholder engagement to ensure resilient and sustainable landscapes.

Keywords: Ecosystem services, Land-use change, Ecological restoration, Pollination, Biodiversity, Carbon cycling, Soil health, Sustainability, Landscape management, Social-ecological systems.

Introduction

Ecosystem services—benefits that humans derive from natural environments—are increasingly threatened by land-use change. Conversion of forests, wetlands and grasslands to agriculture, urban settlements and industrial landscapes disrupts biodiversity, alters hydrological cycles and reduces carbon storage capacity. These changes not only impact ecological integrity but also compromise essential services such as pollination, water regulation and climate mitigation. Conversely, restoration of degraded ecosystems, whether through reforestation, wetland rehabilitation, or habitat reconstruction, can reinstate ecosystem functions, increase biodiversity and improve service delivery. However, the sustainability of these services depends on multiple factors, including the scale and intensity of land-use changes, ecological connectivity, microbial and plant community dynamics and social-ecological governance structures. Understanding the interplay between land-use change, restoration and ecosystem service sustainability is critical for designing landscapes that are productive, resilient and capable of supporting both human and ecological well-being. This article examines evidence from recent research on ecosystem service responses to land-use dynamics and restoration interventions, providing insights for sustainable landscape management. Land-use change often results in habitat fragmentation, species loss and declines in functional diversity (Kale JR, et al. 2009). Pollination services, which are vital for global food security, are particularly sensitive to these changes. Studies in restored quarries and agricultural landscapes show that pollinator communities differ markedly between natural and modified habitats, with restored sites gradually converging toward natural reference states. Yet, intensive land-use practices, including monocultures and pesticide application, can inhibit recovery, leading to reduced pollination efficiency and lower crop yields.

Description

Conversion of natural ecosystems to agriculture or urban land reduces soil organic matter and microbial diversity, impairing carbon sequestration. Land-use change alters microbial-mediated processes, such as nitrogen fixation and decomposition, which are essential for maintaining soil fertility and ecosystem productivity. Degraded soils exhibit lower resilience to climate extremes, highlighting the importance of integrating soil health considerations into land management decisions. Natural landscapes, particularly wetlands and riparian zones, play a crucial role in regulating hydrological processes. Land-use conversion disrupts water infiltration, retention and nutrient cycling, exacerbating flood risks and water quality issues (Saldiva PH, et al. 1995). Studies from river basins in China demonstrate that intact ecosystems provide superior water conservation functions, while degraded landscapes exhibit reduced hydrological regulation. Land-use changes can indirectly impact human health by reducing access to natural environments, which are associated with psychological well-being and exposure to ecosystem services such as clean air and water. The social-ecological perspective emphasizes that human behaviors, governance structures and cultural practices shape land-use decisions, creating feedback loops that either enhance or degrade ecosystem services over time.

Restoration of degraded habitats can enhance pollinator diversity and function. Actively restored landscapes often achieve higher flower visitation rates compared to spontaneously recovering areas, demonstrating the importance of targeted management. Creating floral corridors, planting native species and reducing pesticide use are strategies that foster pollinator abundance, promoting sustainable agricultural and natural systems (Carvalho C, et al. 2022). Restoration interventions, such as afforestation and wetland rehabilitation, improve soil structure, increase microbial diversity and enhance carbon storage. These processes contribute to climate mitigation and ecosystem resilience, especially in areas subject to degradation or climate stress. Monitoring soil microbial communities provides insights into the functional recovery of restored landscapes. Wetland and riparian restoration improves water retention, nutrient filtering and flood mitigation. Controlled inundation experiments demonstrate that vegetation type and hydrological management strongly influence greenhouse gas emissions and water quality outcomes. Integrating hydrological planning into restoration enhances ecosystem service sustainability (Craig JM, et al. 2016). Successful restoration requires engagement with local communities, stakeholders and policymakers. Participatory planning, incentive mechanisms and education programs align ecological goals with social priorities. By incorporating social-ecological feedbacks, restoration projects are more likely to maintain long-term service provision and resilience.

Effective assessment is hindered by limited data on microbial function, long-term restoration outcomes and social-ecological interactions. Advancements in remote sensing, DNA-based microbial surveys and citizen science provide opportunities to bridge these gaps. Ecosystem services often involve trade-offs. For instance, maximizing agricultural yield may reduce pollinator diversity or water quality. Integrating multi-objective management and participatory governance helps reconcile conflicting demands and optimize landscape sustainability (Gallant AL, et al. 2014). Global environmental change introduces uncertainty in restoration success and service provision. Droughts, floods and temperature extremes affect biodiversity, soil microbial communities and hydrological functions. Incorporating climate-adaptive practices and resilient species into restoration planning enhances long-term ecosystem service sustainability..

Conclusion

Land-use change profoundly affects the sustainability of ecosystem services, yet ecological restoration offers pathways for recovery. Integrating biodiversity conservation, microbial ecology, hydrological management and social-ecological governance is essential for resilient landscapes. Pollination, carbon sequestration, water regulation and human well-being are tightly linked to ecological structure, function and management practices. By adopting adaptive, participatory and multi-scale approaches, stakeholders can maintain ecosystem service provision in the face of environmental change. Future research should continue to bridge ecological, microbial and social dimensions, providing robust frameworks for sustainable landscape management that benefit both nature and society.