Ukrainian Journal of Ecology

*Ukrainian Journal of Ecology*, 2025, 15(6), 33-35, doi: 10.15421/2025_650

*Perspective*

# Multiscale interactions in ecosystem function: Connecting soil fungi, plant traits, hydrology and social-ecological dynamics

**Mariam Klueva***

*Department of Crop Science, University of Helsinki, Finland*

**Corresponding author E-mail: mklueva@henki.fi*

***Received:** 01 November, 2025, Manuscript No: UJE-26-178662, **Editor assigned:** 03 November, 2025, PreQC No: P-178662, **Reviewed:** 15 November, 2025, QC No: Q-178662, **Revised:** 21 November, 2025, Manuscript No: R-178662, **Published:** 27 November, 2025*

Ecosystem functioning emerges from the intricate interplay of biological, physical and social processes across multiple scales. Soil fungal communities mediate nutrient cycling, plant growth and carbon storage, while plant functional traits determine resource use, productivity and stress tolerance. Hydrological processes regulate water availability, nutrient transport and microbial activity, linking terrestrial and aquatic components of landscapes. Simultaneously, social-ecological dynamics, including land-use practices, governance and local knowledge, influence ecosystem structure and resilience. This article synthesizes current research on the multiscale interactions among soil fungi, plant traits, hydrology and socio-environmental drivers. We highlight the mechanisms by which these components interact to shape ecosystem services, resilience under environmental stress and human well-being and propose integrative strategies for sustainable landscape management under global change.

**Keywords:** Soil fungi, Plant functional traits, Hydrology, Social-ecological systems, Ecosystem function, Multiscale interactions, Landscape resilience, Sustainability.

## Introduction

Ecosystems are dynamic entities governed by complex interactions among biotic and abiotic factors, with human activities increasingly shaping their trajectories. Soil fungi, particularly mycorrhizal species, are critical mediators of nutrient cycling, carbon sequestration and plant stress tolerance. Plant functional traits—such as root morphology, leaf area and water-use efficiency—modulate the capacity of vegetation to capture resources and adapt to environmental fluctuations (Xu C, et al. 2021). Hydrological regimes further control water availability, sediment transport and nutrient fluxes, thereby influencing both plant and microbial communities. In parallel, social-ecological dynamics—encompassing land-use decisions, governance structures and cultural practices—affect ecosystem management and service provision. Agricultural intensification, urban expansion and restoration initiatives intersect with these ecological processes, creating feedback loops that can either enhance or compromise ecosystem resilience. Understanding multiscale interactions among soil fungi, plant traits, hydrology and social-ecological factors is thus crucial for sustaining ecosystem function and human well-being (Kjøller R. 2006). Recent research emphasizes the importance of integrating microbial ecology, plant functional diversity, hydrological modeling and social-ecological frameworks to capture these complex interactions. This multiscale perspective informs adaptive management strategies capable of mitigating environmental stressors, enhancing ecosystem services and promoting sustainable landscapes.

## Description

Soil fungi, including ectomycorrhizal and arbuscular mycorrhizal species, play pivotal roles in ecosystem functioning. They facilitate nutrient acquisition, particularly phosphorus and nitrogen, for plants and contribute to soil aggregation and carbon stabilization. Ectomycorrhizal fungi often form extensive mycelial networks that connect multiple plants, enhancing nutrient redistribution and buffering against environmental stress. Studies reveal disproportionate abundances between fungal root tips and associated mycelia, indicating that fungal biomass and activity extend beyond localized root interactions to influence broader ecosystem processes. Fungal communities are sensitive to hydrological changes and plant composition, with drought or inundation altering community structure and function (Stokols D. 1996). For example, root exudates released under water stress can shift microbial composition, favoring drought-resistant taxa that maintain nutrient cycling and plant productivity.

Plant traits determine how vegetation responds to environmental constraints and interacts with microbial communities. Root architecture, specific leaf area and water-use efficiency modulate plant capacity to access soil resources and tolerate abiotic stress. Functional trait diversity in plant communities enhances complementarity, promoting productivity and stability across environmental gradients. Root traits, in particular, influence soil microbial communities by shaping rhizosphere chemistry and providing substrates for microbial growth (Pohl M, et al. 2011). Deep-rooted plants can access water and nutrients from lower soil horizons, supporting both aboveground productivity and belowground microbial networks. Traits such as mycorrhizal association type, leaf litter quality and root exudation patterns interact with fungal communities to determine nutrient cycling rates and carbon storage potential.

Hydrological processes regulate water distribution, nutrient transport and microbial activity across landscapes. Variations in soil moisture influence microbial metabolism, decomposition rates and greenhouse gas fluxes. In temperate coastal wetlands, for example, inundation patterns and vegetation types jointly determine soil carbon dynamics and microbial composition. Hydrology also mediates plant-microbial interactions by controlling soil oxygen availability and nutrient solubility. Periodic flooding or drought affects both the composition and functional capacity of soil fungi, altering their ability to support plant growth and maintain ecosystem services. Effective management of hydrological regimes—through wetland restoration, irrigation planning and flood mitigation—enhances the resilience of plant-fungal networks under environmental stress. Human activities directly influence ecosystem function through land-use change, agricultural practices and restoration initiatives (Liu X, et al. 2022). Social-ecological systems frameworks integrate human behaviors, institutional capacity and ecological processes to understand feedbacks that affect ecosystem resilience. Participatory approaches, such as causal loop mapping in organic farming adoption, demonstrate the importance of incorporating local knowledge and stakeholder engagement in sustainable landscape management.

## Conclusion

Ecosystem function is shaped by the multiscale interactions among soil fungi, plant functional traits, hydrological processes and socio-environmental drivers. Soil fungal networks mediate nutrient cycling and plant stress tolerance, while plant traits determine resource acquisition and ecosystem productivity. Hydrology regulates water and nutrient availability, influencing both microbial and plant dynamics. Human land-use practices and governance structures further modulate these ecological processes, producing complex feedbacks that affect ecosystem resilience and service provision. Integrating these components across scales provides a framework for sustaining ecosystem functions under global environmental change. By enhancing fungal diversity, promoting functional plant traits, managing hydrological regimes and incorporating participatory social-ecological approaches, landscapes can maintain multifunctionality, support biodiversity and deliver essential ecosystem services. This multiscale, integrative perspective is critical for developing adaptive management strategies that foster resilient and sustainable landscapes in an era of accelerating climate and anthropogenic pressures. Resilience emerges from diversity, redundancy and connectivity. Soil fungal diversity ensures continuous nutrient cycling under stress, while plant trait diversity buffers against environmental fluctuations. Hydrological connectivity maintains water availability and nutrient transport and adaptive social-ecological governance enables responsive management to changing conditions. By integrating these components, landscapes can maintain multifunctionality and adapt to climate variability and anthropogenic pressures.

## Acknowledgement

None.

## Conflict of Interest

The authors declare no conflict of interest.

## References

Xu, C., Wong, V. N., Reef, R. E. (2021). Effect of inundation on greenhouse gas emissions from temperate coastal wetland soils with different vegetation types in southern Australia. Science of the Total Environment 763:142949.

Kjøller, R. (2006). Disproportionate abundance between ectomycorrhizal root tips and their associated mycelia. FEMS Microbiology Ecology 58:214-224.

Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. American Journal of Health Promotion 10:282-298.

Pohl, M., Stroude, R., Buttler, A., Rixen, C. (2011). Functional traits and root morphology of alpine plants. Annals of Botany 108:537-545.

Liu, X., Zhao, H. (2022). Multiscale analysis of runoff complexity in the Yanhe watershed. Entropy 2:1088.

**Citation:**

Klueva, M., (2025). Multiscale interactions in ecosystem function: Connecting soil fungi, plant traits, hydrology and social-ecological dynamics. *Ukrainian Journal of Ecology.* 15: 33-35.