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Opinion

Ecology across scales: Linking microbial diversity, biodiversity history and social ecological determinants of health

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Ecology operates across multiple scales, from microbial communities in soils to the historical patterns of biodiversity that shape ecosystem structure and further to the social-ecological systems that govern human health. Understanding these interconnected scales is critical for addressing contemporary environmental challenges, including climate change, biodiversity loss and emerging health threats. Microbial diversity underpins nutrient cycling, soil fertility and ecosystem resilience, while biodiversity history informs the evolution of species interactions, ecosystem function and adaptive capacity. Simultaneously, social ecological determinants—including community design, access to natural spaces and resource management—mediate human exposure to ecosystem services and health outcomes. This article synthesizes research across microbial ecology, macroecology and social ecology to illustrate how ecological processes at multiple scales intersect and influence both ecosystem function and public health. By integrating these perspectives, we highlight the importance of multiscale ecological thinking for conservation, urban planning and sustainable health interventions.

Keywords: Microbial diversity, Biodiversity history, Social-ecological systems, Ecosystem services, Human health, Soil ecology, Ecological resilience, Nature-based solutions.

Introduction

Ecology is inherently multiscale, encompassing interactions that span microscopic to planetary dimensions. At the microbial level, soil bacteria and fungi mediate nutrient cycling, organic matter decomposition and plant health, forming the foundation for terrestrial productivity. At larger scales, the historical trajectory of biodiversity—shaped by speciation, extinction and dispersal events—determines current species assemblages, ecosystem function and adaptive potential in the face of environmental change. Overlaying these biological scales are social ecological systems, which capture the interactions between human societies and their environments, influencing health outcomes through access to clean air, water, nutrition and green space. Integrating these scales is essential for understanding ecosystem resilience and human well-being. Microbial diversity not only drives local ecosystem processes but also interacts with plant and animal communities shaped by biodiversity history. These ecological processes, in turn, intersect with social determinants of health, such as urbanization, community planning and socio-economic status, creating complex feedbacks between ecological integrity and human health outcomes (Stokols D 1992). This article explores the links between microbial diversity, biodiversity history and social ecological determinants of health, emphasizing their role in maintaining ecosystem function and promoting human well-being.

Description

Microorganisms are the unseen architects of ecosystem function. Bacteria, fungi and archaea drive nutrient cycling, decompose organic matter and facilitate plant growth through symbiotic associations. Arbuscular and ectomycorrhizal fungi, for example, enhance nutrient and water uptake in plants, improving productivity and resilience under stress conditions such as drought or nutrient limitation (Stokols D 1996). Soil microbial diversity also influences carbon storage, greenhouse gas fluxes and soil structure, playing a critical role in regulating climate and sustaining ecosystem services. Recent studies indicate that microbial diversity is not uniform but structured by environmental gradients, plant communities and land-use history. Functional diversity among microbes ensures redundancy and resilience, allowing ecosystems to maintain critical processes under disturbances such as land degradation, pollution, or climate extremes.

The influence of microbial ecology extends beyond ecosystem function to human health. Soil microbes contribute to the regulation of pathogen populations, production of bioactive compounds and modulation of the human microbiome through environmental exposure. Urban green spaces, community gardens and natural landscapes provide microbial reservoirs that can enhance immune system development, reduce allergy prevalence and promote overall health (Reckrey JM, et al. 2020). Thus, microbial diversity represents a critical link between environmental integrity and public health, underscoring the need to maintain soil and habitat quality within both natural and managed landscapes. Historical patterns of biodiversity—shaped by evolutionary processes such as speciation, extinction and dispersal—inform present-day ecosystem composition and function. Phylogenetic diversity influences species interactions, trophic structure and ecosystem stability. For instance, ecosystems with long evolutionary histories of coexistence often exhibit complementary resource use and increased resistance to invasive species or environmental stress. Understanding biodiversity history provides insights into ecosystem resilience (Benton MJ 2010). Areas with rich evolutionary legacies often host species with specialized traits that buffer against environmental fluctuations, while regions with low historical diversity may be more vulnerable to disturbances and climate change impacts.

Human health is intricately linked to the functioning of ecosystems. Social ecological determinants—including housing, access to green space, education and socio-economic conditions—shape exposure to ecosystem services and environmental stressors. For example, urban residents with limited access to natural environments may experience increased heat stress, air pollution exposure and reduced opportunities for physical activity, all of which contribute to chronic disease risk. Conversely, ecosystems that provide clean water, nutritious food and spaces for recreation directly improve health outcomes (Raup DM 1986)). Nature-based interventions, such as urban greening, wetland restoration and reforestation, can simultaneously enhance ecosystem resilience and mitigate health disparities. Social systems influence ecological outcomes through land-use decisions, pollution, resource management and conservation policies. Poorly managed landscapes may degrade soil microbial communities, reduce biodiversity and impair ecosystem services, which in turn negatively affects human health. Effective governance, community engagement and equitable resource distribution are therefore critical for sustaining ecosystem function and promoting public health.

Conclusion

Ecology operates across interconnected scales—from the microscopic world of soil microbes to the evolutionary legacies of biodiversity and the social-ecological systems that determine human health. Microbial diversity underpins ecosystem productivity and resilience, historical biodiversity informs ecosystem structure and adaptive capacity and social determinants shape access to ecosystem services. Recognizing and integrating these scales is crucial for sustaining ecosystem function, mitigating climate and environmental stressors and promoting public health. By adopting a multiscale perspective, conservation, restoration and policy initiatives can optimize ecological and human health outcomes. Maintaining microbial diversity, protecting evolutionary legacies and addressing social ecological determinants collectively provide a holistic strategy for fostering resilient ecosystems and resilient societies in the face of global environmental change. Biodiversity history also influences the provisioning of ecosystem services. Diverse plant and animal communities resulting from long-term evolutionary processes support pollination, seed dispersal, water regulation and carbon sequestration.

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Conflict of Interest

The authors declare no conflict of interest.

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