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Brief Report

Ecosystem function and resilience across biomes: microbial mediation, dryland productivity and coastal wetland services

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Ecosystem function and resilience are shaped by a complex interplay of biotic and abiotic factors across terrestrial and aquatic biomes. Microbial communities are fundamental mediators of nutrient cycling, carbon sequestration and stress tolerance, influencing the productivity and stability of ecosystems. Drylands, characterized by water scarcity and extreme climate variability, contribute disproportionately to global primary productivity and carbon dynamics due to microbial and plant adaptations. Coastal wetlands provide critical ecosystem services, including flood regulation, nutrient retention and greenhouse gas modulation, yet are highly vulnerable to anthropogenic pressures and climate change. This article synthesizes current knowledge on microbial mediation, dryland productivity and coastal wetland services, highlighting multiscale mechanisms driving ecosystem resilience. Understanding these processes is essential for informed conservation, restoration and climate adaptation strategies across diverse biomes.

Keywords: Ecosystem resilience, Microbial mediation, Drylands, Coastal wetlands, Carbon cycling, Productivity, Climate adaptation, Nutrient cycling, Biodiversity, Ecosystem services.

Introduction

Ecosystems are dynamic networks where organisms interact with each other and with their physical environment, giving rise to essential ecological functions. Resilience, defined as the capacity of ecosystems to absorb disturbances while maintaining structure and function, is increasingly tested under global change. Climatic extremes, land-use shifts and pollution threaten ecosystem stability and the services they provide, necessitating a deeper understanding of the mechanisms that maintain function across biomes. Microbial communities are central to ecosystem resilience. Soil bacteria and fungi regulate nutrient cycling, decompose organic matter, enhance plant growth and mediate stress responses (Li X, et al. 2019). In drylands, microbial and plant adaptations sustain primary productivity under water-limited conditions. Coastal wetlands, acting as natural buffers between terrestrial and marine systems, provide flood control, carbon storage and habitat for diverse species. Integrating insights from microbial ecology, ecosystem productivity and wetland function is critical to predict ecosystem responses to environmental change and inform sustainable management practices. Understanding ecosystem resilience requires integrating microbial, plant and environmental data. Microbial diversity and function modulate plant productivity, which in turn influences nutrient cycling and ecosystem stability. Multiscale monitoring, including remote sensing, high-throughput sequencing and functional assays, allows for predictive modeling of ecosystem responses to stressors. Drylands and coastal wetlands, despite contrasting climates and hydrological regimes, rely on microbial mediation and plant adaptations to maintain function under stress (Menkis A, et al. 2014). These insights inform restoration strategies and sustainable management practices across diverse ecosystems.

Description

Soil microorganisms drive critical ecosystem processes, including nitrogen fixation, decomposition and carbon turnover. Microbial diversity influences the efficiency and stability of these processes, with diverse communities often enhancing ecosystem resilience. Functional redundancy ensures that key processes continue despite environmental fluctuations, while specialized taxa provide unique functions under stress conditions, such as drought or salinity. Plants and microbes form intricate networks that mediate ecosystem function. Mycorrhizal fungi, for example, enhance water and nutrient uptake, supporting plant growth under stress. Rhizosphere bacteria can induce systemic resistance to pathogens and modulate hormonal signaling, improving plant tolerance to abiotic stressors. Legacy effects of land use can reprogram plant physiology *via* microbial communities, influencing productivity and resilience over time. Environmental stress, such as prolonged drought or flooding, alters microbial community composition and function (Poulter B, et al. 2014). Pre-exposure to stress can increase microbial resistance, creating an "ecosystem memory" that enhances resilience to future disturbances. Such microbial mediation is particularly important in ecosystems where plant productivity is limited by water or nutrient availability.

Drylands cover approximately 40% of Earth's terrestrial surface and are characterized by low precipitation, high temperature variability and nutrient-limited soils. Despite these constraints, drylands contribute significantly to global net primary productivity, largely due to microbial and plant adaptations that optimize water use and carbon assimilation. In drylands, microbial communities enhance soil structure, water retention and nutrient cycling. Biological soil crusts, composed of cyanobacteria, fungi and lichens, stabilize soils and facilitate nitrogen fixation (Wang S, et al. 2023). Plant species exhibit physiological adaptations, including deep rooting systems, osmotic adjustment and symbiotic associations with mycorrhizal fungi, enabling survival and productivity under water-limited conditions. Drylands provide essential services, including carbon sequestration, grazing resources and biodiversity habitats. Their disproportionate contribution to global productivity underscores the need for sustainable management practices, including controlled grazing, restoration of degraded areas and microbial augmentation to maintain ecosystem function under increasing climate variability.

Coastal wetlands, including salt marshes, mangroves and tidal flats, provide multiple ecosystem services. They act as natural buffers against storm surges, regulate nutrient and sediment flows and serve as critical habitats for fisheries and migratory species. Wetlands also play a pivotal role in carbon sequestration, storing organic carbon in soils and vegetation and mitigating greenhouse gas emissions. Wetland soil microbial communities drive biogeochemical cycling, including carbon, nitrogen and sulfur transformations. Microbial processes influence greenhouse gas fluxes, including CO_2, CH_4 and N_2O emissions and modulate nutrient availability for plant communities (Narayan S, et al. 2017). Vegetation type and inundation patterns strongly shape microbial composition and function, demonstrating the importance of integrating microbial ecology into wetland management. Coastal wetlands face significant anthropogenic pressures, including land reclamation, pollution and sea-level rise. Restoration strategies that consider hydrological regimes, plant–microbe interactions and nutrient dynamics enhance resilience and the provision of ecosystem services. Participatory approaches involving local communities and stakeholders further promote sustainable management and conservation success. Comparative studies across biomes reveal convergent mechanisms of resilience.

Conclusion

Ecosystem function and resilience are governed by the interplay of microbial mediation, vegetation dynamics and environmental conditions across biomes. In drylands, microbial and plant adaptations sustain productivity under water-limited conditions, contributing disproportionately to global carbon cycling. Coastal wetlands provide essential ecosystem services, including flood mitigation, nutrient regulation and carbon sequestration, mediated by microbial and plant interactions. Integrating ecological monitoring, cross-biome comparisons and adaptive management approaches is critical for understanding and sustaining ecosystem resilience under global environmental change. Conservation and restoration strategies that leverage microbial function, plant adaptations and stakeholder engagement can maintain ecosystem services, biodiversity and human well-being in a rapidly changing world.

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Conflict of Interest

The authors declare no conflict of interest.

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