Bridging the Gap: Advancing Ecological Risk Assessment from Laboratory Predictions to Ecosystem Reality

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The evolution of ecological risk assessment (ERA) for pollutants has been marked by significant advancements in both scope and methodology. Initially focused on individual or sub-individual endpoints, ERA has expanded to encompass landscape-level analyses [1]. The targeted substances considered have gradually changed from single pollutants to mixtures of pollutants, although there is still often little research on relevant mixtures. Concurrently, techniques for assessment have progressed from simplistic hazard quotient methods to more sophisticated probabilistic approaches, which make more complete use of the growing wealth of chemical monitoring and toxicity test data. This expansion has bridged the gap between measurement and assessment endpoints, reducing uncertainty. It is worth noting that the link of real outcomes and starting point is still not established.

Despite these improvements, current ERA methodologies for pollutants remain a work in progress, but still inadequate. Traditional approaches rely heavily on laboratory-derived exposure and toxicity data for individual species, study on the complex interactions present in natural ecosystems is rare. These interactions include species-species and species-multiple stressor dynamics, population-level processes such as density dependence and recovery, and ecosystem-level feedbacks. Moreover, the coexistence and interactions of multiple pollutants in the environment, along with various abiotic and biotic factors, are difficult to account for by traditional methods. Consequently, existing methods fail to capture the full spectrum of ecological risks and threats at the ecosystem level, potentially compromising ecosystem security and functional continuity.

Trait-based approaches offer a promising new direction for stress response and risk assessment at the community scale [2]. Introduce ecological characteristics theory in community ecology into ecological risk assessment, based on toxicity data, expected to more accurately predict impacts on ecosystems and their functions. By linking impacts on individual organisms to broader community dynamics, these approaches can enhance the mechanistic understanding and diagnostic capabilities of ERA. Future developments might involve combining functional traits of sensitive taxa with real environmental stressors to establish trait-based response indicators for specific pollutants. This could facilitate the construction of community-level safety thresholds for more environmentally relevant ecological risk assessments. While some progress has been made in this area, many significant challenges remain, particularly in developing comprehensive taxonomic trait databases for regions outside Europe and North America, and in establishing robust mechanistic relationships between traits and stressors [3].

The realization of more realistic ERA methods necessitates the integration of multiple disciplines and technologies. Contaminant detection technology based on Non-targeted Screening and environmental DNA (eDNA) technology based on high-throughput sequencing shows great potential in elucidating the connections between pollutants and ecosystems. Non-targeted Screening is useful to detect a wider range of pollutants, helping to understand the potential effects of a mix of pollutants. eDNA technology provides real data more quickly, accurately and comprehensively to monitor biodiversity quickly and efficiently [4]. The combination of Non-targeted Screening and eDNA might accelerate integration of predictive risk assessment and biomonitoring, making it possible to assess the impact of pollutants on biodiversity and community structure and function. Mathematical modeling and machine learning techniques can predict higher-level responses using readily available underlying data, such as data from individual-level and molecular level. Integration of these advanced technologies from various disciplines is crucial for the reliability of comprehensive ecosystem assessment and management [5].

In conclusion, "trait-based community-level risk assessment" represents a promising approach for future ERA. We propose that by incorporating the traits of sensitive taxa, considering multiple biological and abiotic factors, and leveraging eDNA technology and machine learning, this approach can develop pollutant-specific measurement indices. Integrating knowledge from environmental chemistry, ecology, and ecotoxicology, it aims to derive community-level ecological risk thresholds that more accurately reflect real-environmental conditions, thereby providing a scientific basis for aquatic ecosystem protection and environmental management.

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