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Viewpoint

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

Xiaowei Jin,[∇] Lin Hou,[∇] Na Liu, Jian Xu, Xiaowei Zhang, Henner Hollert, Andrew C. Johnson, John P. Giesy, and Fengchang Wu*

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The evolution of ecological risk assessment (ERA) for contaminants has been a topic that has continued to evolve over the past 30 years, but it is important to ask ourselves whether it remains up to date. Initially, the process focused on sub-individual end points; ERA has since expanded to encompass landscape-level analyses. After focusing entirely on single substances, we now recognize the reality of exposure to contaminant mixtures. Assessment techniques have progressed from a simplistic risk quotient method to more sophisticated probabilistic approaches as the library of chemical monitoring and toxicity test data has expanded. The probabilistic approaches, where they can be applied, have reduced uncertainty, yet the link to real outcomes in the field is rarely established.[1]

Traditional ERA approaches rely heavily on laboratory-derived exposure and toxicity data for a limited number of individual species, while study of the complex interactions present in natural ecosystems remains rare. These interactions include species−species and species−multiple stressor dynamics (as well as compensating factors), population-level processes such as density dependence and recovery, and ecosystem-level feedback. The outcome for wildlife from the interactions of multiple contaminants in the environment, along with various abiotic and biotic factors, is not taken into account 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. Conversely, the

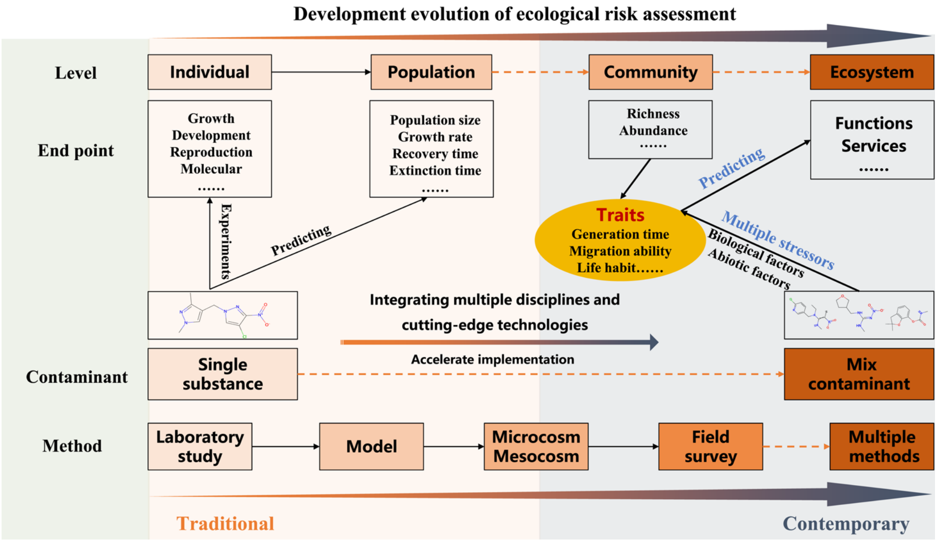


**Figure 1.** Trait-based ecological risk assessment framework for natural ecosystems.

traditional approaches may overestimate risks due to not taking into account animal behavior or compensating factors.

Trait-based approaches offer a promising new direction for stress response and risk assessment at the community scale.[2] Introducing ecological characteristics theory within community ecology into ecological risk assessment, based on toxicity data, may more accurately predict the impact on ecosystems and their functions. By considering impacts on individual organisms to broader community dynamics, these approaches can enhance the mechanistic understanding and diagnostic capabilities of ERA. Future developments may involve combining functional traits of sensitive taxa with real environmental stressors to establish trait-based response indicators for specific contaminants. 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 implementation of more realistic ERA necessitates the integration of multiple disciplines and cutting-edge technologies. Advancements in analytical chemistry and molecular biology offer novel tools for assessing ecological risk with unprecedented precision. Environmental DNA (eDNA) technology based on high-throughput sequencing demonstrates significant potential for rapid and efficient biodiversity monitoring.[4] Trait-based approaches enhance our understanding of the responses of species to environmental stressors, and when combined with trait databases, they provide valuable insights into sensitive taxa and associated traits. eDNA approaches provide efficient tools for evaluating the effects of chemical pollutants on (1) the occurrences and population of wildlife, (2) communities, and (3) the function of an ecosystem in the field.[4] The application of eDNA technology can improve the relevance and immediacy of laboratory toxicological assessment and provide strong scientific support for ecosystem management and protection.

While nontargeted screening techniques can detect a broader spectrum of contaminants, their qualitative or semiquantitative nature limits direct application in quantitative ERA. Combining nontargeted screening with targeted quantitative analysis of numerous chemicals provides a more comprehensive understanding of contaminant mixtures and their potential effects. In addition to applying toxicity data to assess the environmental impact of pollutants, we can establish a nonlinear relationship between the contaminant concentration and organism traits, accounting for the combined effects of other biological or abiotic stressors. The integration of quantitative chemical analysis and eDNA data may accelerate the convergence of predictive risk assessment and biomonitoring, potentially enabling more accurate assessments of contaminant impacts on biodiversity, community structure, and ecosystem function. Nevertheless, establishing quantitative relationships between contaminant concentrations and changes in species biodiversity remains challenging and requires continued research efforts. Advanced mathematical modeling and machine learning techniques offer promising avenues for predicting higher-level ecological responses using readily available underlying data, such as individual-level and molecular-level information. The synergistic utilization of these advanced technologies from analytical chemistry and ecology, coupled with machine learning approaches, could catalyze a paradigm shift in the reliability of comprehensive ecosystem assessment and management.[5]

In conclusion, "trait-based community-level risk assessment" represents a promising paradigm for future ERA (Figure 1). By incorporating the traits of sensitive taxa and considering multiple biological and abiotic factors, this approach can enhance the mechanistic understanding and diagnostic capabilities of ERA. The integration of trait-based ERA with quantitative chemical analysis and eDNA technology offers new perspectives for ERA at the ecosystem level. While challenges remain in developing comprehensive trait databases and establishing robust mechanistic relationships between traits and stressors, continued research in this direction could lead to community-level ecological risk thresholds that more accurately reflect real environmental conditions. This holistic approach has the potential to provide a more sound basis for aquatic ecosystem protection and environmental management, effectively bridging the gap between laboratory predictions and ecosystem reality.


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## AUTHOR INFORMATION


### Corresponding Author

**Fengchang Wu** − *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China;* orcid.org/0000-0001-8595-2243; Email: wufengchang@vip.skleg.cn

### Authors

**Xiaowei Jin** − *China National Environmental Monitoring Centre, Beijing 100012, China;* orcid.org/0000-0002-0478-5306

**Lin Hou** − *Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China; University of Chinese Academy of Sciences, Chinese Academy of Sciences, Beijing 100049, China*

**Na Liu** − *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China*

**Jian Xu** − *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China;* orcid.org/0000-0001-5287-1009

**Xiaowei Zhang** − *State Key Laboratory of Pollution Control & Resource Reuse, School of the Environment, Nanjing University, Nanjing 210023, China;* orcid.org/0000-0001-8974-9963

**Henner Hollert** − *Department Evolutionary Ecology & Environmental Toxicology, Goethe University Frankfurt, 60438 Frankfurt am Main, Germany*

**Andrew C. Johnson** − *UK Centre for Ecology and Hydrology, Wallingford, Oxfordshire OX10 8BB, U.K.;* orcid.org/0000-0003-1570-3764

**John P. Giesy** − *Department of Veterinary Biomedical Sciences and Toxicology Centre, Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, SK S7N 5B4, Canada; Department of Integrative Biology and Center for Integrative Toxicology, Michigan State University, East Lansing, Michigan 48824, United States*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.est.4c10058


### Author Contributions

[∇]X.J. and L.H. contributed equally to this work.

### Notes

The authors declare no competing financial interest.

### Biography

Dr. Fengchang Wu is the director of the State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences (CRAES). His research interests mainly cover environmental toxicology and chemistry by multi-disciplinary approaches, including environmental biogeochemistry, chemistry, toxicology, and risk assessment. He has made remarkable contributions to the protection of the aquatic ecosystem in China through his advancement of environmental science, standards, technologies, and engineering. Dr. Wu was elected as an academician of the Chinese Academy of Engineering in 2017 in recognition of his work in the development of the system of environmental criteria and standards in China.

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## REFERENCES


(1) Johnson, A. C.; Sumpter, J. P. Are we going about chemical risk assessment for the aquatic environment the wrong way? *Environ. Toxicol. Chem.* **2016**, *35*, 1609−1616.

(2) Wilkes, M. A.; Edwards, F.; Jones, J. I.; Murphy, J. F.; England, J.; Friberg, N.; Hering, D.; Poff, N. L.; Usseglio-Polatera, P.; Verberk, W. C. E. P.; Webb, J.; Brown, L. E. Trait-based ecology at large scales: Assessing functional trait correlations, phylogenetic constraints and spatial variability using open data. *Global Change Biology* **2020**, *26* (12), 7255−7267.

(3) Van den Berg, S. J. P.; Baveco, H.; Butler, E.; De Laender, F.; Focks, A.; Franco, A.; Rendal, C.; Van den Brink, P. J. Modeling the Sensitivity of Aquatic Macroinvertebrates to Chemicals Using Traits. *Environ. Sci. Technol.* **2019**, *53* (10), 6025−6034.

(4) Zhang, X.; Xia, P.; Wang, P.; Yang, J.; Baird, D. J. Omics Advances in Ecotoxicology. *Environ. Sci. Technol.* **2018**, *52* (7), 3842−3851.

(5) Sylvester, F.; Weichert, F. G.; Lozano, V. L.; Groh, K. J.; Bálint, M.; Baumann, L.; Bässler, C.; Brack, W.; Brandl, B.; Curtius, J.; Dierkes, P.; Döll, P.; Ebersberger, I.; Fragkostefanakis, S.; Helfrich, E. J. N.; Hickler, T.; Johann, S.; Jourdan, J.; Klimpel, S.; Kminek, H.; Liquin, F.; Möllendorf, D.; Mueller, T.; Oehlmann, J.; Ottermanns, R.; Pauls, S. U.; Piepenbring, M.; Pfefferle, J.; Schenk, G. J.; Scheepens, J. F.; Scheringer, M.; Schiwy, S.; Schlottmann, A.; Schneider, F.; Schulte, L. M.; Schulze-Sylvester, M.; Stelzer, E.; Strobl, F.; Sundermann, A.; Tockner, K.; Tröger, T.; Vilcinskas, A.; Völker, C.; Winkelmann, R.; Hollert, H. Better integration of chemical pollution research will further our understanding of biodiversity loss. *Nature Ecology & Evolution* **2023**, *7* (10), 1552−1555.




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