



MODELLING DAMAGE FROM CHEMICAL EMISSIONS TO TERRESTRIAL BIODIVERSITY AND ECOSYSTEM SERVICES

From possibility to policy: chemical impacts on biodiversity
and data needs for better environmental protection

Policy brief 03

Introduction

Linking chemical effects to terrestrial biodiversity loss

Exposure to chemicals and their mixtures in soils and terrestrial food webs poses a growing threat to biodiversity, yet chemical impacts remain poorly quantified and are mostly restricted to effect assessment on single species. However, biodiversity is much more than a single species, as it encompasses the diversity of species, their functions, their genetic variability and the diversity of ecosystems. The limited set of approaches for assessing chemical effects on biodiversity limits understanding of how chemicals impact ecosystems and the services they provide. This limited understanding also constrains the assessment of chemical risks and the integration of terrestrial biodiversity impacts into policy and decision-making. Here, we present modelling approaches that prospectively link chemical effects to damage, defined as adverse changes in biodiversity attributable to chemical exposure, across terrestrial ecosystems, to expand current environmental risk assessment (ERA) under substance and media related regulations. This further supports progress towards Europe's zero pollution and biodiversity protection goals. Closing these methodological and data gaps and thereby quantifying drivers of biodiversity loss would reduce systemic risks of chemicals to societies and improve financial stability and long-term wealth creation worldwide.

THIS BRIEF

This brief presents how the damage on terrestrial biodiversity from chemical pollution can be quantified across multiple levels of biological organization and how current modelling approaches address these impacts. Specifically, it:

- Outlines how impacts on species, genetic diversity, functional diversity, and ecosystem services can be quantified.
- Summarizes the state of the art in modelling and quantifying biodiversity damage.
- Identifies key opportunities to expand the utility of biodiversity and chemical assessments under EU chemicals legislation.
- Identifies key research needs to substantiate damage modeling methodologies for future regulatory uptake.

WHO SHOULD READ THIS BRIEF

This brief is intended for:

- European policymakers and regulators —the European Commission (notably DG ENV, DG GROW, DG SANTE, JRC) and relevant EU agencies (ECHA, EFSA, EMA, EEA).
- Member State competent authorities, including national regulators and environmental protection agencies responsible for operationalization of chemicals legislation, research organizations, industry stakeholders and non-governmental organisations involved in chemical risk assessment, soil health, and biodiversity protection.

KEY MESSAGES

- 1 Chemicals and chemical mixtures affect biodiversity across species, genetic diversity, functional traits, ecosystems and ecosystem services, yet currently these dimensions are rarely considered in chemical- or biodiversity-related environmental risk assessment (ERA) due to lack of methodologies to specifically quantify damage level impacts.
- 2 TerraChem developed uniform damage assessment methods beyond single species-level impacts allow for insights into multidimensional biodiversity
- 3 Extend pan-European data infrastructure and modelling to assess multidimensional biodiversity damage to support policy needs and consider models as one component within the **EU common data platform (CDP)**.
- 4 Modelling of chemical impacts on biodiversity could be applied for various purposes under specific regulatory frameworks in Europe:
 - A for prioritizing chemicals and chemical mixtures under the **EU early-warning systems** to flag chemicals for further in-depth assessment and management
 - B applied under **substance-specific ERA** procedures of data rich chemicals, mainly pesticides, where such data at higher-tier could already be considered.

- C** as a decision tool to aid the development of conservation strategies that align with the **EU biodiversity strategy including restoration targets, and the Convention on Biological Diversity.**
- D** for environmental performance assessment of products, technologies, and organizations under the **European Product Environmental Footprint (PEF)** initiative.

5 Invest in further research to substantiate the damage level models at larger spatial and temporal scales to make methods fit for purpose for conservation and risk assessment procedures, particularly to be prepared to interpret data collected under the Soil Monitoring Law.

6 In the long term, when more data evolve these models will allow a more robust quantification of chemicals as drivers of biodiversity change relative to other drivers, and thereby provide the essential evidence base for targeted conservation and chemical risk-management measures to achieve the EU sustainability and biodiversity protection goals set out under the Chemicals Strategy for Sustainability (CSS), Zero Pollution Ambition (ZPA), One Substance One Assessment (OSOA) package, the Convention on Biological Diversity (CBD), and the EU Biodiversity Strategy for 2030.



KEY MESSAGE 1

Chemical pollution affects biodiversity at the species, genetic, functional trait, ecosystem and ecosystem service levels, yet these dimensions are rarely considered in current chemical- or biodiversity-related ERA

Chemical pollution affects all dimensions of biodiversity—including species, genetic, and functional diversity—as well as ecosystem diversity and functioning and ecosystem services. However, these dimensions are rarely incorporated into chemical or biodiversity ERA because current approaches rely heavily on single species indicators and lack methods to quantify broader ecological damage. Without integrated approaches, it is challenging to compare risks across chemicals or anticipate cumulative effects on terrestrial ecosystems. Capturing multiple dimensions of biodiversity in parallel is essential to provide a realistic and actionable picture of chemical impacts. Such integration helps identify vulnerable species and ecosystems, informs regulatory assessments, and supports prioritization of interventions to reduce chemical pressures on terrestrial biodiversity.¹

HOW TerraChem HELPS

Advancing multi-dimensional biodiversity assessment

Parallel integration of biodiversity dimensions. TerraChem assessed concurrently chemical impacts on multiple dimensions of biodiversity – species, genetic and functional diversity, and ecosystem services – providing a holistic understanding of biodiversity damage rather than a sequential or isolated view.

Capturing ecological interactions. TerraChem demonstrates how incorporating trait-based, food-chain, and community-level data enables exploration of potential cascading effects across biodiversity dimensions, reflecting ecological complexity.

Improving quantitative assessment

From chemical exposure to biodiversity impact. TerraChem modelled chemical exposure into ecological responses, enabling quantitative estimates with implications across multiple levels of biodiversity.

Supporting cumulative impact evaluation. TerraChem's novel mixture toxicity assessment approaches enable evaluation of the combined effects of multiple chemicals in terrestrial ecosystems.

¹ IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (pp. 1–1082). Brondízio, E. S., Settele, J., Díaz, S., and Ngo, H. T. (eds). IPBES secretariat, Bonn, Germany. DOI:<https://doi.org/10.5281/zenodo.3831673>



KEY MESSAGE 2

TerraChem developed uniform damage assessment methods beyond single species-level impacts that allow for insights into multidimensional biodiversity

Knowledge from the TerraChem project provides uniform, comparable methods for assessing chemical-induced damage to biodiversity, enabling consistent evaluation of impacts across chemicals and ecosystems. This harmonization reveals broader ecological effects that single-indicator approaches often miss. This shift supports higher-level environmental protection by revealing important effects that go unobserved when focusing solely on single-species impacts or species counts. Broadening damage assessment in this way strengthens the scientific basis for precautionary decision-making and helps align chemical management with long-term ecosystem integrity and resilience.

HOW TerraChem HELPS

Extending biodiversity damage concepts

Adapting species-based methods to terrestrial systems. TerraChem extends the species-loss method from freshwater ecosystems to terrestrial ecosystems exposed to chemical stressors, thereby quantifying species loss.²

Linking chemical field exposure to broader ecological effects. TerraChem demonstrated the use of field-measured chemical concentrations to estimate potential species loss at individual sites, supporting assessment of biodiversity damage under realistic exposure conditions.

Demonstrating feasibility beyond species metrics

Proof-of-concept development. TerraChem developed novel approaches to quantify biodiversity impact beyond species loss, including its functional and genetic dimensions.^{3,4}

Informing future standards. TerraChem developed methodologies comparable to species-loss models enabling cross-evaluation of multiple biodiversity dimensions. These novel methods provide the foundation for harmonized approaches to quantify biodiversity damage across multiple dimensions in terrestrial ecosystems. Considering species' roles in ecosystems. TerraChem models utilize actual species population data to relate biodiversity impacts to species' roles or functions within ecosystems. Assessing species' functions allows for valuation of changes to ecosystem services.

² Oginah, S. A., Posthuma, L., Slootweg, J., Hauschild, M., & Fantke, P. (2025). Calibrating predicted mixture toxic pressure to observed biodiversity loss in aquatic ecosystems. *Global Change Biology*, 31(6), e70305.

³ Boeije, A., Barmantlo, S. H., Vijver, M. G., & Scherer, L. (2026). Ecotoxicity effects on functional diversity—A proof of concept using a sensitivity distribution approach. *Environment International*, 110078.

⁴ Guignard D., Büttner M., Scholier T., Kosnik MB. (2026). A novel reuse of data from lab mouse models to inform chemical impacts on the genetics of wild mouse populations. *Computational Toxicology*, 38, 100419.



KEY MESSAGE 3

Extend pan-European data infrastructure and modelling to assess multidimensional biodiversity damage to support policy needs and consider models as one component within the EU common data platform (CDP)

The large amounts of data on biodiversity change do not overcome the need for study designs that allow distinguishing between causation and correlation. Quantifying chemical impacts on terrestrial biodiversity requires accurate and simultaneous chemical and biological monitoring, data on chemical properties, toxicity profiles, and exposure pathways. Large-scale, validated datasets of physicochemical and biochemical parameters are critical to improve the reliability of model outputs. Tools that support modelling of chemical fate, exposure, and effects, and identify the most accurate predictive models, provide the foundation for robust assessments. While complete terrestrial food-web modelling is still under development due to complex trophic interactions, rigorous data collection ensures future assessments will be more consistent and credible.

These efforts enable linking chemical exposure to impacts on species, functional traits, genetic diversity, and ecosystem services, supporting evidence-based decision-making and the prioritization of interventions to protect terrestrial ecosystems. However, for many terrestrial taxa, monitoring data are sparse, traits are not documented for the same species that are ecotoxicologically assessed, and genetic and ecotoxicity information is relatively limited. These data constraints make it difficult to scale from individual species responses to broader ecosystem consequences, increasing uncertainty in damage estimates, and reducing comparability across studies. Filling these gaps is essential to provide credible, evidence-based insights into biodiversity loss and to inform policies that aim to safeguard terrestrial ecosystems and maintain the services they provide. Opportunities are readily available in the new Soil Monitoring Law to adopt monitoring efforts to support biodiversity damage assessments and future-proof chemical risk assessments. The data and approaches necessary for environmental damage level modelling should be considered during the ongoing conceptualization and later implementation of the EU common data platform (CDP) set out under Regulation 2025/2455 and, in the long term, become one of the components of the EU Early Warning System.⁵

HOW TerraChem HELPS

Building robust modelling foundations through data curation and validation

Compiling chemical and biochemical datasets. Comprehensive chemical and biochemical datasets have been compiled and validated to reduce uncertainty in exposure and effect models.

Tool development for accurate predictions. The PROVES Python package supports modelling chemical fate, exposure, and effects, and identifies the most accurate predictive models.

⁵ Regulation (EU) 2025/2455 of the European Parliament and of the Council of 26 November 2025 establishing a common data platform on chemicals, laying down rules to ensure that the data contained in it are findable, accessible, interoperable and reusable and establishing a monitoring and outlook framework for chemicals, 2025 O.J. (L 2025/2455). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202502455

Integrating datasets needed for functional assessments. For effective modelling of functional impacts, chemical, species' trait, and species' occurrence datasets combined with ecotoxicity information are needed. TerraChem examined and combined the overlap in these different forms of information on a species name basis.

Integrating existing genetic datasets. TerraChem bridged disconnected datasets characterizing chemical activity, biological signaling pathways, and genetic variability in different species.

Expanding data coverage

Field-based chemical measurements to support modelling. TerraChem collected soil and environmental samples across multiple sites to generate reliable datasets of chemical concentrations.

Species monitoring with Environmental DNA (eDNA). TerraChem used this technique to detect species presence, thus improving data coverage for modelling species loss.

Supporting model scaling and validation

Integrating multiple datasets. TerraChem combined chemical, ecological, and genetic data to enable scaling from species-level responses to ecosystem-level impacts.

Reducing uncertainty. TerraChem's improved data coverage supports more accurate, validated predictions of chemical impacts on terrestrial biodiversity.

Promoting new data generation opportunities

Assessing inter-species variability with non-invasive methods. TerraChem notes that eDNA methods for assessing inter-individual variability are improving; non-invasive whole genome sequencing (WGS) should be expanded across species and populations to track genetic composition responses to chemical exposures.





KEY MESSAGE 4

Potential regulatory uptake of biodiversity level modeling

There is still a substantial lack of data on chemical concentrations, ecotoxicity, and biota in the terrestrial compartment. Now is the time to start synchronized data collection on exposure and biodiversity change, in parallel to substantiating the modelling approaches by further research investments. Doing this now will ensure that methods are already established to support appropriate analyses of biodiversity states under the upcoming EU Soil Monitoring Law and the associated EU Soil Directive.

These frameworks foresee routine monitoring of soil chemical concentrations alongside eDNA and other biodiversity indicators, providing a long-term backbone of policy-relevant data needed to apply damage-level models and advanced risk assessment tools in regulatory decision-making:

- To support EU early-warning prioritization of chemicals and mixtures,
- To strengthen higher-tier ERA for data-rich chemicals under the EU pesticides regulations (EC 1107/2009, EC528/2012)



- To guide the development of conservation strategies that align with EU biodiversity and restoration targets (according to the Nature Restoration Law, the Birds and Habitats Directives and the Biodiversity Strategy for 2030).
- To assess the environmental performance of products, technologies, and organizations under the European Product Environmental Footprint (PEF) initiative. Together, these applications could enable more targeted restrictions, authorisation decisions, and mitigation measures for chemicals with identified impacts, thereby strengthening the evidence base for managing chemical pollution within the broader EU chemical and biodiversity frameworks.

HOW TerraChem HELPS

Showcasing proof of principle to support prioritization of chemicals.

Within TerraChem case studies showcasing damage to different levels of biodiversity were fed into an Early Warning System and prioritization of chemicals for risk assessment.

Promoting method development and suggesting potential ERA adjustment by implementing damage level model for data rich chemicals.

Giving advice to EU authorities, particularly EEA and ECHA, for the design of the EU CDP and the Early Warning and Action System regarding data needs and approaches on how to assess damage to different levels of biodiversity.



KEY MESSAGE 5

Invest in research to validate biodiversity level models across spatial and temporal scales, ensuring they are robust for conservation and risk assessment under the Soil Monitoring Law

Effective biodiversity protection and soil-health management in the EU require assessment tools that can reliably capture chemical impacts across diverse spatial and temporal scales. Some of the TerraChem-developed models are proof-of-concept that provide an important foundation; however, they require further validation to ensure consistent application across regulatory and conservation contexts. Strengthening these models through targeted research — across broader spatial and temporal scales — is essential to ensure they reflect real environmental variability and can support robust ecological interpretation. This need becomes even more critical with the implementation of the Soil Monitoring Law, which will generate extensive new data on soil condition, biodiversity, and chemical pressures. Validated models will enable authorities to translate these data into meaningful indicators, improve comparability across regions, and better inform conservation planning, risk-management action prioritization, and long-term sustainability assessments.

HOW TerraChem HELPS

Developing and validating biodiversity damage-level models that can be applied across larger spatial and temporal scales, making them fit for conservation planning, soil-health assessments, and interpretation of data under the Soil Monitoring Law.

Providing universal and transparent indicators that support regulators and policymakers in assessing chemical impacts consistently across regions and monitoring programs.

Photo: Caroline Legg CC-BY





KEY MESSAGE 6

As data improve, validated models will better quantify chemicals' contributions to biodiversity change, providing essential evidence for targeted conservation and chemical risk-management aligned with EU sustainability goals

Understanding how chemicals contribute to biodiversity change requires long-term, harmonized monitoring data that captures variability across species, ecosystems, and environmental pressures. As these datasets expand, improved and validated damage-level models will become essential for distinguishing chemical impacts from other drivers such as climate change, invasive species, and habitat degradation. Strengthening these models will allow more precise attribution of observed biodiversity trends to specific chemical groups, exposure patterns, and mixtures — thereby enhancing the scientific confidence behind regulatory decisions.

This evidence is crucial for prioritising risk-management actions and designing targeted conservation measures that address the most influential pressures. By enabling more accurate and transparent quantification of chemicals' contributions to biodiversity loss, these models directly support implementation of EU sustainability commitments, including the Chemicals Strategy for Sustainability (CSS), Zero Pollution Ambition (ZPA), One Substance One Assessment (OSOA), the Convention on Biological Diversity (CBD), and the EU Biodiversity Strategy for 2030.⁶⁻⁹

HOW TerraChem HELPS

TerraChem advances support the integration of monitoring data with mechanistic and statistical models to determine how chemicals contribute to biodiversity change, while accounting for soil chemical and physical properties that may modify these effects. The modelling framework developed in TerraChem is also designed to allow future integration of additional environmental pressures as new data becomes available.

TerraChem advances enable forward-looking evaluations, allowing authorities to anticipate emerging risks and align conservation and chemical risk-management strategies with EU sustainability frameworks (CSS, Zero Pollution Ambition, OSOA, CBD, EU Biodiversity Strategy 2030).

⁶ European Commission. (2020). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: Chemicals strategy for sustainability: Towards a toxic-free environment (COM (2020) 667 final). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020AE5343&qid=1771322630586>

⁷ European Commission. (2021). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, and the Committee of the Regions: Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' (COM/2021/400 final). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1771322770881>

⁸ Convention on Biological Diversity, Decision adopted by the Conference of the Parties to the Convention on Biological Diversity 15/4, 'Kunming-Montreal Global Biodiversity Framework 2022, CBD/COP/DEC/15/4, Distr. General (19 December 2022). <https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf>

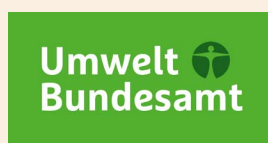
⁹ European Commission, Communication on EU Biodiversity Strategy for 2030 – Bringing nature back into our lives COM (2020) 380 final (20 May 2020). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380>

Information about TerraChem

TerraChem (From soils to apex species: chemical pathways, effects and impacts on terrestrial biodiversity and ecosystem services and applications for better chemicals management – Project no. 101135483) is a c. €6.5M Horizon Europe collaborative project led by the Environmental Institute (Slovakia), running from November 2023 to October 2026.

The overall aim of TerraChem is to develop, demonstrate and apply a novel systems approach integrating monitoring, environmental modelling, data management, analytical tools and user guidance to better understand exposure of terrestrial biota across trophic levels (from soil and soil water to plants to primary and secondary consumers to apex species) in Europe to the universe of environmentally-relevant anthropogenic chemicals and their damage on terrestrial biodiversity and ecosystem services, with a view to enabling more efficient environmental risk assessment of chemicals in the terrestrial compartment and more effective prevention and mitigation, accelerating achievement of the EU's zero pollution ambition.

TerraChem Partners



Universiteit
Leiden



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