TerraChem

REDUCING THE IMPACTS OF CHEMICALS ON TERRESTRIAL BIODIVERSITY IN EUROPE

A new systems approach

Policy brief 01

Introduction

Nature's decline is unprecedented in human history, with around 1 million species threatened with extinction and 75% of land and 66% of marine environments significantly altered by human activity.[1] While global produced capital (e.g. infrastructure, built environment, etc.) and human capital (skills, expertise, knowledge, health, etc.) have grown since 1992, global natural capital has plummeted by 40%.[2] Fourteen of 18 critical ecosystem services (nature's contributions to people) have steeply declined since 1970[1] This poses a major risk for economic resilience and human wellbeing.

Anthropogenic chemicals are a key driver of this biodiversity loss and decline in natural capital. Global chemical production has increased 50-fold since the 1950s, and is projected to triple by 2050 compared to 2010; the production volume, diversity and release of chemicals into the environment increasingly exceed society's capacity to adequately assess and manage the associated risks.[3] In the European Union (EU), there are around 100,000 chemicals on the market and of these, some 70% are poorly assessed for their safe use and a further 20% have very limited exposure and hazard information available.[4] Many of these chemicals are classified as hazardous to the environment and/or human health.

Managing chemical risks to meet EU targets for biodiversity and pollution. Recognising the importance of biodiversity and the challenge of pollution, the EU has set a target to set nature on the path to recovery by 2030,[5] and has also set a 'zero pollution' ambition.[6] Meeting these targets requires effective assessment and management of the risks posed by chemicals to biodiversity.

[1] IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Brondizio, E. S., Settele, J., Díaz, S. and Ngo, H. T. (eds.). Bonn: IPBES secretariat.
[2] Dasgupta, P. (2021) The Economics of Biodiversity: The Dasgupta Review. Full Report. London: HM Treasury.
[3] Persson, L.; Carney Almroth, B. M.; Collins, C. D.; Cornell, S.; de Wit, C. A.; Diamond, M. L.; Fantke, P.; Hassellöv, M.; MacLeod, M.; Ryberg, M. W.; Søgaard Jørgensen, P.; Villarrubia-Gómez, P.; Wang, Z.; Hauschild, M. Z. Outside the Safe Operating Space of the Planetary Boundary for Novel Entities. Environ. Sci. Technol. 2022, 56 (3), 1510–1521.
[4] European Environment Agency (2019) The European Environment — State and Outlook 2020: Knowledge for Transition to a Sustainable Europe. Luxembourg: Publications Office of the European Union.
[5] European Commission (2020) EU Biodiversity Strategy for 2030: Bringing nature back into our lives. COM(2020) 380 final. Brussels: European Commission.
[6] European Commission (2019) The European Green Deal. COM(2019) 640 final. Brussels: European Commission.

However, this is currently severely constrained by **four key knowledge gaps:**

- **GAP 1: Data on real-world exposure in terrestrial ecosystems.** Data, information and knowledge on chemicals in the aquatic environment, and related effects on aquatic biota, has been boosted by monitoring under the Marine Strategy Framework Directive[7] and the Water Framework Directive.[8] However, until recent adoption of the Soil Monitoring Law,[9] there was no equivalent EU framework for monitoring of chemicals in the terrestrial environment. Consequently, monitoring of chemicals in soils and terrestrial biota has been fragmented, typically limited to restricted regions and one-off studies, focused on a single trophic level (e.g. top predators) rather than food chains/webs, limited to specific chemical groups (e.g. pesticides, PCBs, PFAS) and detached from biodiversity monitoring.

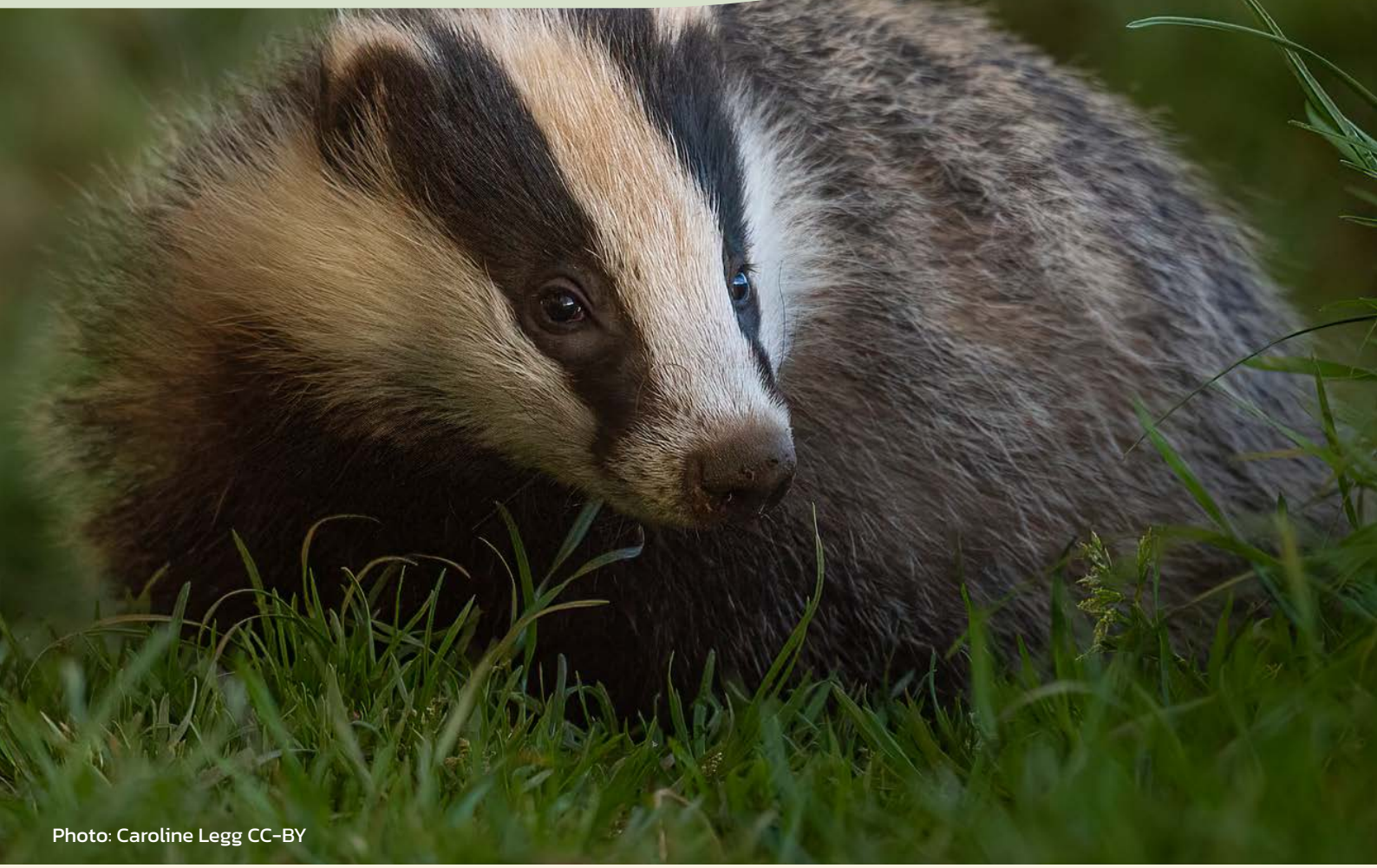
- **GAP 2: Biodiversity damage modelling.** Modelling of chemicals damages to terrestrial biodiversity is constrained by the paucity of spatially and temporally matched data on chemicals exposure, genetic variability and species diversity, and the paucity of related datasets on species traits and chemicals ecotoxicity. Moreover, such modelling has tended to focus on damages to species diversity, with little attention to date on damages to genetic diversity, functional diversity, or ecosystem services.

- **GAP 3: Data integration.** Interpretation of data relevant to understanding the impact of chemicals on terrestrial biodiversity in Europe is constrained by three structural deficits related to data integration: (1) exposure data across European soils and terrestrial wildlife are highly fragmented, with biomagnification consequently unmonitored, while ecotoxicological thresholds are largely unavailable for terrestrial species groups; (2) existing data on exposure, hazard

[7] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal L 164, 25 June, pp. 19–40.
[8] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal L 327, 22 December, pp. 1–73.
[9] Directive (EU) 2025/2360 of the European Parliament and of the Council of 23 October 2025 on soil monitoring and resilience (Soil Monitoring Law). Official Journal L, 28 November.

and risk remain siloed across unharmonised repositories, using inconsistent chemical identifiers, preventing interoperable matching and signalling of chemical risks and damages on biodiversity; (3) a unified governance framework to link these elements has been missing.

- **GAP 4: Tools for regulatory assessment and management of risks posed by chemicals to terrestrial biodiversity.** Finally, there is a gap in terms of tools for translation of data into useful information, and the application of this information for regulatory purposes, including for: (a) early warning of emerging contaminants; (b) prioritisation of substances for regulatory watch lists and for detailed environmental risk assessment (ERA); and (c) performance of ERA using a weight of evidence approach.



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THIS BRIEF

This brief provides an overview of the TerraChem Systems Approach, which addresses the four gaps outlined above, and brings evidence to bear for effective assessment and management of risks posed by anthropogenic chemicals to terrestrial biodiversity in Europe. The approach has been developed and tested through the Horizon Europe TerraChem project 2023–2026, in close dialogue with the relevant agencies (ECHA, EFSA, EEA) and is already feeding knowledge into regulatory processes.

The TerraChem Systems Approach integrates four components:

- **C1.** The TerraChem monitoring approach for real-world monitoring of terrestrial wildlife food chains and soils to anthropogenic chemicals.
- **C2.** The TerraChem modelling approach, for source-to-damage modelling of chemicals damages to terrestrial biodiversity.
- **C3.** The TerraChem database system bringing together chemicals exposure, hazard and risk data for soils and terrestrial biota in support of the EU Common Data Platform (CDP) as part of the One Substance, One Assessment (OSOA) approach.
- **C4.** TerraChem data interpretation and regulatory applications tools in support of early warning of emerging contaminants, prioritisation of substances for watchlists and for further ERA, performance of ERA, and other regulatory actions for the protection of terrestrial biodiversity.

This brief presents key messages related to these four components.

Further details on each component are provided in the related TerraChem Policy Briefs:

- **Policy Brief 02.** Monitoring ~100,000 Anthropogenic Chemicals in Terrestrial Apex Species, their Food Chains and Soil, in Europe – the TerraChem Monitoring Approach
- **Policy Brief 03.** 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 04.** TerraChem Data Management System in Support of the EU Common Data Platform
- **Policy Brief 05.** Early Warning Signals and Multiple-Lines-of-Evidence-based Chemical Prioritisation – Tools for Identifying the Chemicals that Contribute to Terrestrial Biodiversity Loss

WHO SHOULD READ THIS BRIEF

This brief is intended for:

- European policy makers and regulators, including the European Commission (notably DGs ENV, GROW, SANTE, JRC), the European Parliament's Committee on Environment, Climate and Food Safety (ENVI), the European Chemicals Agency (ECHA), European Food Safety Authority (EFSA), European Environment Agency (EEA), European Medicines Agency (EMA)
- Member State competent authorities, including regulators and environmental agencies responsible for implementation of legislation and policy related to chemicals and the environment, including the One Substance One Assessment (OSOA) concept.

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- The scientific community engaged in research and innovation on chemicals and biodiversity in the terrestrial environment, in particular related to monitoring of exposure, modelling of damages, data management, and regulatory impact.
- The chemicals industry and chemicals users interested in addressing the potential damages on terrestrial biodiversity of the chemicals they produce and/or import.

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KEY MESSAGES

1. **The TerraChem Monitoring Approach** integrates: (a) real-world measurements of chemical exposure and magnification from soils to biota and along terrestrial wildlife food chains (up to top predators), spanning the full universe of environmentally-relevant anthropogenic chemicals, at pan-European scale; and (b) co-located measurements of species richness (soil bacteria, soil fungi, soil and ground-dwelling invertebrates). These measurements provide real-world evidence to underpin modelling of chemicals damage to biodiversity (Key Message 2), generate exposure data for the EU Common Data Platform (Key Message 3) and underpine key regulatory applications (Key Message 4).

2. **The TerraChem Modelling Approach** integrates predictive modelling of chemicals damages across multiple dimensions of biodiversity (genetic, species, functional) and damages to ecosystem services. It builds on real-world chemical exposure monitoring in soils and terrestrial wildlife food chains to provide a systemic diagnostic tool. Modelling helps decode the underlying mechanisms of biological damage and, informed by complementary data on chemicals emissions and fate across Europe, facilitates prediction of damages at European scale.

3 **The TerraChem Database System** is a FAIR-compliant, modular database system that brings together harmonised data on: (a) hundreds of millions of data points on measured exposure to chemicals in terrestrial biota and soils; (b) modelled damages to terrestrial biodiversity and ecosystem services; (c) hazardous properties of chemicals; and (d) chemicals risk data (e.g. predicted no effect concentrations – PNECs) for terrestrial biota and soils. The database system can support the EU Common Data Platfom and is an essential precursor to key regulatory applications of the data.

4 **TerraChem Regulatory Applications**, integrated into the database system, automate the integration of data from multiple lines of evidence (including data on exposure, damages, hazard and risk) to generate early warning signals and connect signals to regulatory actions, including through: (a) prioritisation of substances for further environmental risk assessment; (b) informing such ERA through a weight-of-evidence approach; and (c) identification of candidate substances for regulatory watch-lists. These and other applications support regulators in more efficient and more effective management of chemicals risks to terrestrial biodiversity, and thereby support efforts to meet EU targets related for biodiversity restoration and zero pollution.

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KEY MESSAGE 1

The TerraChem Monitoring Approach integrates: (a) real-world measurements of chemical exposure and magnification from soils to biota and along terrestrial wildlife food chains (up to top predators), spanning the full universe of environmentally-relevant anthropogenic chemicals, at pan-European scale; and (b) co-located measurements of species richness (soil bacteria, soil fungi, soil and ground-dwelling invertebrates). These measurements provide real-world evidence to underpin modelling of chemicals damage to biodiversity (Key Message 2), generate exposure data for the EU Common Data Platform (Key Message 3) and underpine key regulatory applications (Key Message 4).

The TerraChem Monitoring Approach involves:

- Robust, co-located sampling of representative apex species, their food chains and soils across key European habitats.
- Advanced chemical screening covering >95,800 substances including transformation products and metabolites in each and every sample.
- Complementary analyses, including: stable isotopes for tracking biomagnification; and eDNA-based monitoring to generate species lists, supporting modelling of chemical damages.

Periodic monitoring campaigns using the TerraChem Monitoring Approach would ensure up-to-date evidence on anthropogenic chemicals in soils and terrestrial wildlife and tracking of temporal trends.

The TerraChem Monitoring Approach is cost-efficienct, with the potential financial benefits of early risk mitigation far outweighing the modest monitoring costs.

The TerraChem Monitoring Approach complements planned chemicals monitoring in soils and soil biota under the Soil Monitoring Law, which addresses a more restricted set of substances and does not extend to higher trophic levels.

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HOW TerraChem HELPS

TerraChem successfully demonstrates pragmatic real-world monitoring including the establishment of protocols for sampling of sentinel apex species like barn owls and selected apex mammal species, their food chains (rodents/shrews and ungulates, invertebrates, plants) and soil.

Through 12 terrestrial apex species food chain case studies, each involving 6 locations, TerraChem generated over 1300 samples including apex species, rodents/shrews, invertebrates, plants and soil. Following pooling of samples below apex species level, over 450 samples were analysed using wide-scope target analysis (c. 2800 substances) and suspect screening (>93,000 substances) generating >42M data points.

Stable isotope analysis of biota samples enabled calculation of biota-to-soil magnification factors, biomagnification factors and trophic magnification factors, thereby tracking routes of exposure across trophic levels. TerraChem also demonstrated the use of metabarcoding to generate species lists for the same soil and invertebrate samples used for chemical analysis, allowing for training of predictive models of chemical damages on biodiversity.

Photo: Alexis Lours CC-BY

KEY MESSAGE 2

The TerraChem Modelling Approach integrates predictive modelling of chemicals damages across multiple dimensions of biodiversity (genetic, species, functional) and damages to ecosystem services. It transforms real-world chemical exposure monitoring into a systemic, ecological diagnostic tool on a European scale. Modelling helps decode the underlying mechanisms of biological damage and facilitates a spatial and temporal upscaling for the entire EU territory.

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, failing to capture the true complexity of biological systems.

The TerraChem Modelling Approach links sources and environmental fate of chemicals, and measured exposures in soils and terrestrial wildlife, to chemicals damages across multiple dimensions of terrestrial biodiversity – genetic diversity, species diversity, functional diversity, and related damages to ecosystem services. It applies uniform modelling methodologies across these multiple dimensions to reveal broad ecological degradation that single indicators (such as the potentially disappearing fraction of species, PDF) miss.

The TerraChem Modelling Approach complements field exposure measurements in predicting and scaling damages to biodiversity. Modelling output feeds into the same regulatory applications as the real-world exposure monitoring measurements, including early warning of emerging contaminants, prioritisation of chemicals for further ERA, and implementation of ERA using a weight-of-evidence approach. Output can also guide biodiversity conservation measures.

TerraChem aims to integrate platforms for modelling of damages on multiple dimensions of biodiversity into the TerraChem Database System. Such platforms should in due course be incorporated in the EU Common Data Platform (CDP). Targeted investments are required to validate models over larger scales, including leveraging data from the upcoming Soil Monitoring Law.

Marrying real-world exposure monitoring with multi-tier biodiversity damage modeling gives the EU the scientific architecture required to enforce the Kunming-Montreal Global Biodiversity Framework (which mandates a 50% reduction in overall risk from pesticides and highly hazardous chemicals) and the Chemicals Strategy for Sustainability. This helps shifts environmental protection from reactive, local crisis management to proactive, EU-wide management of chemical risks to biodiversity.

HOW TerraChem HELPS

TerraChem provides concrete proofs-of-concept to systematically integrate monitoring data with advanced damage models. By modelling chemicals damages on multiple biodiversity dimensions, the project demonstrates how previously disconnected data on chemicals exposure, species diversity, species traits, biomagnification and ecotoxicity can track cascading community-level impacts can be linked to scale individual species responses up to broader ecosystem consequences. TerraChem has also engineered the PROVES Python package to precisely predict chemical fate, exposure, and cumulative mixture toxicities.

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KEY MESSAGE 3

The TerraChem Database System is a FAIR-compliant, modular database system that brings together harmonised data on: (a) hundreds of millions of data points on measured exposure to chemicals in terrestrial biota and soils; (b) modelled damages to terrestrial biodiversity and ecosystem services; (c) hazardous properties of chemicals; and (d) chemicals risk data (e.g. predicted no effect concentrations – PNECs) for terrestrial biota and soils. The database system can support the EU Common Data Platfom and is an essential precursor to key regulatory applications of the data.

Establishing a centralised digital platform is essential for execution of meaningful, comparable risk assessments of complex chemical mixtures. To effectively characterise chemical risks to terrestrial biodiversity, such a platform needs to incorporate a wide range of data on exposure, hazard and risk, including data from novel analytical methods such as suspect screening, bioassays for mixture effects, and AI toxicity modeling.
The platform must also meet FAIR data requirements, implementing findable, accessible, interoperable, and reusable (FAIR) information structures so that regulators can exploit automated assessment tools transparently.

Through systematic aggregation of real-world chemical occurrence data, such a platform can generate early warning signals to feed the European Early Warning and Action System.

HOW TerraChem HELPS

The TerraChem Database System has bridged critical gaps by developing an interconnected digital platform populated with comprehensive terrestrial monitoring data. Utilizing the NORMAN infrastructure, it has established standardized Data Collection Templates (DCTs) and interoperable data modules including for: (a) substance data (for over 120,000 chemicals); (b) exposure data in soils and terrestrial apex species and their food chains (from both target analyses of c. 2800 substances and suspect screening of c. 93,00 substances); (c) risk data including ecotoxicity threshold values for terrestrial species; (d) hazard data including on PBMT, CMR and ED properties and related physico-chemical and environmental fate; (e) Mixture toxicity data from bioassays; (f) raw high-resolution mass spectrometry files for retrospective screening of unknown substances; (g) predictive model training sets; and (h) additional exposure data compiled from published literature.

TerraChem has advanced FAIR data processes and structures, including the development of harmonised data collection templates, harmonisation of data formats with the NORMAN Database System and built-in API protocols for automated data exchange, automated prioritisation tools for prioritisation of chemicals based on exposure, hazard and risk data, using exposure data from both target and suspect screening. TerraChem is also bringing together automated prioritisation across target and suspect data and bringing in additional lines of evidence such as TerraChem modelling output on damages to biodiversity.

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KEY MESSAGE 4

TerraChem Regulatory Applications, integrated into the database system, automate the integration of data from multiple lines of evidence (including data on exposure, damages, hazard and risk) to generate early warning signals and connect signals to regulatory actions, including through: (a) prioritisation of substances for further environmental risk assessment; (b) informing such ERA through a weight-of-evidence approach; and (c) identification of candidate substances for regulatory watch-lists. These and other applications support regulators in more efficient and more effective management of chemicals risks to terrestrial biodiversity, and thereby support efforts to meet EU targets related for biodiversity restoration and zero pollution.

Reversing biodiversity loss requires identifying which specific chemical pressures drive damage on biodiversity, a task heavily constrained by underdeveloped tools for separating correlation from causation. While Europe possesses the technical capability to detect such damage, existing early warning signals remain severely fragmented across disconnected databases, sectors, and regional agencies. Crucially, standard frameworks lack systems to translate exposure indicators into real-world terrestrial ecosystem degradation. To bridge this gap, a centralised signaling mechanism is urgently needed to link empirical chemical concentrations with systemic ecological impacts, providing vital guidance for EU chemicals risk assessment and management in relation to biodiversity, and for EU nature restoration measures.

Establishing a biodiversity-focused chemicals early warning and risk assessment framework requires:

- **Core biomonitoring streams:** Soil and wildlife food-chain data should serve as primary inputs for the European Early Warning and Action System (EWAS) to identify chemical threats including biomagnification.
- **Explicit ecological endpoints:** European early warning categories must expand beyond basic chemical hazards to explicitly evaluate actual biodiversity damage endpoints.
- **Central platform functionality:** The EU Common Data Platform on Chemicals (CDP) should integrate standardised substance identifiers and ecotoxicity metadata.
- **Multiple lines of evidence:** Prioritising hazardous chemical mixtures requires multi-evidence scoring models instead of isolated endpoints.
- **Direct regulatory loops:** Chemical prioritisation must be tied to clear regulatory pathways to trigger immediate mitigation.

HOW TerraChem HELPS

TerraChem has delivered a blueprint that combines machine-readable chemical occurrence data with advanced prioritisation algorithms. It successfully pairs wide-ranging chemical occurrence data from target, suspect, and non-target analyses with concrete ecological indicators to reveal masked impacts including sublethal mixture effects and food-chain biomagnification. TerraChem has implemented a comprehensive Multiple-Lines-of-Evidence-Based Prioritisation (MEBP) scheme for over 3800 suspect substances. Furthermore, TerraChem structured a six-tier regulatory decision support workflow that segments compounds into action classes—ranging from continuous monitoring to immediate restriction—providing actionable screening and prioritisation of chemicals for subsequent expert review and regulatory uptake.

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

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