TerraChem

EARLY WARNING SIGNALS & MULTIPLE-LINES OF EVIDENCE BASED CHEMICAL PRIORITISATION

Tools for identifying the chemicals that contribute to terrestrial biodiversity loss

Policy brief 05

Introduction

Policy gap: Europe needs a biodiversity-focus early warning system for chemicals of emerging concern

Reversing biodiversity loss requires knowing which pressures drive it. For chemical pollution, this means identifying which chemicals are key in impacting biodiversity. This is a huge challenge and, to date, this knowledge has been largely absent. The data, methods and metrics needed to quantify the contribution of chemicals to biodiversity loss – that is, biodiversity damage – and to separate causation from correlation between chemical exposure and ecological effect are until now under developed[1–2]. This constrains both the prioritisation and the regulatory risk assessment of thousands of chemicals in use, including their transformation products, and the integration of biodiversity impacts into those assessments. Advances in measuring biodiversity change[1–4], in characterising chemical exposure and risks[1,5] and in predictive effect modelling[2,6,7] mean that Europe now holds the scientific and technical capacity for effective early warning of emerging chemical risks[8,9]. Data on chemicals and biodiversity as well as early warning signals nevertheless remain fragmented across databases, sectors, agencies and Member States, and existing systems have no mechanism for quantifying chemical impacts on biodiversity loss, particularly in the terrestrial environment. The policy need is therefore a mechanism that links measured or predicted chemical exposure data to biodiversity loss, integrates the available evidence transparently and systematically, and thereby prioritizes chemicals with potential ecosystem impacts beyond hazard and risk assessment alone. That is, an essential signalling function that can provide guidance in relation to a range of policies and regulations from nature restoration to authorization of chemicals (REACH, Pesticides & Biocides).

HOW TERRACHEM HELPS TO CLOSE THE GAP

TerraChem developed and tested two complementary approaches to support biodiversity-focused early warning for chemicals in the terrestrial environment:

1. An early-warning approach that uses wide-scope target, suspect and non-target screening data from soil, terrestrial biota and food chains to generate structured, machine-readable occurrence signals based on concentrations, detection frequencies, spatial patterns and trophic transfer.
2. An integrated multiple-lines-of-evidence-based prioritisation (MEBP) scheme to identify and rank strong early-warning signals. For this purpose, chemical occurrence is combined with intrinsic chemical properties, hazard and risk information and – for the first time – (prospective) biodiversity-damage metrics derived from damage assessment[6,7] in a flexible and largely automated multiple-lines-of-evidence assessment.

The tools are compartment-agnostic and the approach is a transferable blueprint for freshwater and marine ecosystems. The prioritisation scheme can be applied in two ways: first, to generate biodiversity-relevant signals to feed into the European Early Warning and Action System (EWAS); and second, as a stand-alone regulatory tool to support authorities in screening chemicals under different EU chemicals legislation wherever biological and chemical monitoring data are available. Both components, the TerraChem early warning approach and prioritization schema complement, rather than duplicate, existing regulatory processes and are designed to support the One Substance One Assessment (OSOA) package15 including the EU EWAS currently under development by the EEA.

TerraChem tested whether the developed early-warning and prioritization tools can be applied to real-world terrestrial monitoring data at the European scale and whether they yield signals that can feed into the EWAS. Read our proof of concept here.

THIS BRIEF

This brief describes how:

- the early warning tool developed in TerraChem systematically converts heterogeneous, difficult-to-interpret chemical and biological signals from European soils and terrestrial food-chain samples into structured and informative early-warning signals;
- these signals then feed into the integrated TerraChem prioritisation scheme, together with conventional hazard and risk information and biodiversity-damage metrics, through a multiple-lines-of-evidence assessment;
- these two components jointly support the identification and ranking of chemicals with potential damage on terrestrial biodiversity, providing a decision-support tool for regulatory follow-up action.

This brief provides specific policy recommendations on the components and aspects that should be considered when generating future terrestrial signals to feed into the European Early Warning and Action System currently being established.

WHO SHOULD READ THIS BRIEF

This brief is intended for:

- European policymakers and regulators — primarily from the European Environment Agency (EEA), but also from the European Commission (DG ENV, DG GROW, DG SANTE), ECHA, EFSA, EMA and the Joint Research Centre — and national authorities responsible for implementing chemicals legislation. For this audience, the brief shows how TerraChem approaches, tools and data can support the EU early warning and action system in identifying chemicals with terrestrial biodiversity impacts or chemicals that biomagnify in food chains.
- For academia and practitioners in risk assessment, soil health and conservation, it offers transferable tools to screen for such chemicals.

KEY MESSAGES

The EU currently lacks a mechanism to identify and quantify chemicals that contribute biodiversity loss and those that biomagnify in food-chains in terrestrial ecosystems. Novel methods and approaches are needed to generate signals feasible to feed into the EU early warning and action system for the terrestrial compartment to close this gap.

1. **Use environmental biomonitoring as a core early-warning evidence stream.** Soil and terrestrial food-chain data from chemical and biodiversity monitoring should become a core evidence stream of the EU EWAS to allow for identification of chemicals with potential biodiversity impacts and those biomagnifying in food chains, particularly in apex predators.

2. **Close the terrestrial blind spot.** The upcoming EU EWAS should explicitly include a signal category that addresses substances which contribute to terrestrial biodiversity damage. Further research funding is needed to develop the methods applied in TerraChem and beyond to quantify the contribution of chemicals to biodiversity loss.

3. **Design the Common Data Platform on Chemicals (CDP) for this function.** Build in the identifiers, metadata, curated ecotoxicity data and interfaces that automated early warning and multi-evidence prioritisation require.

4 **Prioritise chemicals within the EWAS using multiple lines of evidence rather than a single score or endpoint.** Combine monitoring data from food-chains, biota and soil with hazard, risk and biodiversity-damage information, using automation for large-scale triage and expert review for interpretation.

5 **Connect prioritisation directly to regulatory action in future.** Reducing chemical pressure to the environment requires a central mechanism that interprets reported signals, evaluates and weighs the relevance of a substance. Scientists in TerraChem developed criteria and workflows to provide decision support for follow-up regulatory action. This makes explicit actions and feedback of monitoring possible into the regulations.

TIME HORIZONS OF SUGGESTED POLICY ACTIONS

short term (2026–2027):	Validate terrestrial early-warning signals, evidence-integration and prioritisation workflows from TerraChem and comparable activities within the developing EU architecture.
medium term (2028–2030):	Implement validated terrestrial signal generation and prioritisation workflows to feed into EWAS, CDPC and OSOA; extended TC approach to other environmental compartments, to suspect-screening data, and cover mixture risks and potential damage arising co-exposure to multiple chemicals
long term (beyond 2030):	Institutionalise validated approaches in EU chemical governance and assess transfer of the methodological framework to other environmental compartments, to suspect screening data and cover risks and damage from exposure to.

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KEY MESSAGE 1

Use environmental biomonitoring as a core early-warning evidence stream

Prospective risk assessment remains essential, but it cannot capture every exposure pattern that develops once chemicals are used and consequently enter the environment. Early warning must therefore complement predicted exposure with measured environmental occurrence and concentrations. Monitoring of both soil and biotic food chains is particularly informative because it integrates exposure over time and captures pathways that soil concentrations alone may miss (TerraChem Policy Brief no. 2). Measurements in organisms, particularly apex predators, reveal uptake, internal exposure and transfer between trophic levels, thereby identifying substances that biomagnify in terrestrial food chains. Appropriate sampling design, wide scope target, suspect and non-target screening can identify substances that are widespread, occur unexpectedly, biomagnify reaching high contaminant level particularly in apex predators, or show spatial-temporal patterns that warrant further investigation.

TerraChem shows how terrestrial monitoring results can be converted into structured early-warning signals and combined with hazard, risk and biodiversity-damage evidence. Environmental biomonitoring should therefore be treated not as supplementary information, but as a core evidence stream for an EU early-warning signal for the terrestrial compartment.

POLICY RECOMMENDATIONS

2026–2027:

- Pilot on proofing the utility of wide-scope target, suspect and non-target screening data from TerraChem and other research activities for EWAS in close collaboration with EU PARC project and NORMAN.
- Agree on minimum reporting standards for wide-scope target, suspect and NTS screening data including quality assurance and control measures.
- Continue generation of harmonised terrestrial chemical-monitoring data across Member States from biotic food chains and soil to validate TerraChem signals beyond the initial six-country dataset.

2031–2040: Feed terrestrial monitoring generated under the Soil Monitoring Law when established in 2031 and other EU into the EU EWAS as routine early-warning evidence stream with defined governance.

KEY MESSAGE 2

Make terrestrial biodiversity damage an explicit EU early-warning endpoint and develop the methods to quantify contribution of chemicals to biodiversity loss

Chemical early warning should identify more than just substances with hazardous properties or with rising environmental occurrence. It should identify substances for which the available evidence indicates a plausible contribution to terrestrial biodiversity damage. This requires moving beyond traditional hazard or exposure signals towards an evidence chain that connects measured chemical exposure, ecotoxicological effects, and potential biodiversity impacts.

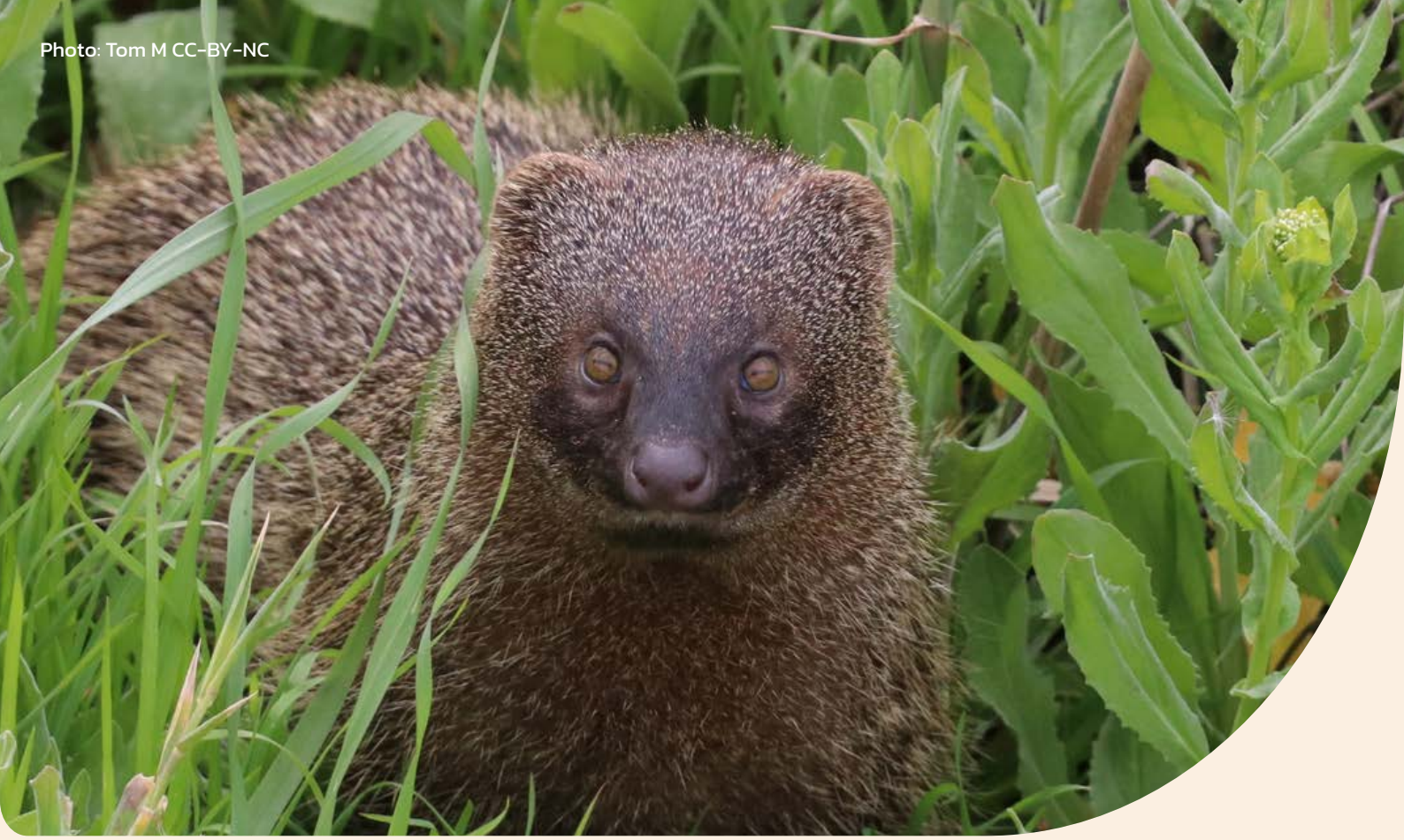
TerraChem operationalizes this evidence chain for terrestrial ecosystems. It complements prospective risk assessment with evidence from environmental monitoring and biodiversity assessment and can therefore identify chemicals with potential biodiversity impact not identified via conventional regulatory risk and hazard assessment alone (TerraChem Policy Briefs nos. 2 and 3). This is particularly important for persistent substances, those accumulating through food chains or with chronic and sublethal effects, and emerging risks that become visible only after widespread environmental exposure. For instance, Köninger et al.[1] recently showed for 373 LUCAS sites across Europe that pesticide mixtures were, after soil properties, the second strongest driver of taxonomic and functional soil biodiversity loss or alteration.

POLICY RECOMMENDATIONS

2026–2027: Conduct a proof of concept of the TerraChem signals and of other initiatives which indicate terrestrial biodiversity impacts beyond species richness loss, e.g. in the EU PARC project;

2028–2030:

- The European Commission should invest via the Horizon Europe work programme and other funding instruments in the development of methods that (i) quantify the contribution of chemicals to biodiversity loss – covering not only species richness loss but also functional biodiversity loss, genetic diversity loss, and ecosystem services loss, (ii) improve mechanistic and statistical approaches for terrestrial systems, including ecosystem-level exposure and food-chain magnification models, and cross-species extrapolation approaches to bridge the scarcity of ecotoxicity and bioaccumulation data.
- The EEA should then incorporate validated terrestrial biodiversity-damage signals into the EWAS and consider them systematically to increase the evidence for follow-up reagulatory action.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KEY MESSAGE 3

Build the required functionality into the Common Data Platform on Chemicals now

Automated generation of early warning signals and their prioritisation depend on interoperable, machine-readable data: common substance identifiers, curated ecotoxicity data, harmonised metadata, spatial and temporal information, descriptors of analytical confidence, and machine-readable interfaces. Adding these functions after databases have been designed would require costly restructuring.

The development of the Common Data Platform on Chemicals under OSOA therefore provides an important implementation opportunity. The platform should not only enable retrieval of chemical information. Its data architecture should allow automated linkage of the information required for the generation of early warning signals and their prioritisation from research projects like TerraChem.

For terrestrial early warning, this means enabling automated linkage of evidence that is currently generated and stored separately: chemical identity and regulatory status, environmental occurrence and concentrations in soil and biota, hazard and ecotoxicity information, persistence and bioaccumulation properties, effect data, and evidence of biodiversity damage. Within the TerraChem project, concrete terrestrial use cases illustrated which evidence streams need to be connected and how they can be processed together (TerraChem Policy Brief no. 4). The CDPC should provide the data backbone; EWAS should provide the signal-identification and prioritisation process; and competent authorities should retain responsibility for formal assessment and regulatory decisions for regulatory follow up.

POLICY RECOMMENDATIONS

2026-30: Build the identifiers, metadata, data-quality descriptors and interfaces required for environmental early warning and multi-lines-of-evidence prioritisation into the CDPC now. TerraChem can provide a practical test case for specifying and validating these requirements for the terrestrial compartment.

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KEY MESSAGE 4

Prioritise chemicals based on multiple lines of evidence rather than a single score or endpoint

No single indicator captures the impacts a chemical poses to terrestrial ecosystems. Early warning must therefore rest on complementary signal types – intrinsic substance properties, hazard profiles, biological and ecological monitoring, and evidence of environmental exposure – integrated transparently and systematically. Monitoring is the central pillar: the system must process wide-scope target, suspect and non-target screening outputs to characterise spatiotemporal exposure and to detect bioaccumulation and biomagnification along terrestrial food webs. As measured concentrations frequently diverge from modelled predictions, monitoring-based signals cannot be replaced by modelled estimates alone. The TerraChem prioritisation tool implements this principle by combining independent lines of evidence for single chemical assessments. A substance ranked high across independent lines of evidence warrants a different regulatory response from one receiving the same preliminary score on a single, uncertain signal. This makes the approach transparent, repeatable and readily applicable in future regulatory assessment.

POLICY RECOMMENDATIONS

2026-27: Further research activities, e.g. via EU PARC case studies, to test and validate the TerraChem MEBP prioritisation scheme (i) against substances with well-characterised environmental hazards and risks in terrestrial organisms, food chains and soil; (ii) by adapting the workflow and criteria to extend the tool to the 3852 chemicals identified in TerraChem via suspect screening; and (iii) to address mixture toxicity risks and the potential damage to biodiversity arising from co-exposure to multiple chemicals.

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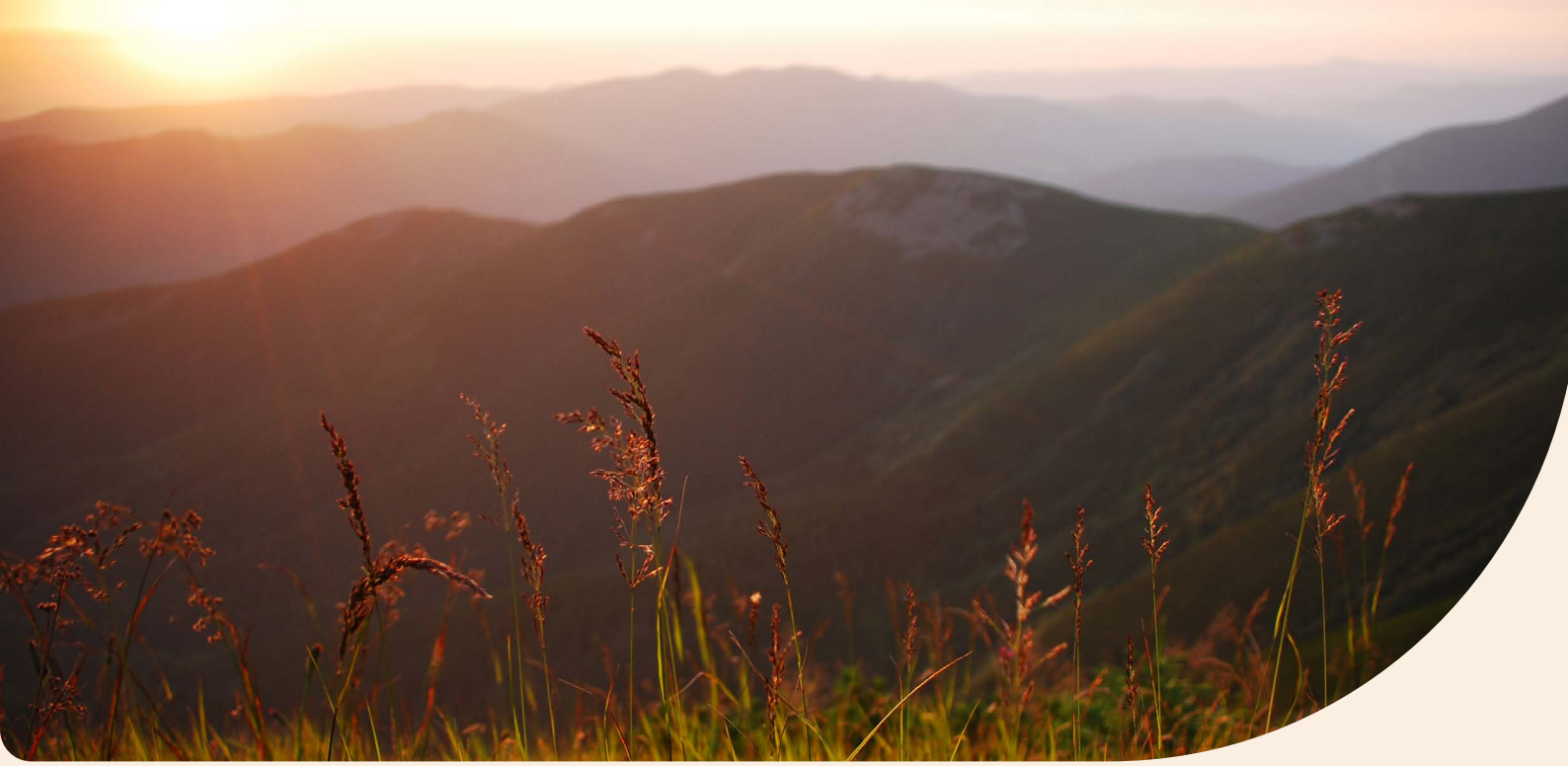

KEY MESSAGE 5

Connect prioritisation directly to regulatory action in future

Prioritisation creates regulatory value only if the resulting signal leads to a defined next action. To reduce chemical pressure on the environment, EEA is developing a central mechanism that interprets reported signals, judges the relevance of a substance, and assigns the resulting regulatory action to the responsible authority. TerraChem proposes a decision-support workflow in which the priority and confidence assigned to a substance determine the potential follow-up of identified chemicals with impact on biodiversity, hazards or risks which could provide future decison support.

TerraChem distinguishes between five broad action classes: (1) no current action where evidence does not indicate sufficient concern; (2) continued monitoring where a signal exists but remains uncertain; (3) targeted evidence generation where critical exposure/ hazard data is lacking; (4) regulatory (re)assessment where converging evidence indicates risk, hazard or potential damage on biodiversity substance; (5) further development of methodologies for chemical analysis, and (6) consideration of targeted risk-management measures where concern is sufficiently substantiated.

POLICY RECOMMENDATIONS

2026–28: Expand and test the decision workflow on the top priority substances identified by TerraChem for follow up regulatory action, and evaluate how the resulting conclusions compare with those reached through existing regulatory assessments and management measures, e.g. within an EU PARC case study.

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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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