Integrated Environmental Assessment and Management, 2026, **00**, 1–15
https://doi.org/10.1093/inteam/vjag145
Published: August 26, 2026
Workshop Synthesis

Biodiversity and chemical regulation: Status quo, data gaps, and recommendations for future action

Anja Gladbach[1], Christoph J. Mayer[2], Aaron Stoler[3,], Sian Ellis[4], Marta Baccaro[5], David A. Bohan[6], Franziska Enzmann[7], Emily Garman[8], Jutta Hellstern[9], Sarah A. Hughes[10], Philippe Lemaire[11], Jan-Dieter Ludwigs[12], Lorraine Maltby[13], Anna-Maija Nyman[14], Hans Sanderson[15], Simran Sandhu[16], Marco Thines[17,], Johannes Tolls[7], Lucy Wilmot[18], and Nika Galic[19,*,]

[1]Bayer AG, Monheim, Germany
[2]BASF SE, Limburgerhof, Germany
[3]Exponent, Inc, Philadelphia, PA, United States
[4]Corteva, Abingdon, United Kingdom
[5]Joint Research Centre, European Commission, Ispra, Italy
[6]INRAe, Dijon, France
[7]Henkel, Düsseldorf, Germany
[8]NiPERA, Durham, NC, United States
[9]F-Hoffmann-La Roche, Basel, Switzerland
[10]Shell Global Solutions US, Inc., Houston, TX, United States
[11]TotalEnergies, Paris, France
[12]Rifcon, Hirschberg an der Bergstraße, Germany
[13]University of Sheffield, Sheffield, United Kingdom
[14]ECHA, Helsinki, Finland
[15]Aarhus University, Aarhus, Denmark
[16]Unilever, Bedford, United Kingdom
[17]Senckenberg Biodiversity and Climate Research Centre, Frankfurt am Main, Germany
[18]ECETOC, Brussels, Belgium
[19]Syngenta AG, Basel, Switzerland
*Corresponding author: Nika Galic, Email: Nika.Galic@syngenta.com

Abstract

Global biodiversity is declining, driven by multiple interacting pressures, including the five most prominent: resource use, habitat loss, invasive species, climate change, and chemical pollution. While chemical exposure is recognized as a potential driver of biodiversity loss, quantitative links and its relative impact as compared with other stressors remain poorly understood. The European Union (EU) has intensified efforts to reduce pollution and restore biodiversity through strategic frameworks such as the Biodiversity Strategy, Farm to Fork Strategy, Zero Pollution Action Plan, and Chemical Strategy for Sustainability. Key chemical regulations such as REACH and the Plant Protection Products Regulation aim to protect ecosystems; however, due to the complexity of ecosystems and the range of stressors, it is difficult to measure their direct impact on maintaining or improving biodiversity objectives. This review, conducted by a multidisciplinary task force brought together by ECETOC, evaluates the current state of biodiversity research efforts and their integration within EU chemical regulation. We examined EU legislation, strategy documents, EU-funded research, and peer-reviewed literature to identify biodiversity definitions, metrics, and methodologies and to highlight gaps in linking chemical exposure to biodiversity outcomes. Findings indicate that current chemical regulations mainly reference biodiversity qualitatively, biodiversity research often lacks a focus on chemical impacts, and research outcomes are not clearly linked to regulatory frameworks. The relationship between biodiversity and chemical impacts is further complicated by diverse definitions and metrics of biodiversity in the academic literature, with limited consistency across biomes and minimal alignment with chemical risk assessment practices. To strengthen biodiversity considerations in chemical regulation, we recommend the following: developing operational definitions of biodiversity applicable across regulatory contexts; standardizing metrics and indicators; establishing a centralized data platform for biodiversity research; and leveraging existing data, methodologies, tools, and new technologies (e.g., machine learning). Bridging knowledge gaps between policy objectives and available approaches, while aligning biodiversity considerations across chemical regulation and other regulations that

Received: January 23, 2026. **Revised:** June 26, 2026. **Accepted:** August 10, 2026
© The Author(s) 2026. Published by Oxford University Press on behalf of the Society of Environmental Toxicology and Chemistry.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

can affect biodiversity, such as habitat loss, will promote coherence and cooperation. Continued multistakeholder engagement and alignment is critical in achieving these recommendations.

Keywords: biodiversity, chemicals, regulation, chemicals management, environmental risk assessment

Introduction

There is now widespread evidence that biodiversity is globally declining, although location-specific trends depend largely on scale, habitat, and region (Dornelas et al., 2023). Mounting evidence for the negative impacts of biodiversity loss (Brondízio et al., 2019) has led the United Nations to prioritize a halt to biodiversity loss in its sustainable development goals (Goal 15; https://www.un.org/en/exhibits/page/sdgs-17-goals-transform-world). Pollution, including chemical exposure, is cited as one of the key drivers of biodiversity loss in the 2022 Kunming-Montreal Global Biodiversity Framework, which aims to halve and reverse biodiversity loss by 2030 (Convention on Biological Diversity [CBD], 2022). Other key drivers listed as having an impact on biodiversity include habitat loss, invasive species, overexploitation of resources, and climate change (CBD, 2022). The European Union (EU) and European Commission are increasingly focused on pollution reduction to restore and preserve biodiversity. This shift is evidenced by several new strategic documents, such as the EU Biodiversity Strategy (European Commission, 2020b), Farm to Fork Strategy (European Commission, 2020c), Zero Pollution Action Plan (European Commission, 2021), Chemical Strategy for Sustainability (European Commission, 2020a), and One Health approach (European Commission, 2024a). These strategy documents explicitly target chemical inputs as one of the main drivers of biodiversity decline and set ambitious goals for reducing their entry into the environment. In addition, researchers highlight the role of chemicals in biodiversity declines (Groh et al., 2022) and call for stricter, more holistic assessment of risks from exposure to chemicals (Axelman et al., 2024; Brühl & Zaller, 2019; Topping et al., 2020). However, quantitative links between biodiversity loss and chemical exposure for different groups of organisms and systems are yet to be fully understood. Moreover, the effects of chemical exposure on biodiversity relative to other pressures (e.g., habitat loss) have yet to be quantified (Semenchuk et al., 2022; Tilman et al., 2017). To bridge these knowledge gaps, there is a need to develop clear definitions, identify the state and trajectory of existing research, interpret how that research is integrated with chemical legislation, and explore existing tools that can facilitate quantitative linkages between measurement and assessment endpoints (Forbes & Galic, 2016; Maltby et al., 2021).

Chemical industries in the EU are subject to strict regulation, with specific requirements to assess and demonstrate acceptable risk to the environment from chemical exposure before a substance enters the market (e.g., REACH Regulation [EC] No 1907/2006 [European Parliament and Council, 2006b]; Plant Protection Products Regulation [EC] No 1107/2009 [European Parliament and Council, 2006a]). Environmental risk assessments (ERAs), carried out in line with the relevant regulatory guidance and internationally agreed practice under the Organisation for Economic Co-operation and Development, determine the risk to a set of standard representative species using conservative predicted exposure estimates and margins of safety. This process is intended to ensure that other species within the same ecosystem are also protected. Studies have been conducted with the aim to link risk assessment methodology to biodiversity metrics, including the alignment between species sensitivity to chemical toxicity and species abundance in aquatic systems (Hoeks et al., 2020) and the effect of chemical mixtures with environmental stressors on biodiversity in surface waters (Posthuma et al., 2019). However, significant work is still needed to establish if these and any additional approaches effectively address ambitious targets set by recent EU biodiversity strategies.

This issue was recently highlighted in a Joint Research Centre of the European Commission report that examined how standard ecotoxicological studies address each class of Essential Biodiversity Variables (EBVs): a set of descriptors that capture key aspects of biodiversity. The report highlighted how the potential misalignment between ecotoxicological endpoints and EBVs can hinder establishing a causal link between chemical pollution and biodiversity effects (Baccaro et al., 2025). The European Food Safety Authority (EFSA) proposes defining specific protection goals (SPGs) within the ecosystem services context to better assess and manage risks to biodiversity (EFSA Scientific Committee, 2016). This approach acknowledges that biodiversity is crucial for the functioning of ecosystems and the services that they provide. The EFSA's framework for developing SPGs involves identifying relevant ecosystem services, the units providing those services, and the levels of protection needed for those units. However, operationalizing SPGs has been challenging due to limited specific definitions and scales of biodiversity. In addition, corporate reporting requirements, such as those mandated by the Corporate Sustainability Reporting Directive (European Parliament and Council, 2022) and the EU Taxonomy (EU No 2020/852), include biodiversity considerations; however, it is unclear whether these reporting frameworks are aligned with biodiversity definitions and metrics used in other regulatory contexts and academic research, thereby complicating coordinated efforts to monitor and manage biodiversity risks related to chemical exposure.

To address these challenges and knowledge gaps, the European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) initiated a task force at the end of 2023.

The task force reviewed the status quo with respect to three key objectives:

- To evaluate existing EU legislation and strategic documents to clarify how the term *biodiversity* is used and defined, including the metrics and methods employed in these high-level documents
- To compile an overview of recent and ongoing EU-funded research projects related to chemical impact on biodiversity to identify how new scientific knowledge can inform regulatory frameworks and to highlight future research needs

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

- To evaluate the landscape of biodiversity definitions and metrics across biomes, with the goal of offering insight into potential frameworks for standardization across global regions

The aim of this article is to present the outcomes of this review, integrating these insights to highlight critical knowledge gaps and misalignments. By doing so, this article contributes to advancing a discussion on the link between chemical exposure and biodiversity loss, including aspects of biodiversity metrics as well as research needs. This emphasizes the need for continued stakeholder engagement to advance the scientific understanding required for robust and ecologically relevant risk assessments.

Objective 1: biodiversity considerations in EU legislation and strategic documents

Aim

By reviewing existing high-level EU legislation and strategic documents, we aimed to evaluate how the term *biodiversity* is defined and considered within the context of EU chemical regulation, including the metrics and methods employed. The analysis focused on EU chemical regulatory frameworks, which establish the legal scope, overarching protection goals, and risk assessment paradigms. In addition, some more conservation-focused documents were considered for a broadened perspective. The review did not assume that EU legislation should include detailed quantitative specifications; instead, it examines whether biodiversity is explicitly represented within the regulatory baseline. The identification of specific species, habitats, or systems and their treatment in detailed annexes or technical guidance, as well as national implementation, was considered out of scope. While this downstream guidance for implementation provides quantitative details (e.g., habitat quality criteria or species lists), the focus of this review was on chemical regulation and legislation and how effects on biodiversity are defined. Assessing this legislative level was essential to identify systemic gaps and differences rather than implementation variability.

Methods

Initially, 41 legislative and strategy documents were identified by expert judgment as being potentially relevant for this evaluation based on the broad expertise of the task force with chemical regulations in the EU. The EUR-Lex website was searched (https://eur-lex.europa.eu/advanced-search-form.html; search criteria: "Domain: All, Type of act: Regulation, Directive, Results containing: biodiversity In title and text, Results containing: chemical In title and text, Search language: English"), and key documents from different chemical sectors were selected. This was not necessarily comprehensive, but the evaluation focused on the most widely used regulations from different chemical sectors within chemical risk assessments. These comprised 15 European regulations, 12 European directives, 6 policy strategies from the European Commission (ECHA's Key Areas of Regulatory challenge document was included here), 6 frameworks (4 from the EU, 2 transnational agreements), 1 national law, and 1 other type of document. Of the 41 documents reviewed, 28 stated biodiversity with a notable increase in prominence since the 1990s, potentially due to the 1992 Rio Convention on Biodiversity (Figure 1).

As a first step, the 41 documents were screened for several aspects (Table 1), the two most important criteria being (a) "biodiversity explicitly stated" or "biodiversity addressed via a generic surrogate e.g., nature, environmental, wildlife" and (b) the presence of a specific focus on chemical impact on the environment or the mitigation of chemical impacts on the environment. If either criterion was fulfilled, the documents were taken to the next step of the evaluation. The resulting list was condensed by excluding documents where biodiversity was referred to very few times or in a general manner and therefore not considered useful for evaluation. This included the strategy documents as well as some directives and frameworks, such as the EU habitat conservation directive, EU CS3D (Corporate Sustainability Due Diligence Directive), EU WEEE (Waste Electrical and Electronic Equipment) directive, EU Pollinators Initiative, and EU SSbD (Safe and Sustainable by Design) framework. In addition, two regulations linked to the data requirements for plant protection products (PPPs) were excluded as they were considered being under the main PPP Regulation 2009/1107. From the initial list of 41 documents, 25 remained for an evaluation on how biodiversity is currently defined and considered for regulatory purposes.

Outcomes

The main findings from the 25 legislative and strategy documents identified for evaluation can be summarized as follows.

- Definitions for biodiversity are rarely provided and, where provided, largely follow the CBD 1992 definition of biological diversity (5 total).
- Metrics for biodiversity in relation to chemical risk are rarely reported in legislative and strategy documents; although it is noted that downstream national regulations will contain more specific details for biodiversity, these are not apparent in the legislative documents (8 total). Where provided, such

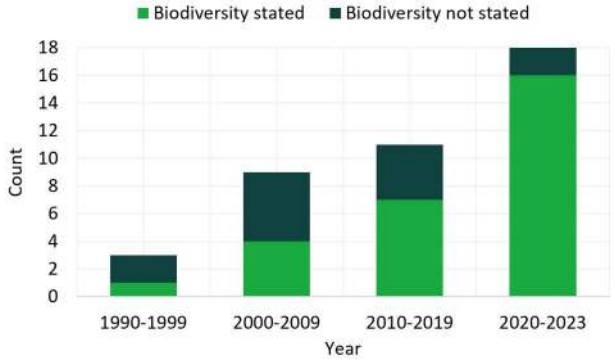

Figure 1 Number of chemical regulations and strategy documents, out of the 41 identified as potentially relevant, that state and do not state "biodiversity."

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

Table 1 Forty-one legislative and strategy documents identified by expert judgment as being potentially relevant for this review and screening for further evaluation based on relevance criteria.

Legislation or strategy document	Biodiversity stated[a]	Biodiversity stated but not yet in force[b]	Biodiversity not stated nor addressed[c]
Regulations			
EU Reg: Taxonomy for sustainable activities 2020/852	×		
EU Reg: PPP 1107/2009	×		
EU Reg: Data requirements PPP actives 283/2013	×[d]		
EU Reg: Data requirements PPP products 284/2013	×[d]		
EU Reg: CLP 1272/2008	×		
EU Reg: REACH 1907/2006	×		
EU Reg: POPs 2019/1021	×		
EU Reg: Vet med products 2019/6	×		
EU Reg: Fertilising products 2019/1009	×		
EU Reg: Biocides 528/2012	×		
EU Reg: (Batteries, 2023)	×		
EU Reg: Commodities/products associated with (Deforestation, 2023)			×
EU Reg: 1229/2009 Cosmetic products			×
EU Reg: Nature restoration 2024/1991		×	
Proposed EU Reg: Sustainable use PPP (2022) (withdrawn in 2024)		×	
Directives			
EU Dir: Water framework 2000/60	×		
EU Dir: Soil monitoring 2025/2360		×	
EU Dir: Urban Waste Water Treatment 2024/3019	×		
EU Dir: CSRD 2022/2464	×		
EU Dir: (Industrial Emmissions, 2010)	×		
EU Dir: PPP (Sustainable Use, 2009)	×		
EU Dir: Conservation wild birds 2009/147	×		
EU Dir: Habitat conservation 92/43			×
EU Dir: Marine strategy framework 2008/56	×		
EU Dir: CS3D 2024/1760			×
EU Dir: WEEE 2012/19/EU			×
EU Dir: Med products 2001/83	×		
Strategies			
EU strategy: (Green Deal, 2019)			×
EU strategy: (Biodiversity, 2020)			×
EU Com: Farm to (Fork, 2020)			×
EU Com: (Chemicals Strategy for Sustainability, 2020)			×
EU Com: (Zero Pollution, 2021)			×
ECHA key areas of regulatory challenge (KARC) (2023)			×
Frameworks			
EU Com: (Circular Economy, 2020)			×
EU Com: (Pollinators, 2018)			×
EU Policy: (Commonagricultural: Directorate-General for Agriculture and Rural Development, 2012)	×		
EU Rec: SSbD framework (2022)			×
Int Framework: (KM Biodiversity, 2022)	×		
Int Convention: OSPAR (1992)	×		
National laws			
Nat Act: (German supply chain, 2021)	×		
Other			
Int Manufacturing Standard: AMR industry alliance (2022)	×		

Note. EU = European Union; PPP = plant protection products; CLP = classification, labeling, and packaging; REACH, Registration, Evaluation, Authorisation and Restriction of Chemicals; POPs = persistent organic pollutants; CSRD = Corporate Sustainability Reporting Directive; CS3D = Corporate Sustainability Due Diligence Directive; WEEE = waste electrical and electronic equipment; SSbD = safe and sustainable by design; KM = Kunming-Montreal; OSPAR = Oslo and Paris Conventions; AMR = antimicrobial resistance.

[a]Biodiversity stated or addressed via surrogate or specific focus on chemical impacts on environment.

[b]Biodiversity stated or addressed via surrogate or specific focus on chemical impacts on environment but not yet in force.

[c]Biodiversity neither stated nor addressed via a surrogate or specific focus on chemical impacts, or biodiversity stated only few times or only in vague terms.

[d]EU Regulation Data requirements PPP actives 283/2013 and EU Regulation Data requirements PPP products 284/2013 were not further evaluated as they were considered as being under the main PPP regulation 2009/1107.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

metrics are often qualitative (e.g., habitat conditions, political indices, "good conditions"), but they become more specific (e.g., populations of surrogate species) for regulations relating to chemicals intended for use in the environment or where their release is anticipated. Examples for the latter are the regulations for plant protection and biocidal products.
- Methodology to assess the chemical impact on biodiversity or a proxy thereof is considered in only a few documents (3 total).

The technical guidance documents associated with the legislative documents were not evaluated, as these were out of scope of the focus of the evaluation, even though some of these documents may provide more precise metrics than the main legal text of regulations and directives. For instance, subject-specific documents supporting the PPP regulation (EC No 1107/2009) include guidance on conducting ERAs for birds and mammals (EFSA et al., 2023). Here, the operational protection goal focuses on "no visible mortality" and "no long-term repercussions for abundance and biodiversity" of birds and mammals in agricultural areas, and biodiversity definition is in line with the one from CBD 1992. The focus of risk assessment in the birds and mammals guidance is on species that typically occur in or adjacent to agricultural landscapes and on the protection of potentially sensitive species or vulnerable populations. The recently published proposed strategy for the definition of SPGs for terrestrial organisms for pesticide ERA addresses several taxonomic groups occurring in agricultural landscapes, including nontarget plants, nontarget arthropods, and soil organisms (micro- and mesofauna as well as microorganisms; EFSA et al., 2025). Nevertheless, some potentially important components of biodiversity may still be underrepresented or only indirectly covered in current schemes (e.g., fungi, protists), noting that aspects of soil microbial functioning are considered via soil microflora tests such as nitrogen transformation. A systematic evaluation of coverage across all taxa and functions was beyond the scope of the present analysis and would require a dedicated assessment. It should also be noted that while the EU Habitats Directive (Council Directive 92/43/EEC) includes annexes of species lists to determine habitat quality, the directive does not have a specific focus on chemical impact on the environment.

The mechanisms for regulation and risk management of chemicals across the 25 legislative and strategy documents were reviewed. It can be summarized that each document generally states several mechanisms, with hazard/risk assessments and use restrictions and limitations being the most common. The choice and combination of the mechanisms applied is linked to the purpose and scope of the document. For example, in cases where a release into the environment is not intended, the focus is on mechanisms safeguarding that the risks from releases are controlled (e.g., by use instructions/use limitations). For chemicals where release to the environment is intended or unavoidable, hazard and risk assessment is more in focus (e.g., PPP and biocides). In more recent legislation, including the EU Regulation on Taxonomy for sustainable activities (EU No 2020/852) and the EU directive on corporate sustainability reporting (EU No 2022/2464), monitoring and financial mechanisms are incorporated as part of the EU's sustainable finance initiatives (https://finance.ec.europa.eu/news/sustainable-finance-2025-05-21_en). The latter includes payments, reporting obligations, and due diligence for sustainability and impacts on biodiversity.

Conclusion

In the 25 high-level legislative and strategy documents reviewed, a limited number include definitions for biodiversity, and where it is mentioned, the CBD 1992 definition is generally used.

Metrics for biodiversity are currently variable in availability and application and are often qualitative rather than fully standardized and quantitative. However, they tend to be more clearly defined in regulatory frameworks for chemicals intended for environmental use or with anticipated release (e.g., plant protection and biocidal products), where assessment typically centers on focal species representing potentially affected communities.

Mechanisms for regulation and risk management of chemicals vary depending on the scope. Hazard and risk assessment often forms the basis, followed by obligations for appropriate risk management measures when a risk is indicated or suspected. More recent legislation includes payments, reporting obligations, and due diligence for sustainability and impacts on biodiversity.

While it is acknowledged that downstream guidance documents and national laws for habitat protection include specific details for determining biodiversity and habitat quality, these aspects are not explicitly stated in chemical regulation and risk assessment, and so there is an opportunity for future coordination.

Objective 2: EU-funded research projects relating to biodiversity

Aim

We aimed to overview the recent and ongoing EU-funded research projects related to chemical impact on biodiversity with two objectives: to identify how new scientific knowledge can better inform regulatory frameworks and to highlight future research needs in the field.

Methods

As a first step, we considered which databases to leverage to inform the question about European Commission–funded research projects related to biodiversity and chemicals. We identified the CORDIS database (Community Research and Development Information Service) as the one with the most comprehensive and up-to-date information. The CORDIS database is the European Commission's primary source of results from the projects funded by the EU's framework programs for research and innovation, from Framework Programme 1 to Horizon 2020 (2014–2020) and Horizon Europe (2021–2027). The review thus extracted the information from the CORDIS database (https://cordis.europa.eu/search; data extracted on December 21, 2023). We acknowledge that European Commission–funded research on biodiversity may fall under

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

programs other than these framework programs, and these are not captured in this review.

The objective of the review was to map all potentially relevant projects, and it was set up to be inclusive of all chemical groups, environmental compartments, and species taxa. Keyword searches were performed in the CORDIS standard search interface, which applies terms simultaneously to the project title and objective (abstract) fields as searchable in the CORDIS database. The objective field contains the project summary/abstract as submitted by the project consortium at the time of registration; this field is referred to as "project description" in some CORDIS interface views but corresponds to the "objective" column in the exported data (see online supplementary material Supplemental Information 1 [SI1]). The search was initially tailored to identify projects started since 2017 using the keyword "biodiversity," which resulted in 1,251 projects. These projects were then categorized by their potential to be informative for regulatory frameworks assessing the effects of chemicals on biodiversity as follows:

- Projects considered directly relevant were those whose objective indicated that chemical exposure and biological or ecological outcomes were being studied within an ERA-relevant environmental compartment. EU chemical ERA under key legislative instruments reviewed in Chapter 2—notably, REACH (EC No 1907/2006), the PPP regulation (EC No 1107/2009), and the Biocides Regulation (EU No 528/2012)—is structured around specific environmental compartments: aquatic (freshwater and marine), terrestrial (including soil and agricultural land), and sediment. The keywords set used to identify projects addressing these compartments were therefore "environmental," "ecological systems," "soil (health)," "freshwater," "marine," or "agricultural ecosystems," applied in combination with "biodiversity" and "chemicals." These compartment-based keywords served as a regulatory proxy: projects using this vocabulary in combination with biodiversity and chemicals were considered likely to generate the empirical exposure–effects data most applicable to ERA frameworks. Following keyword prescreening, expert validation confirmed 34 projects (∼3%) as directly relevant.
- Projects considered indirectly or potentially relevant were those whose objective addressed frameworks, concepts, metrics, or policies that could support how ERA for biodiversity is designed or operationalized, such as protection goals, biodiversity indicators, risk management options, or policy instruments, without themselves generating direct chemical–biodiversity effect data. These projects were identified where the objective mentioned "metrics," "indirect effects," "system level," "protection goals," "risk management," or "policies," in the absence of the direct compartment–chemical–biodiversity co-occurrence required for direct relevance. While these keywords can in principle co-occur with those of the directly relevant category, the distinction is one of primary research purpose: directly relevant projects aim to characterize chemical effects on biodiversity empirically; indirectly relevant projects aim to inform the conceptual or policy infrastructure within which such effects would be assessed. In total, 234 projects (∼19%) were identified as indirectly relevant based on these criteria.
- Projects considered not relevant were those whose descriptions mentioned "biodiversity" but, based on the project description, were related to topics such as climate change, astronomy, law, language and literature, history, or clinical medicine. An overall 983 projects (∼78%) were identified as not relevant according to these criteria.

The directly relevant projects were checked for additional available information in the project-related websites. As direct links to project website were available for only a few in the CORDIS database, the project names were entered into a search engine to look for additional details. To evaluate the EU investment into this research area, we searched for the funding information in terms of "EU contribution" to total costs within the CORDIS information. We also added the information on participating institutions in each project.

Outcomes

EU-funded research spending on biodiversity and chemicals increased sharply after 2019, as shown by total and average costs per project (Figure 2; see online supplementary material SI1, columns M–AH of tab "summary 2017-2023_cordis-search"). While not all biodiversity-related research projects focus on chemical exposure or inputs, the impact of chemicals on biodiversity is mentioned in many of them. Of these, 34 projects were identified as directly relevant projects (green highlighted rows in online supplementary material SI1, tab "summary 2017-2023_cordis-search"); however, none focused on developing methodologies or research outputs for direct implementation in chemical regulation to assess impacts on biodiversity.

Instead, they tended to address biodiversity within broader studies of specific habitats (soil, marine, agricultural) or chemical groups (PPPs, pharmaceuticals), often focusing narrowly on individual chemicals or species.

Taxonomic representation was uneven: vertebrates (fish, birds), insects (primarily pollinators), and plants (wild and crop) were prominently represented, while fungi and protists received comparatively less coverage. Determining the precise extent of

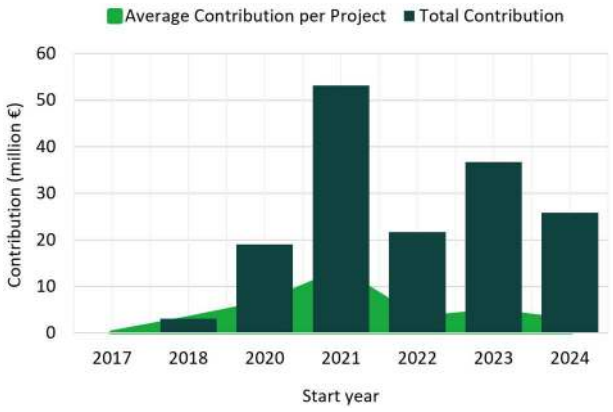

Figure 2 Total and average contribution of European Union funding toward research projects on biodiversity and chemicals, based on data extracted from the CORDIS database, which includes projects under Framework Programme 1, Horizon 2020 (2014–2020), and Horizon Europe (2021–2027).

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

this disparity requires a more thorough database analysis to identify key research gaps. As a result, while most of these projects demonstrated a range of applicable methods, their findings were not always directly actionable for policy makers or regulatory decision making. In more recent projects, researchers have begun examining system- and landscape-level questions more relevant to chemical regulation—for example, the effects of PPPs on nontarget organisms across terrestrial landscapes.

A consistent challenge is represented by the fact that detailed content information on EU-funded projects is difficult to retrieve, consolidate, and analyze due to the absence of a centralized and FAIR data source (i.e., findable, accessible, interoperable, and reusable; GO FAIR 2016, https://www.go-fair.org/fair-principles/). While CORDIS contains substantial information (e.g., involved institutions, funding, timelines), direct links to full proposal texts, current status, and, importantly, outputs and findings are not systematically captured. The platform often lacks direct links to project webpages, and there is limited archiving of past projects.

Conclusion

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Brondízio et al., 2019) and the United Nations Environment Programme identify five key direct drivers of biodiversity loss: land use change, overexploitation of organisms, climate change, pollution (including chemical exposure), and invasive alien species. These drivers rarely act in isolation: the majority of species under threat worldwide face two or more of these pressures simultaneously, and their interactions can be synergistic or antagonistic in ways that single-driver studies cannot detect.

The analysis of EU research activities demonstrates that the need of implementable tools, knowledge, and data regarding the impact of chemicals on biodiversity is not yet clearly reflected in EU-funded research projects. In the context of assessing chemical risks to biodiversity, actionable regulatory recommendations are a crucial factor. A more detailed analysis of this aspect in the projects considered directly relevant could yield valuable input for effective chemical regulation and biodiversity protection.

Given the scale of EU investment in biodiversity-related research, there is a compelling case for conducting meta-analyses across projects to synthesize existing findings, rather than relying on isolated project outputs. Such cross-project meta-analyses could, for the first time, enable quantitative attribution of biodiversity change to individual and combined drivers and reveal where chemical exposure interacts most critically with other pressures. However, our review confirmed that conducting such analyses is currently not feasible in a consistent and systematic way.

The core obstacle is the absence of a centralized and FAIR data source. The CORDIS database provides basic project metadata (institutions, funding, timelines), but full proposals, outputs, and underlying datasets are not systematically captured and archiving of past projects is limited. Under Horizon Europe, open science and FAIR data management are legal obligations, and the Horizon 2020 Guidelines on FAIR Data Management explicitly state, “Good research data management is not a goal in itself, but rather the key conduit leading to knowledge discovery and innovation, and to subsequent data and knowledge integration and reuse” (European Commission, n.d.). Nevertheless, the gap between formal requirements and practical implementation remains substantial. Harmonized data-reporting standards, agreed metadata schemas, and accessible long-term repositories are prerequisites for cross-project synthesis, and these are currently far from consistently applied across EU-funded biodiversity research.

Several opportunities exist to make future research more impactful. Progressive projects that explicitly build on prior work would support more informed regulatory frameworks and enable feedback on their effectiveness. Early collaboration between researchers and regulators is essential to ensure that research addresses genuine policy gaps and that outputs align with decision-making needs. Actionable, standardized, and transparent results increase applicability in regulatory contexts, as does grounding research in real-world evidence, such as integrated biological and chemical monitoring data, with a clear understanding of existing regulatory frameworks. We recommend that future scientific efforts include meta-analyses across projects to consolidate the state of knowledge, identify gaps, and clarify emerging research needs.

Finally, analyzing the cross-links between regional regulatory frameworks and their global implications represents an important additional focus for Horizon Europe projects (European Commission, 2020b). Effectively addressing biodiversity loss requires coordinated global action, and such analysis would help ensure that regulatory interventions do not unintentionally export environmental footprints.

Objective 3: definitions, metrics, and tools for biodiversity in scientific literature

Aim

We evaluated peer-reviewed literature to generate an overview of biodiversity definitions across biomes and the myriad metrics and methods used to assess and quantify biodiversity. The proximate goal of our review is to reveal the landscape of these definitions and metrics, whereas the ultimate goal was to provide a stepping-stone toward consistent frameworks for biodiversity assessment that can be used in legislation. To capture the broadest sweep of information, the primary focus of our search was on review articles, perspectives, and meta-analyses.

Methods

Text-mining analytics were employed to assess the definitions and metrics for biodiversity in academic literature. Of specific interest was how definitions and metrics vary across major biomes, including aquatic and terrestrial (see online supplementary material Table S1 in SI2). For consistency and reproducibility, separate searches were conducted in Google Scholar (on April 18, 2024) for each biome via the following search phrase:

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

[ecosystem] biodiversity review* OR perspective* OR synthesi* OR "meta-analysis" OR "meta analysis" monitor* OR measur*

The term *[ecosystem]* was replaced with a search phrase that included associated habitats for each biome, as well as alternative names for that biome (see online supplementary material Table S1). For example, the grassland biome has several common names across the world; all were included within the search. The time range of the search was limited from 2014 to 2024, and the search was restricted to titles, abstracts, and metadata (e.g., keywords, key highlight statements). The top 100 citations were extracted from the search algorithm. Following the removal of any citations focused only on case studies, most biomes were represented by 30 to 50 articles. The top 25 articles for each biome, in terms of relevance, were then identified. This article selection per biome generally aligned with the top-ranked articles according to number of citations. The 25 articles selected for each biome are provided in online supplementary material SI3 (yellow highlighted rows). Some articles overlapped biomes; a total of 205 articles were identified.

Following selection of articles, the entire corpus of each selected text (i.e., title, abstract, keywords, and body) was downloaded into a single text file for each biome. The *tm* (Feinerer, 2013) and *SnowballC* (Bouchet-Valat, 2020) packages in R were used for stopword removal and stemming, respectively. The JMP statistical software text-mining toolkit was used to identify the relative differences among sets of biome-relevant literature by conducting singular value decomposition across all biomes. For this analysis, the maximum number of words per phrase was set to four, the minimum characters per word were set to two, and terms were weighted by frequency.

The first analysis assessed the association between the biome-specific corpora from the literature and GEOBON's six EBV classes (Balvanera et al., 2022; Pereira et al., 2013), which are a set of descriptors that capture key aspects of biodiversity. The document–term matrix of each biome was mined for keywords associated with each EBV name (i.e., subcategories; see online supplementary material Table S2 in SI2). Because the previous analysis already stemmed every word, stemmed names of each EBV class were also used. The total number of instances for all EBV names was summed within an EBV class.

To identify the dominant types of organisms studied within biomes, additional text-mining analyses for biological keywords associated with EuropaBON's EBVs were conducted (Junker et al., 2023). Whereas GEOBON's EBVs describe ecosystem-agnostic and scalable variables, EuropaBON's EBVs identify target species within marine, terrestrial, or freshwater ecosystems. A similar mining exercise with the document–term matrix was conducted to identify the associations between biome literature and EuropaBON's suggested target species.

All analyses were performed in R Statistical Software (Version 4.5.2; R Core Team, 2018, 2021).

Outcomes

The first three singular vectors of the singular value decomposition analysis accounted for 19.1%, 14.2%, and 11.6% of the total variation (cumulative variation = 44.9%). A *k*-means clustering analysis (in the *stats* R package) with all three vectors indicated that five and six clusters accounted for 87.5% and 94.1% of the variation between the sum of squares, respectively. The only difference in clustering between the five- and six-cluster analyses was the separation of the "urban" biome as an independent cluster in the latter analysis. The five-cluster representation is displayed in Figure 3. Major biome clusters included (a) "grassland" and "forest"; (b) "soil"; (c) "urban," "tundra," and "desert"; (d) "freshwater" and "coral"; and (e) "coastal" and "marine."

The GEOBON EBV class representation for each biome is shown in Figure 4. The most represented EBV class across biomes was "species traits," followed by "ecosystem function." In contrast, EBV classes "community composition" and "ecosystem structure" were the least represented. Representation of individual EBV classes among biomes was not always consistent. Notably, the prevalence of terms related to the "genetic composition" class was lower in strictly terrestrial biomes (i.e., soils/croplands, deserts, forests, and grasslands). The prevalence of terms related to the "ecosystem function" class was lower in tundra, desert, and urban biomes. Terms related to "community composition" were generally lacking except for coral, freshwater, forest, and grassland biomes. Terms related to "ecosystem structure" were present at low levels except in coastal/marine, soil, grassland, and forest biomes.

The frequency of major organism groups in the corpora for each biome, as identified in the EuropaBON EBVs target organisms, is displayed in the form of word clouds in Figure 5 and as percentages of total mentions of organismal keywords in online supplementary material Table S3 in SI2. As indicated by the target species with the highest percentage in each biome, articles discussing terrestrial biomes (i.e., grasslands, forests, croplands, desert, tundra, and urban systems) tended to emphasize "plants," whereas articles discussing aquatic biomes (i.e., freshwater, coral, coastal, and marine system) tended to emphasize "fish." Grassland articles had a secondary focus on "herbivores," whereas desert and tundra articles tended to focus on "mammals," likely reflecting differences in available primary production among biomes. However, there is little focus on either "herbivores" or "mammals" in forest articles, suggesting a possible bias in the choice of organisms studied that does not

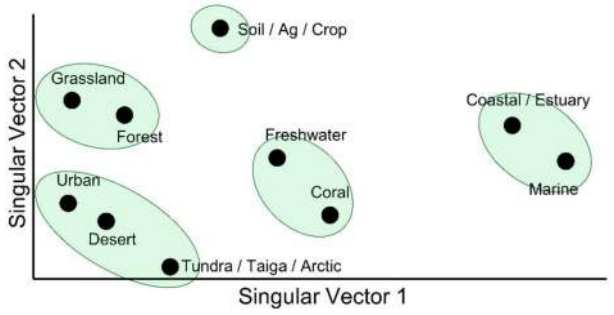

Figure 3 Singular value decomposition (SVD) of document-term matrix associated with the 10 biomes explored in this study. Only SVD 1 and SVD 2 are presented, which account for 33.3% of the total variation. Ellipses represent clusters determined by *k*-means clustering analysis and account for 87.5% of total sum of squares.

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

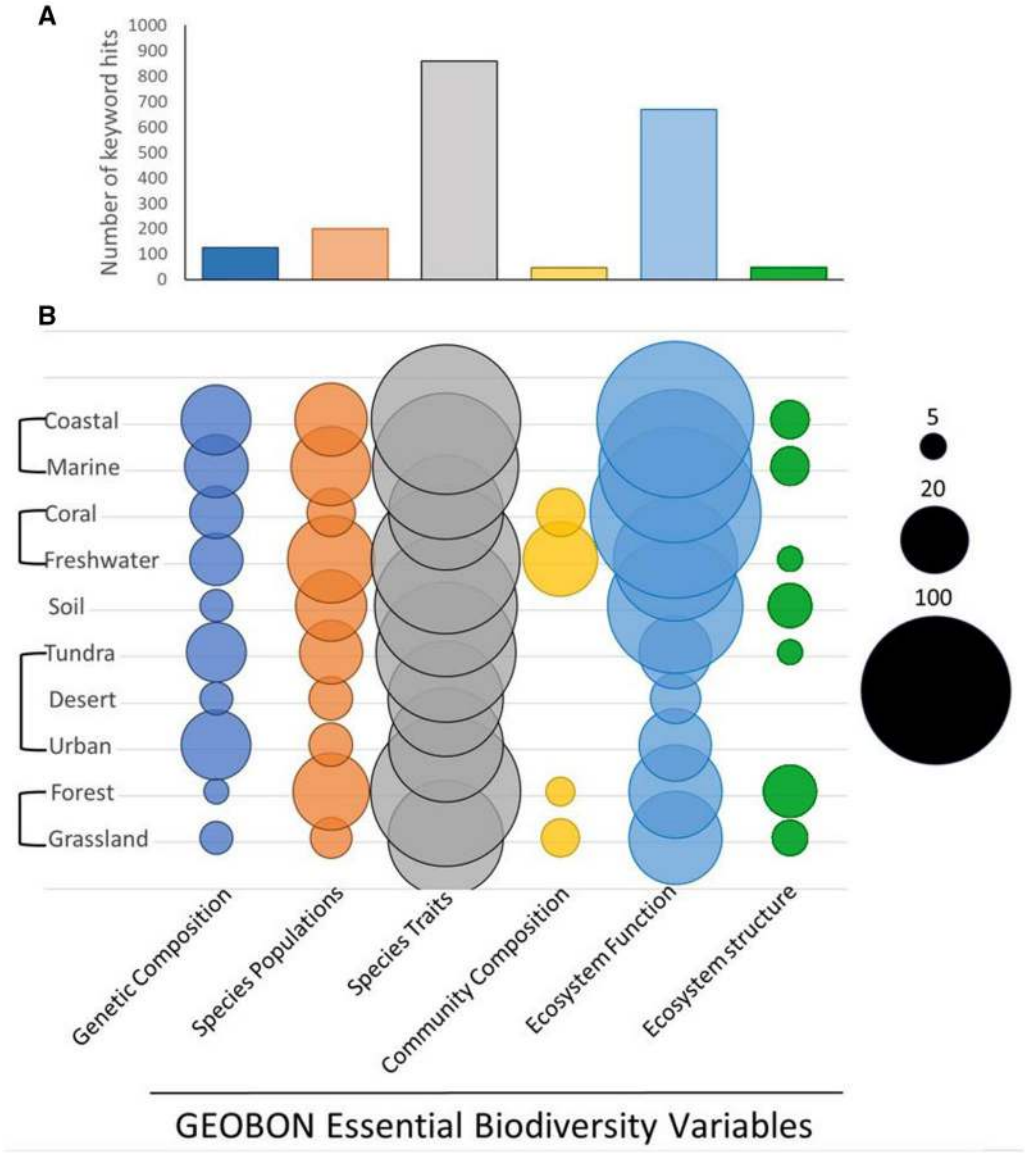

Figure 4 Instances of keywords related to GEOBON's Essential Biodiversity Variables (EBVs) across biomes (A) and within biomes (B). A single instance of a keyword represents a detection of a stemmed word or phrase associated with any EBV subcategory for a given EBV class (see online supplementary material Table S2 in SI2). Brackets next to biomes in panel B represent clusters detected following singular value decomposition (Figure 3). GEOBON = Group on Earth Observations Biodiversity Observation Network.

fully reflect the ecological species present. "Birds" were a secondary focus of several biomes, including forest, desert, tundra, and urban biomes. "Microbes" were also mentioned in cropland research and to a lesser extent in desert research. "Invertebrates" was a secondary focus in tundra and freshwater biomes. "Plankton" was primarily mentioned among marine biome articles, and "algae" was primarily mentioned among freshwater biome articles. Keywords related to "invasive species" were found in every corpus, but articles on freshwater biodiversity had more than double the frequency of mentions than any other biome. Overall, although fungi are a fundamental eukaryotic group, being foundational in forests as decayers of wood, symbionts (mycorrhiza), and pathogens, they are scarcely addressed, indicating a major research gap. Also notably absent were mentions of macroinvertebrates, despite their cosmopolitan role in nearly all ecosystems—terrestrial (e.g., pollinators), freshwater (e.g., detrital grazers), and marine (e.g., crustaceans). In general, the collection of studies in our analysis tended to be underrepresented by research on organisms that have been historically challenging to observe because of their small size (e.g., fungi, plankton) or cryptic habits (e.g., bats).

Conclusion

We found distinct patterns in the discussion of biodiversity definitions, metrics, and methods across biomes. While many ecosystems tended to discuss these topics with similar language, distinct clusters of biomes were also found. The reasons for this

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

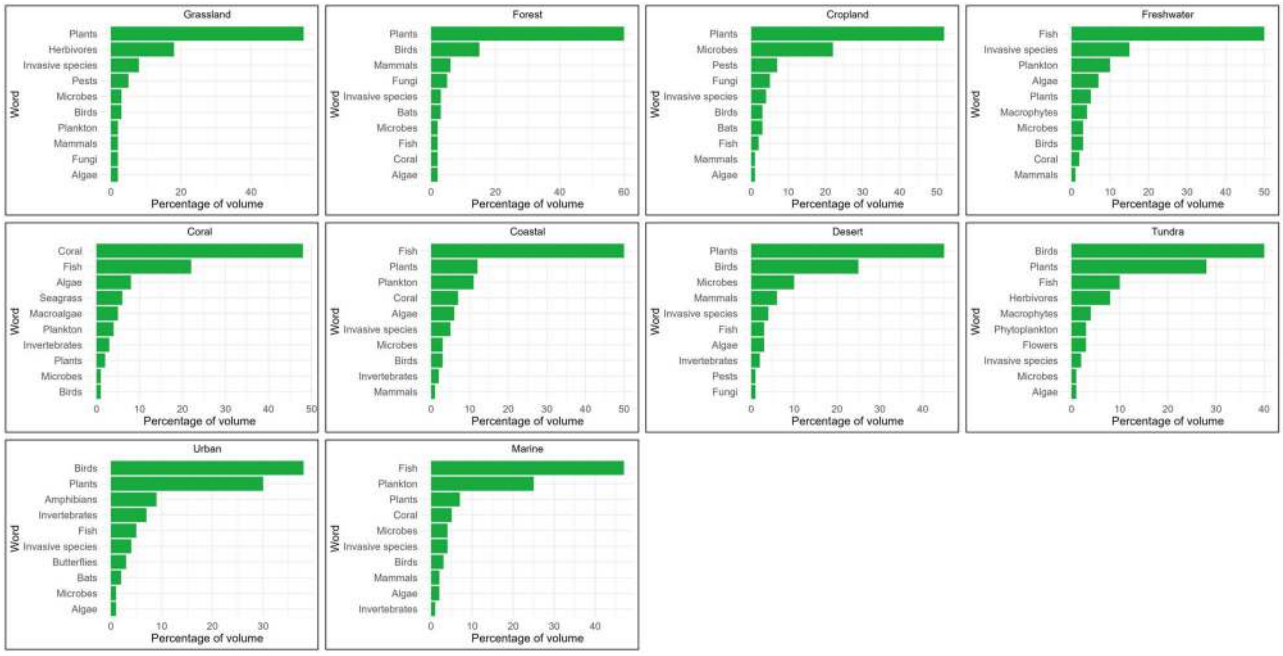

Figure 5 The number of instances (i.e., mentions) that organismal groups appear in the literature for each biome analyzed. Only the top 10 words are shown for each biome. Organismal groups were identified as EuropaBON Essential Biodiversity Variable target species and analyzed in the corpora for each biome.

clustering likely occur due to differences in food web structure between terrestrial and aquatic biomes, species density, variation in the physical nature of the biome (e.g., aquatic vs. terrestrial), and degree of disturbance. We discuss each of these factors in turn.

The absolute density of species often determines the method for describing and enumerating biodiversity. This is exemplified in the distinct clustering of coral and freshwater biomes, apart from marine and coastal biomes. Coral and freshwater systems typically have relatively higher biodiversity per unit area than marine and coastal systems (Miller, 2021). A higher density of all distinct units allows for statistically less variable and more accurate estimations of biodiversity using nearly any method in a shorter timeframe. This also permits temporal and spatial estimates of biodiversity. In contrast, the lower biodiversity per unit area of marine and coastal systems (Wu et al., 2023) necessitates more frequent use of techniques with greater data intensity (Mora et al., 2011), such as eDNA and acoustic monitoring. Moreover, the expense and time intensity of these techniques limit the ability of researchers to gain a more temporal understanding of biodiversity.

Diversity in terrestrial systems is generally higher than in aquatic systems (Mora et al., 2011), but terrestrial and aquatic systems have well-known physical and chemical differences that impart unique ecological patterns (Shurin et al., 2006). Terrestrial ecosystems typically have shorter food chain lengths, lower rates of energy transfer, and a plant-dominated biomass pyramid. In contrast, the smaller size and greater edibility of primary producers in aquatic systems usually lead to an inverse biomass pyramid with the inclusion of secondary predators (Chase, 2000; Shurin et al., 2006). In line with the general perception, the main organisms of aquatic interest in our analysis were fish, whereas the main organisms of terrestrial interest were plants. Given the vastly different logistical challenges associated with measuring and monitoring sedentary plants in contrast to mobile consumers, it is reasonable to expect that research on these systems would be associated with different syntax. In any case, there is a striking imbalance between the key organismic components of the ecosystems studied and those considered in current research efforts.

The distinctiveness of cropland biodiversity research relative to research in all other biomes is likely attributed to intensity of management and disturbance frequency. In general, terrestrial systems are more sensitive to small-scale perturbations than aquatic systems (Carr et al., 2003). Most agricultural ecosystems, by definition, are intensely and frequently disturbed environments that, as a result, continually return to the earliest stages of ecological succession.

Diversity assessments in cropland systems often focus on microorganisms (Figure 5) and associated biodiversity metrics (e.g., operational taxonomic units and functional diversity). This is likely due to the large focus on soil health and its role in productivity. While the importance of microorganisms for agricultural ecosystems has long been recognized, their appreciation in other ecosystems is lower. However, even in agricultural systems, microbial risk assessment remains relatively narrow with a focus on functional assessments. In pesticide risk assessment, a soil nitrogen transformation study is required, reflecting the importance of nitrogen cycling to agriculture. However, broader species–level assessments or other microbial functions are not generally considered.

Overall, our analysis points to real differences in the way that the academic literature defines, identifies, and measures diversity across biomes. The strength of our analysis lies in its ability

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

to agnostically assess diverse literature for trends. This strength is bolstered by limiting our analysis to meta-analyses, reviews, and perspective articles. However, this approach excludes more empirical work that often defines new waves of emerging science and might exclude older literature that is not included in contemporary reviews. According to Chow et al. (2023), 70% of references in the literature are from the past 10 years, and articles in conservation science often have a publication delay of approximately 3 years (Christie et al., 2021). In addition, there is often a substantial lag between research publication and legislative consideration or adoption (Hocherman et al., 2025; Suazo-Galdames et al., 2025). Such lag times are typically the result of fragmented advisory systems and unstructured communication between researchers and policy makers. Such limitations remain an unfortunate yet fundamental part of global communication and activity.

Conclusions and recommendations

By reviewing EU chemical legislation and strategic documents (Objective 1), EU-funded research (Objective 2), and peer-reviewed literature on biodiversity assessment methods and metrics (Objective 3), we aimed to evaluate the current status of biodiversity research and its connection to chemical regulation. This review also sought to identify key needs for advancing the evaluation of chemical impacts on biodiversity and to highlight critical knowledge gaps requiring attention.

Key insights from this review are as follows:

- Current EU chemical legislation considers biodiversity more explicitly when chemicals are intended to be released into the environment. However, definitions of biodiversity within chemical risk assessment and overarching legislation guidance remain mostly qualitative, generally referencing the CBD definition. Downstream documents of legislations (annexes and technical guidance documents), not in scope of this review, may provide examples where attempts have been made to better operationalize definitions.
- EU-funded biodiversity research has increased since 2019, but few projects explicitly address chemical exposure as a driver of biodiversity change, and linkages between research outputs and regulatory frameworks remain weak. The absence of a centralized, FAIR-compliant data platform for EU biodiversity research severely restricts cross-project synthesis and regulatory uptake.
- A wide variety of biodiversity definitions, metrics, and methodologies are currently employed in academic research. Although there are likely explanations for differences among ecosystems, our analysis suggests that a one-size-fits-all approach to biodiversity assessment may not lead to effective and actionable legislation. This will be particularly true when legislation targets physically and biologically different biomes.

This review highlights significant gaps that need to be addressed to strengthen the explicit consideration of biodiversity within chemical regulation. Most notably, limited access to relevant biodiversity research outcomes and the lack of standardized, applicable definitions and metrics for regulatory contexts are major barriers to progress. Critically, these gaps cannot be resolved within individual research projects or a single regulatory review; they require sustained, long-term, multistakeholder engagement and coordinated investment, ideally through dedicated research initiatives driven by the European Commission.

Given these insights, we recommend the following actions:

- Develop operational definitions of biodiversity applicable across chemical regulatory frameworks, compatible with the CBD 1992 definition currently referenced in most EU legislation.
- Identify appropriate biodiversity metrics and indicators—including spatial and temporal scales and relevant entities (e.g., ecosystem services, focal species, and indicator species)—applicable to chemical risk assessment.
- Identify relevant databases, tools, and methodologies, including mechanistic effect modeling and AI approaches, that correspond to these metrics/indicators and can be leveraged to support assessments of potential impacts of chemicals on biodiversity.
- Fill gaps in our knowledge of biodiversity, particularly for organisms that have been historically challenging to quantify (e.g., fungi, invertebrates, and plankton).
- Design research questions that are explicitly multifactorial and systematically capture data on all five drivers for biodiversity decline per the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. This will enable the quantification of the relative contribution of chemicals in context and inform the derivation of impactful regulatory actions.
- Establish a centralized, FAIR-compliant data platform to collate and share EU-funded (biodiversity) research outputs, including underlying datasets, methodological documentation, and project deliverables, enabling cross-project meta-analyses and informing regulatory decision making and research prioritization.
- Match policy objectives against available knowledge and tools and identify knowledge gaps to better direct future research, for example, by evaluating the full hierarchy of regulatory instruments (framing legislation, technical guidance, and member state transpositions) rather than high-level documents alone.

It is noted that biodiversity research is part of the three key priority areas of the new Horizon Europe strategic plan (2025–2027) with 10% of the total Horizon Europe budget dedicated to this topic (https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/strategic-plan_en).

- Explore the alignment and discrepancies between biodiversity definitions and metrics used in chemical regulation and those applied in sustainable finance initiatives.

The breadth of these recommendations underscores the need for continued multistakeholder engagement and a global perspective. Organizations such as SETAC and ECETOC play crucial roles in facilitating this dialogue. Reflecting its mission to develop practical, science-based tools and solutions for advancing chemical safety assessment, ECETOC has identified biodiversity

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

as a priority area. ECETOC organized a multistakeholder workshop on May 4–6, 2026, bringing together >40 experts from industry, regulatory, policy, and academic arenas, to start to advance some of these recommendations. The workshop aimed to do the following: explore available and developing biodiversity definitions, metrics, and methodologies relevant to chemical risk assessment; understand the landscape of biodiversity metrics used in sustainable finance initiatives and their relationship to chemical safety assessment; and align tools and methodologies to achieve the biodiversity policy objectives. A workshop synthesis is being drafted and will be made publicly available.

Supplementary material

Supplementary material is available at *Integrated Environmental Assessment and Management* online.

Author contributions

Anja Gladbach (Conceptualization, Methodology, Writing—original draft, Writing—review & editing), Christoph J. Mayer (Conceptualization, Methodology, Writing—original draft, Writing—review & editing), Aaron Stoler (Conceptualization, Methodology, Writing—original draft, Writing—review & editing), Sian Ellis (Conceptualization, Methodology, Writing—original draft, Writing—review & editing), Marta Baccaro (Conceptualization, Writing—review & editing), David A. Bohan (Conceptualization, Writing—review & editing), Franziska Enzmann (Conceptualization, Writing—review & editing), Emily Garman (Conceptualization, Writing—review & editing), Jutta Hellstern (Conceptualization, Writing—review & editing), Sarah A. Hughes (Conceptualization, Writing—review & editing), Philippe Lemaire (Conceptualization, Writing—review & editing), Jan-Dieter Ludwigs (Conceptualization, Writing—review & editing), Lorraine Maltby (Conceptualization, Writing—review & editing), Anna-Maija Nyman (Conceptualization, Writing—review & editing), Hans Sanderson (Conceptualization, Writing—review & editing), Simran Sandhu (Conceptualization, Writing—review & editing), Marco Thines (Conceptualization, Writing—review & editing), Johannes Tolls (Conceptualization, Writing—review & editing), Lucy Wilmot (Conceptualization, Writing—review & editing), and Nika Galic (Conceptualization, Methodology, Writing—original draft, Writing—review & editing)

Funding

This article relates to work undertaken by the European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) Task Force "assessing risks to biodiversity from exposure to chemicals." ECETOC is a not-for-profit scientific organization that provides a collaborative space for scientists from industry, academia, and regulatory bodies to develop and promote trusted and practical scientific solutions to chemical safety assessments. ECETOC is financed by its membership, which comprises leading companies with interests in the manufacture and use of chemicals, biomaterials, and pharmaceuticals (http://www.ecetoc.org/ecetoc-membership/member-companies/). Task force members do not receive compensation from ECETOC.

Conflicts of interest

ECETOC is a not-for-profit scientific organization that provides a collaborative space for scientists from industry, academia, and regulatory bodies to develop and promote trusted and practical scientific solutions to chemical safety assessments. The 20 participants to the task force comprised 14 from companies that manufacture or use chemicals or are involved in the applied research of their impact on the environment, 3 from academia or research institutes, 2 from a European Union policy support institution and regulatory agency, and 1 from ECETOC. The chemical sectors represented included industrial chemicals, consumer products, and plant protection products. ECETOC Task Force members aim to provide an objective, scientific assessment of the topic. Some members of this task force work for companies that produce chemicals, and assessing the risks of chemicals to biodiversity may affect substances that are of commercial importance to these companies. The potential conflict of interest does not apply to the task force members from academia and regulatory bodies. This article was subjected to internal peer review from participating companies/organizations, as needed, and only minimal changes were requested. This article was also reviewed by the ECETOC Scientific Committee, consisting of representatives of academia and industry (http://www.ecetoc.org/about-ecetoc/scientific-committee/). This review yielded very few and only minor comments.

Disclaimer

This work was conducted as part of the ECETOC Task Force "assessing risks to biodiversity from exposure to chemicals." The authors of this article consist of ECETOC Task Force members (comprising members from industry, academia, and regulatory bodies) and stewards from the ECETOC Scientific Committee. The views expressed in this article are solely those of the authors and may not represent those of their organizations.

Acknowledgments

We thank the ECETOC Scientific Committee for its critical comments and valuable feedback during the preparation of this article. We thank the ECETOC Secretariat for organizational and technical assistance to the task force. We also thank the three reviewers selected by the editor, who were anonymous to the authors. The comprehensive and helpful comments served to improve the article.

Data availability statement

There are no new data associated with this article.

References

Axelman, J., Aldrich, A., Duquesne, S., Backhaus, T., Brendel, S., Focks, A., Holz, S., Knillmann, S., Pieper, S., Silva, E., Schmied-Tobies, M., Topping, C. J., Wipfler, L., Williams, J., & Sousa, J. P. (2024). A systems-based analysis to rethink the European

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

environmental risk assessment of regulated chemicals using pesticides as a pilot case. *The Science of the Total Environment*, *948*, 174526. https://doi.org/10.1016/j.scitotenv.2024.174526

Baccaro, M., Focks, A., Worth, A., Chinchio, E., Dubois, G., Robuchon, M., Carletti, A., Bernasconi, C., & Bopp, S. (2025). *Protection of biodiversity as the ultimate goal of environmental safety assessment: How does chemical pollution affect biodiversity*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/1215173

Balvanera, P., Brauman, K., Cord, A., Drakou, E., Geijzendorffer, I. R., Karp, D., Martín-López, B., Mwampamba, T., & Schröter, M. (2022). Essential ecosystem service variables for monitoring progress towards sustainability. *Current Opinion in Environmental Sustainability*, *54*, 101152. https://doi.org/10.1016/j.cosust.2022.101152

Batteries: European Parliament & Council of the European Union. (2023). Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC. *Official Journal of the European Union*, *L 191*, 1–117. https://eur-lex.europa.eu/eli/reg/2023/1542/oj

Biodiversity: Convention on Biological Diversity. (2022). Kunming-*Montreal Global Biodiversity Framework*. https://www.cbd.int/gbf

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

Bouchet-Valat, M. (2020). *Package SnowballC: R package* (Version 0.7.0). R Project.

Brondízio E. S.,, Settele J.,, Díaz S., & Ngo, H. T. (Eds.). (2019). *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat.

Brühl, C. A., & Zaller, J. G. (2019). Biodiversity decline as a consequence of an inappropriate environmental risk assessment of pesticides. *Frontiers in Environmental Science*, *7*, 177. https://doi.org/10.3389/fenvs.2019.00177

Carr, M., Neigel, J., Estes, J., Andelman, S., Warner, R., & Largier, J. (2003). Comparing marine and terrestrial ecosystems: Implications for the design of coastal marine reserves. *Ecological Applications*, *13*, 90–107. https://doi.org/10.1890/1051-0761(2003)013[0090:CMATEI(2003)013[0090:CMATEI]2.0.CO;2

Chase, J. (2000). Are there real differences among aquatic and terrestrial food webs? *Trends in Ecology & Evolution*, *15*, 408–412. https://doi.org/10.1016/s0169-5347(00)01942-x

Chow, N. L. Y., Tateishi, N., Goldhar, A., Zaheer, R., Redelmeier, D. A., Cheung, A. H., Schaffer, A., & Sinyor, M. (2023, May 22). Does knowledge have a half-life? An observational study analyzing the use of older citations in medical and scientific publications. *BMJ Open*, *13*, e072374. https://doi.org/10.1136/bmjopen-2023-072374

Christie, A. P., White, T. B., Martin, P. A., Petrovan, S. O., Bladon, A. J., Bowkett, A. E., Littlewood, N. A., Mupepele, A. C., Rocha, R., Sainsbury, K. A., Smith, R. K., Taylor, N. G., & Sutherland, W. J. (2021). Reducing publication delay to improve the efficiency and impact of conservation science. *PeerJ*, *9*, e12245. https://doi.org/10.7717/peerj.12245

Circular Economy: European Commission. (2020). A new Circular Economy Action Plan: For a cleaner and more competitive Europe (COM(2020) 98 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098

Commonagricultural: Directorate-General for Agriculture and Rural Development. (2012). *The Common Agricultural Policy: A partnership between Europe andfarmers*. Publications Office of the European Union. https://doi.org/10.2762/46630

Convention on Biological Diversity. (2022). *Decision adopted by the conference of the parties to the Convention on Biological Diversity (CBD): 15/4 Kunming-Montreal Global Biodiversity Framework* (CBD/COP/15/L.25). https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Deforestation: European Parliament & Council of the European Union. (2023). Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010. *Official Journal of the European Union*, *L 150*, 206–247. https://eur-lex.europa.eu/eli/reg/2023/1115/oj

Dornelas, M., Chase, J. M., Gotelli, N. J., Magurran, A. E., McGill, B. J., Antão, L. H., Blowes, S. A., Daskalova, G. N., Leung, B., Martins, I. S., Moyes, F., Myers-Smith, I. H., Thomas, C. D., & Vellend, M. (2023). Looking back on biodiversity change: Lessons for the road ahead. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *378*, 20220199. https://doi.org/10.1098/rstb.2022.0199

EFSA Scientific Committee. (2016). Guidance to develop specific protection goals options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services. *EFSA Journal*, *14*, 4499. https://doi.org/10.2903/j.efsa.2016.4499

European Commission. (n.d.). Cross-cutting issues: Data management. In *Horizon 2020 online manual*. https://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/open-access-data-management/data-management_en.htm#:~:text=This%20document%20helps%20Horizon%202020%20beneficiaries%20make%20their,reusable%20%28FAIR%29%20to%20ensure%20it%20is%20soundly%20m
anaged

European Commission. (2020a). *Communication from the commission to the European Parliament, 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).

European Commission. (2020b). *Communication from the commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions: EU biodiversity strategy for 2030. Bringing nature back into our lives*. (COM[2020] 380).

European Commission. (2020c). *Communication from the commission to the European Parliament, the council, the European Economic and Social Committee and the Committee of the Regions: A farm to fork strategy for a fair, healthy and environmentally-friendly food system*. (COM/2020/381).

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

European Commission. (2021). *Communication from the commission to the European Parliament, 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).

European Commission. (2024a). *One Health governance in the European Union*. https://data.europa.eu/doi/10.2777/8697309

European Commission. (2024b, March). *Strategic plan: What Horizon Europe's strategic plan is and how it is developed*. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/strategic-plan_en

European Food Safety Authority; A., Aagaard, P., Berny, P.-F., Chaton, A. L., Antia, E., McVey, M., Arena, G., Fait, A., Ippolito, A., Linguadoca, R., Sharp, A., Theobald, & T., Brock (2023). Risk assessment for birds and mammals. *EFSA Journal 21*, e07790. https://doi.org/10.2903/j.efsa.2023.7790

European Food Safety Authority; P., Adriaanse, G., Arts, S. B., Lassen, P.-F., Chaton, M., Fuerst, B., Ingels, S., Pieper, M., Rundlof, J. P., Sousa, R., Van Eekelen, M., Arena, G., Fait, A., Ippolito, L., Padovani, R., Sharp, & D., Auteri (2025). Analysis of the evidence to support the definition of specific protection goals for terrestrial organisms—Part 1: Proposed strategy. *EFSA Journal*, *23*, e9501. https://doi.org/10.2903/j.efsa.2025.9501

European Parliament and Council. (2006a). Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. *Official Journal of the European Union*, *L309* 1–588.

European Parliament and Council. (2006b). Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. *Official Journal of the European Union*, *L396*, 1–849.

European Parliament and Council. (2022). Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. *Official Journal of the European Union*, *L 322/15*, 15–80.

Feinerer, I. (2013). *Introduction to the tm Package Text Mining in R*. http://cran.r-project.org/web/packages/tm/vignettes/tm.pdf

Forbes, V. E., & Galic, N. (2016). Next-generation ecological risk assessment: Predicting risk from molecular initiation to ecosystem service delivery. *Environment International*, *91*, 215–219. https://doi.org/10.1016/j.envint.2016.03.002

German Supply Chain: Federal Republic of Germany. (2021). Gesetz über die unternehmerischen Sorgfaltspflichten in Lieferketten (Lieferkettensorgfaltspflichtengesetz – LkSG). *Bundesgesetzblatt, Part I*, 2959–2969. https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl121s2959.pdf

Fork: European Commission. (2020). A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system (COM(2020) 381 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

GO FAIR. (2016, March). *FAIR principles*. https://www.go-fair.org/fair-principles/

Green Deal: European Commission. (2019). The European Green Deal (COM(2019) 640 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

Groh, K., Vom Berg, C., Schirmer, K., & Tlili, A. (2022). Anthropogenic chemicals as underestimated drivers of biodiversity loss: Scientific and societal implications. *Environmental Science & Technology*, *56*, 707–710. https://doi.org/10.1021/acs.est.1c08399

Hocherman, T., Trop, T., & Ghermandi, A. (2025). Time lags in environmental governance: A critical review. *Ambio*, *54*, 2042–2059. https://doi.org/10.1007/s13280-025-02211-y

Hoeks, S., M. A., Huijbregts, M., Douziech, A. J., Hendriks, & Oldenkamp, R. (2020). Mean species abundance as a measure of ecotoxicological risk. *Environmental Toxicology and Chemistry*, *39*, 2304–2313. https://doi.org/10.1002/etc.4850 32786097

Industrial Emmissions: European Parliament & Council of the European Union. (2010). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). *Official Journal of the European Union*, *L 334*, 17–119. https://eur-lex.europa.eu/eli/dir/2010/75/oj

Junker, J., Beja, P., Brotons, L., Fernández, M., Fernández, N., Kissling, W., Lumbierres, M., Solheim, A., Maes, J., Morán-Ordóñez, A., Moreira, F., Musche, M., Santana, J., Valdez, J., & Pereira, H. (2023). *D4.1: Revised list and specifications of EBVs and EESVs for a European wide biodiversity observation network*. https://doi.org/10.3897/arphapreprints.e102530

Maltby, L., Brown, R., Faber, J. H., Galic, N., Van den Brink, P. J., Warwick, O., & Marshall, S. (2021). Assessing chemical risk within an ecosystem services framework: Implementation and added value. *The Science of the Total Environment*, *791*, 148631. https://doi.org/10.1016/j.scitotenv.2021.148631

Miller, E. C. (2021). Comparing diversification rates in lakes, rivers, and the sea. *Evolution: International Journal of Organic Evolution*, *75*, 2055–2073. https://doi.org/10.1111/evo.14295

Mora, C., Tittensor, D., Adl, S., Simpson, A., & Worm, B. (2011). How many species are there on earth and in the ocean? *PLoS Biology*, *9*, e1001127. https://doi.org/10.1371/journal.pbio.1001127

Pereira, H. M., Ferrier, S., Walters, M., Geller, G. N., Jongman, R. H. G., Scholes, R. J., Bruford, M. W., Brummitt, N., Butchart, S. H. M., Cardoso, A. C., Coops, N. C., Dulloo, E., Faith, D. P., Freyhof, J., Gregory, R. D., Heip, C., Höft, R., Hurtt, G., Jetz, W., … Wegmann, M. (2013). Essential biodiversity variables. *Science*, *339*, 277–278. https://doi.org/10.1126/science.1229931

Pollinators: European Commission. (2018). EU Pollinators Initiative (COM(2018) 395 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0395

Posthuma, L., D., de Zwart, & Dyer, S. D. (2019). Chemical mixtures affect freshwater species assemblages: From problems

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

to solutions. *Current Opinion in Environmental Science & Health*, *11*, 78–89. https://doi.org/10.1016/j.coesh.2019.09.002

R Core Team. (2018). *Package stats: The R stats package.*

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Semenchuk, P., Plutzar, C., Kastner, T., Matej, S., Bidoglio, G., Erb, K.-H., Essl, F., Haberl, H., Wessely, J., Krausmann, F., & Dullinger, S. (2022). Relative effects of land conversion and land-use intensity on terrestrial vertebrate diversity. *Nature Communications*, *13*, 615. https://doi.org/10.1038/s41467-022-28245-4

Shurin, J. B., Gruner, D. S., & Hillebrand, H. (2006). All wet or dried up? Real differences between aquatic and terrestrial food webs. *Proceedings: Biological Sciences*, *273*, 1–9. https://doi.org/10.1098/rspb.2005.3377

Suazo-Galdames, I. C., Saracostti, M., & Chaple-Gil, A. M. (2025). Scientific evidence and public policy: A systematic review of barriers and enablers for evidence-informed decision-making. *Frontiers in Communication*, *10*, 1632305. https://doi.org/10.3389/fcomm.2025.1632305

SustainableUse: European Parliament & Council of the European Union. (2009). Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. *Official Journal of the European Union*, *L 309*, 71–86. https://eur-lex.europa.eu/eli/dir/2009/128/oj

Chemicals Strategy for Sustainability 2020: European Commission. (2020). Chemicals Strategy for Sustainability: Towards a toxic-free environment (COM(2020) 667 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0667

Tilman, D., Clark, M., Williams, D. R., Kimmel, K., Polasky, S., & Packer, C. (2017). Future threats to biodiversity and pathways to their prevention. *Nature*, *546*, 73–81. https://doi.org/10.1038/nature22900

Topping, C. J., Aldrich, A., & Berny, P. (2020). Overhaul environmental risk assessment for pesticides. *Science*, *367*, 360–363. https://doi.org/10.1126/science.aay1144

Wu, N., Zhang, M., Qu, X., & Martinez-Capel, F. (2023). 02/06) Editorial: Biodiversity conservation and ecological function restoration in freshwater ecosystems. *Frontiers in Ecology and Evolution*, *11*, 1137985. https://doi.org/10.3389/fevo.2023.1137985

Zero Pollution: European Commission. (2021). 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:52021DC0400

Downloaded from academic.oup.com/ieam/advance-article/doi/10.1093/inteam/vjag145/8771054 by guest on 26 November 2026

© The Author(s) 2026. Published by Oxford University Press on behalf of the Society of Environmental Toxicology and Chemistry.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.
Integrated Environmental Assessment and Management, 2026, 00, 1–15
https://doi.org/10.1093/inteam/vjag145
Workshop Synthesis