Matière à débattre & décider

Impacts of plant protection products on biodiversity and ecosystem services

S. Leenhardt, L. Mamy, S. Pesce, W. Sanchez, eds

éditions Quæ

Impacts of plant protection products on biodiversity and ecosystem services

Sophie Leenhardt, Laure Mamy, Stéphane Pesce,
Wilfried Sanchez, editors

Éditions Quæ

The publication of this book received financial support from the French Biodiversity Agency (AFB), now the French Office for Biodiversity (OFB) as manager of the funds of the Ecophyto II national action plan (AFB/2019-327 agreement).

This book is a synthesis of a collective scientific assessment (CSA) requested jointly by the Ministries of Ecology, Agriculture and Research. It was produced by a group of scientific experts without prior approval by either the sponsors, INRAE or Ifremer. The present summary, taken from the extended report, is the sole responsibility of its authors.

The documents associated with this assessment are available on the websites of INRAE (www.inrae.fr) and Ifremer (www.ifremer.fr).

This document is the condensed version of the extended report, authored by the expert committee, *ad hoc* contributors requested by the experts, and DEPE contributors, as listed in the reference below:

Laure Mamy (coord.), Stéphane Pesce (coord.), Wilfried Sanchez (coord.), Marcel Amichot, Joan Artigas, Stéphanie Aviron, Carole Barthélémy, Rémy Beaudouin, Carole Bedos, Annette Bérard, Philippe Berny, Cédric Bertrand, Colette Bertrand, Stéphane Betoulle, Eve Bureau-Point, Sandrine Charles, Arnaud Chaumot, Bruno Chauvel, Michael Coeurdassier, Marie-France Corio-Costet, Marie-Agnès Coutellec, Olivier Crouzet, Isabelle Doussan, Jean-Paul Douzals, Juliette Faburé, Clémentine Fritsch, Nicola Gallai, Patrice Gonzalez, Véronique Gouy, Mickael Hedde, Alexandra Langlais, Fabrice Le Bellec, Christophe Leboulanger, Christelle Margoum, Fabrice Martin-Laurent, Rémi Mongruel, Soizic Morin, Christian Mougin, Dominique Munaron, Sylvie Nélieu, Céline Pelosi, Magali Rault, Nicolas Ris, Sergi Sabater, Sabine Stachowski-Haberkorn, Elliott Sucré, Marielle Thomas, Julien Tournebize, Anne-Laure Achard, Morgane Le Gall, Sophie Le Perchec, Estelle Delebarre, Floriane Larras, Sophie Leenhardt (coord.) (2022). *Impacts des produits phytopharmaceutiques sur la biodiversité et les services écosystémiques.* Rapport d'ESCo, INRAE-Ifremer (France), 1,408 pages. https://dx.doi.org/10.17180/ogp2-cd65

To cite this publication:

Leenhardt S., Mamy L., Pesce S., Sanchez W., 2023. *Impacts of plant protection products on biodiversity and ecosystem services*, Versailles, Éditions Quæ, 174 p.

ISBN paper: 978-2-7592-3748-7
ISBN pdf: 978-2-7592-3749-4
ISBN ePub: 978-2-7592-3750-0
ISSN: 2115-1229

Éditions Quæ
RD 10
78026 Versailles Cedex
www.quae.com
www.quae-open.com

Contents

Forword

As part of the Ecophyto II+ plan, various expert studies have been conducted in a complementary manner. In June 2021, the French National Institute for Health and Medical Research (Inserm) presented the results of a collective scientific assessment (CSA) on the effects of plant protection products (PPPs) on human health, entitled 'Effects of Pesticides and Health - New Data'. The CSA presented here focuses on the impacts of PPPs on biodiversity and ecosystem services. Another CSA, delivered on 20 October 2022, examines the use of plant diversity in agricultural areas to regulate crop pests.

Requested in March 2020 by the Ministries of the Environment, Agriculture and Research, the present CSA was assigned to INRAE and Ifremer. It updates and supplements previous studies published in 2005 (*Pesticides, agriculture et environnement*) and in 2008 (*Agriculture et biodiversité*).

The results are published on the INRAE and Ifremer websites in three formats. The full 1,408-page extended report provides the background and context of the assessment, describes the method used, contains the full bibliography (more than 4,500 references), provides the scientific framework specific to this CSA, includes all of the analyses conducted by its experts, and presents the general conclusions drawn from them. The summary, which is also the subject of this book, brings together the main findings of the CSA extended report, without citing the entire body of literature used. In this document, references are only cited when the data or examples mentioned are taken directly from a publication. The 14-page summary presents the main conclusions drawn from this collective assessment.

Introduction

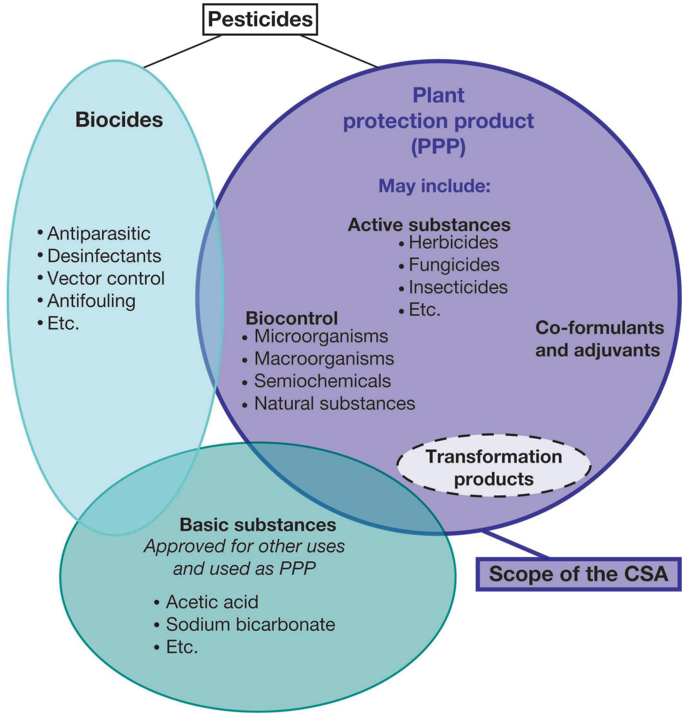
Each year, between 55,000 and 70,000 tonnes of plant protection product (PPP) active ingredients, including those that can be used in organic farming and biocontrol, are sold in France and its overseas territories[1]. These substances are mainly intended for crop protection, with an estimated 2-5% of the total used for non-agricultural practices (i.e. maintenance of gardens, green spaces and infrastructures). They are used in the composition of commercial products incorporating co-formulants that may be associated with adjuvant. After use, they may undergo various biotic and abiotic degradation processes leading to the appearance of transformation products. Crop protection is largely based on synthetic organic molecules and mineral substances, but it can also use biocontrol products, i.e. natural substances from plants, animals or minerals, microorganisms, macroorganisms and semiochemicals (e.g. pheromones, kairomones) that contribute to the control of populations of target organisms. All substances and organisms used for crop protection and maintenance of non-agricultural areas, as well as their co-formulants and adjuvants, are included here under the term ‘plant protection products’ (PPPs). PPP transformation products are also considered. Although the term 'pesticides' is more widely used in everyday language, PPP has been chosen here to more precisely define the scope of the collective scientific assessment (CSA). This is consistent with the vocabulary used in regulatory documents to distinguish, from pesticides, all biocides used for various purposes, and PPPs used for crop protection or the maintenance of non-agricultural areas (Figure 1). Therefore, the use is what characterises a PPP in relation to other regulatory categories.

PPPs are designed to be used directly in the environment, on surfaces that can range from a few dozen square metres to several hundred hectares for a single application. In France, they can potentially cover around 20 million hectares for agricultural treatments[2], and between 3 and 4 million hectares for non-agricultural areas (Ballet, 2021)[3]. Their use is designed to target organisms that cause damage to crops and beneficial organisms, but they can also cause unintended effects. These include direct effects on the physiology of non-target organisms exposed to PPPs, depending on the environmental fate of these products, as well as indirect effects. The stress on directly impacted organisms has repercussions on the ecological dynamics in which they play roles. This large-scale use, within areas integrated into ecosystems, of molecules intended to eliminate certain

1. Source: Ecophyto monitoring notes: https://agriculture.gouv.fr/le-plan-ecophyto-quest-ce-que-cest. Only those French overseas territories falling within the scope of the diffuse pollution fee are included here: Guadeloupe, Martinique, French Guiana, and Réunion.
2. Source: Agreste Statistique agricole annuelle 2020: usable agricultural area (SAU) 28 Mha; surface area under grass (STH) 8 Mha. https://agreste.agriculture.gouv.fr/agreste-web/disaron/SAANR_1/detail/ (accessed 9/01/2023).
3. Teruti survey: stabilised permeable artificial soils (railways, forest tracks, non-agricultural roads, landfills) and other permeable artificial soils (lawns, gardens, parks, roadsides), i.e. about two thirds of the 5 Mha of artificialised land.

organisms considered harmful naturally raises the question of the consequences of their application on biodiversity.

Figure 1. Range of substances considered (adapted from Pesce *et al.*, 2023a)



Today's taxonomic and functional biodiversity is the result of evolution. This precious heritage should be preserved first and foremost for its own sake, which does not preclude the use of the resources it offers, but it should be used sustainably and for the common good, as promoted by the International Union for Conservation of Nature (IUCN). It is essential for life and a source of resilience in the context of global changes induced by human activities. In particular, it can help to regulate and limit the imbalances and some of the effects resulting from these global changes. At the same time, these same global changes, through displacement of species' ranges, increases in the amplitude and frequency of extreme events, and changes in the physico-chemical conditions prevailing in the various environments, are weakening biodiversity. When the magnitude of change exceeds the capacity of living organisms to adapt, species disappear or decline, sometimes to the benefit of other species that may become invasive. Habitats and ecosystems are then more or less profoundly modified, as are the associated ecological processes.

Changes in biodiversity under the influence of now clearly identified pressures have been noticeable for many decades. According to the IUCN, 22.7% of the 15,060 European species that have been assessed are threatened with extinction[4]. However, these changes show varying and sometimes contrasting trends depending on the timeframe, geographical areas, species and habitats considered, which makes their characterisation complex. These contrasting trends are evidence of the diverse processes of resilience, adaptation and weakening that coexist. However, it is now clearly established that the erosion of biodiversity is the dominant global trend and that it compromises the capacity of ecosystems to adapt to global change.

The use of PPPs contributes to this dynamic in a paradoxical manner. Although their purpose is to protect crops against species considered harmful, they also contribute to increasing the vulnerability of production by abandoning preventive strategies and/or by stimulating the appearance of harmful species resistant to the PPPs applied, and/or by altering the natural regulatory processes favourable to crops.

Moreover, PPP contamination occurs in addition to that from other chemical substances and other types of pressure, including, for example, the permanent destruction of ecological habitats due to increased urbanisation and the intensification of agricultural and forestry crops. The pressures on biodiversity are therefore multiple and vary greatly depending on the context, including with regard to PPPs. The specific impacts of a substance for a given use on biodiversity as a whole is therefore very difficult to measure quantitatively. However, this question is important from a regulatory perspective for the marketing of products, which can only be marketed if they "have no harmful effects on human or animal health and no unacceptable effects on the environment" (European Commission, 2009b). In the light of this regulatory requirement, numerous alerts have been issued, leading to specific initiatives of various kinds. At the French level, some of these include the National Chlordecone Plan (since 2009), the Glyphosate Exit Plan (2019), the National Strategy on Endocrine Disruptors (since 2014), the referral to the French Agency for Food, Environmental and Occupational Health and Safety (Anses) of SDHIs (succinate dehydrogenase inhibitor fungicides) in 2019, the National Biocontrol Deployment Strategy (2020), and the ban followed by reauthorisation of neonicotinoid insecticides (2021 and 2022). The regulatory assessment of the risk of PPPs to biodiversity is thus subject to conflicting criticisms. On the one hand, it is denounced by some stakeholders as imposing too many constraints on the authorisation and use of PPPs and, on the other hand, it is criticised by others as insufficiently protective of human health and the environment.

Context

In light of the evidence of the impact of PPPs on the environment (Aubertot *et al.*, 2005b), the first Ecophyto plan was set up in 2008, in conjunction with the adoption by the

4. https://www.iucnredlist.org/regions/europe (accessed 9/01/2023).

European Union in 2009 of the Pesticides Package, which is a set of directives and regulations governing the use of PPPs. This public policy framework for PPPs has various components: objectives and action plans for reducing PPP use, rules for assessing and placing PPPs on the market, and mechanisms for monitoring environmental contamination and the resulting unintended effects.

Since 2008, successive versions of the Ecophyto plan have reaffirmed the objective of drastically reducing the use of PPPs and the associated risks. However, the means employed and the actions deployed to this end have not achieved the objectives set, as highlighted in 2019 by the French Court of Auditors[5].

With regard to the evaluation of products before they are placed on the market, the Pesticides Package and the Ecophyto plan have led to the development of risk indicators, including the specific monitoring of sales of substances considered to be of greatest concern. A campaign to re-evaluate these substances has been initiated, with a view to reducing the range of authorisations and considering their replacement by less dangerous substances. Significant scientific activity has been conducted at EFSA (European Food Safety Authority) at the European level, as well as at Anses at the national level, to improve the methodological framework of the risk assessment process. A revision of the more general framework of this assessment also came into force at the Community level in 2021 following the 2017 citizens' initiative on glyphosate. This includes improvements to transparency (accessibility of studies and data used by the applicant, confidentiality rules, etc.), the opening of EFSA's governance to Member States, parliamentarians and community representatives, and the introduction of a coordinated risk communication plan. These developments have led to the non-renewal or withdrawal of approval for certain substances or uses, while new chemicals have been placed on the market, particularly in the area of biocontrol.

In terms of environmental monitoring, the inclusion of PPPs in monitoring programmes has been progressively strengthened across the various environmental matrices and environments, in line with regulations dedicated to the protection of environments and biodiversity[6].

Request for assessment

In this context, axis 2 (research and innovation) of the Ecophyto II+ plan, through its Scientific Steering Committee on ‘Research and Innovation’ (CSO R&I), proposed in 2019 that a scientific assessment be conducted on ‘the effects on biodiversity and alternatives to plant protection products’[7], as a complement to that of Inserm on the effects on human health (Inserm, 2021). On this basis, the Ministries of the Environment, Agriculture

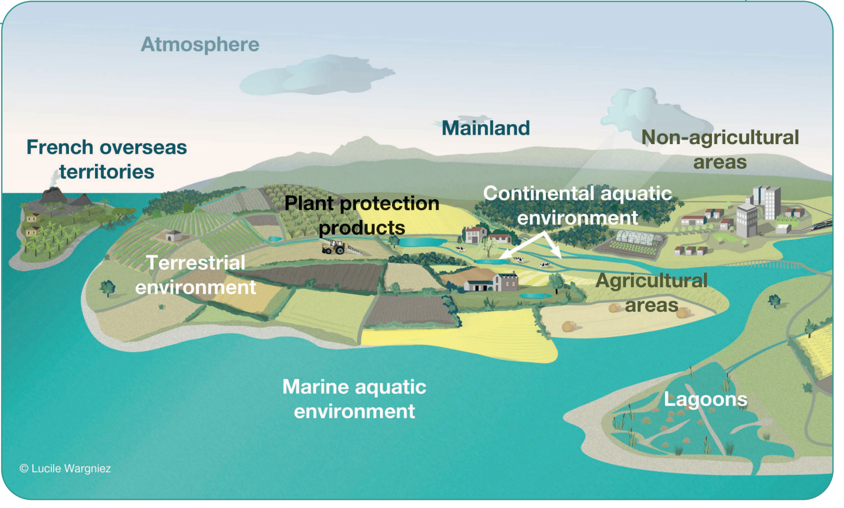
5. Cour des comptes, 2019. Le bilan des plans Écophyto. Référé n° 22109-2659. https://www.ccomptes.fr/system/files/2020-01/20200204-refere-S2019-2659-bilan-plans-ecophyto.pdf (accessed 9/01/2023).
6. WFD (Water Framework Directive); Habitats Direstive (Directive on the conservation of natural habitats and of wild fauna and flora); Directive on the conservation of wild birds, MSFD (Marine Strategy Framework Directive).
7. https://agriculture.gouv.fr/le-plan-ecophyto-quest-ce-que-cest (accessed 9/01/2023).

and Research commissioned two parallel CSAs, one on the impact of PPPs on biodiversity and ecosystem services, and the other on the use of diverse plant cover to regulate pests and protect crops. With regard to the prospects for reducing the use of PPPs, the priority research programme (PPR) *'Cultiver et protéger autrement'* (Growing and Protecting Crops Differently)[8] was also initiated in 2019; its direction is based in part on the foresight study '*Agriculture européenne sans pesticides*' (Pathways to European Pesticide-free Agriculture)[9], coordinated by INRAE. Finally, this assessment echoes the '*Océan et climat*' (Oceans & Climate) PPR, coordinated since 2021 by Ifremer and the CNRS. One of its themes involves the development of knowledge on the contamination of the marine environment and the effects of this contamination on marine organisms and associated ecosystem services, in order to propose solutions for a clean, healthy, safe and resilient ocean.

This CSA, on the impacts of PPPs on biodiversity and ecosystem services, also follows on from the 2005 CSA '*Pesticides, agriculture et environnement*' (Pesticides, agriculture and the environment)[10], which showed that the common use of these substances was leading to environmental degradation and that it was therefore necessary to reduce it. Subsequently, the 2008 CSA *'Agriculture et biodiversité'* (Agriculture and Biodiversity) and the 2017 EFESE study *'l'Evaluation française des écosystèmes et des services écosystémiques'* (French Evaluation of Ecosystems and Ecosystem Services), and in particular its *Assessing Agricultural Ecosystem Services for Better Management* component, demonstrated the complexity of the interrelations between crop protection and biodiversity. Indeed, biodiversity provides essential resources for crops, but it also includes species that are considered harmful to them. Conversely, crop protection treatments targeted at some species have effects on many others, with implications for ecosystem functions and services well beyond the treatment area due to the different modes of transfer of PPPs and their effects. Since the 2005 CSA, crop protection and non-agricultural area management tools have evolved, notably with the banning of certain substances or uses, the introduction of new families of chemicals, and the increasing use of biocontrol treatments. The available data on product use, associated ecotoxicological risks and the state of the environment has also evolved. In particular, the importance of the direct and indirect impacts of PPP use on the functioning of ecosystems is increasingly recognised. In this respect, and given the contextual changes outlined above, a more holistic approach to biodiversity and ecosystem services has been favoured, with a focus on continuums and interdependencies between environments, from the PPP application site to the marine environment. INRAE and Ifremer were therefore jointly tasked with implementing this assessment, given that it consids the entire land-sea environmental continuum. The geographic scope is shown in Figure 2.

8. https://www6.inrae.fr/cultiver-proteger-autrement/Le-Programme/Presentation (accessed 9/01/2023).
9. https://www6.inrae.fr/cultiver-proteger-autrement/Les-Outils-de-pilotage/Prospective-2050 (accessed 9/01/2023).
10. https://www.inrae.fr/actualites/pesticides-agriculture-environnement-reduire-lutilisation-pesticides-limiter-impacts-environnementaux (accessed 9/01/2023).

Figure 2. Geographic scope of the CSA across the land-sea continuum



CSA principles

A CSA's purpose is to establish an inventory and critical analysis of available scientific knowledge at the global level on subjects with multiple dimensions. This analysis is carried out by a committee of scientific experts from public research or higher education institutions. In addition to an overview of the environmental contamination by PPPs and its effects, this assessment also analyses methods, their diversity and areas of applicability, and the development of innovation in this field. By updating the knowledge acquired, the areas of uncertainty and controversy, as well as the questions for which knowledge remains insufficient, this work is intended to inform various stakeholder groups on how to address the impacts of PPPs on biodiversity and ecosystem services from a public policy perspective. It thus contributes to the mission of the research organisations to contribute to public policy.

The CSA process is based on INRAE's 'Guidelines for the Conduct of Collective Scientific Assessments and Advanced Studies'[11]. Experts are selected on the basis of their publications in peer-reviewed scientific journals, while ensuring that links of interest (e.g. funding, intellectual affinities, collaborative links), which are inevitable in targeted research, are balanced within the collective, and excluding cases of conflict of interest. Transparency is ensured by describing, within the CSA extended report, the sources and methods used. This CSA was

11. https://www.inrae.fr/sites/default/files/pdf/DEPE_Principes_Conduite_ESCo_Etudes_V2_20211110.pdf (accessed 9/01/2023).

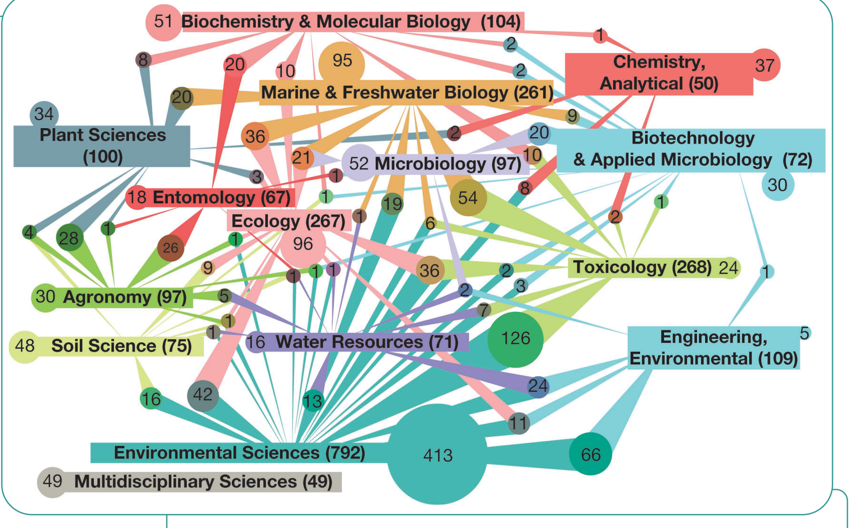
conducted in collaboration with a stakeholder advisory committee that brings together the main stakeholders involved in the issue of PPP impacts on biodiversity and ecosystem services.

Composition of the expert group

The expert group was recruited on the basis of an initial search of bibliographic databases to encompass the diversity of topics covered by this CSA. It was headed by three scientific leads: Laure Mamy and Stéphane Pesce, from INRAE, and Wilfried Sanchez, from Ifremer. The 46 researchers (including the leads) involved in the CSA come from 19 research organisations.

At the beginning of the CSA process, these 46 experts had authored a total of 1,875 publications indexed in the Web of Science™ (WoS) bibliographic database across a range of research fields (Figure 3). These fields are based on the WoS categories for scientific journals. The majority of experts published in environmental sciences and ecotoxicology fields, with biology of organisms, chemistry and agronomy also represented. Publications in the humanities and social sciences are less commonly referenced in the WoS and are therefore underrepresented in this figure. However, these disciplines are also represented in the CSA by two economists, two legal experts, one sociologist and one anthropologist.

Figure 3. Clustering of the top 15 Web of Science™ (WoS) categories among the 1,875 expert publications at the onset of the CSA



In brackets: number of publications classified in the given WoS category.
Disks: number of publications ranked within the two linked WoS categories simultaneously.
Graph produced with Intellixir©.

Sources used

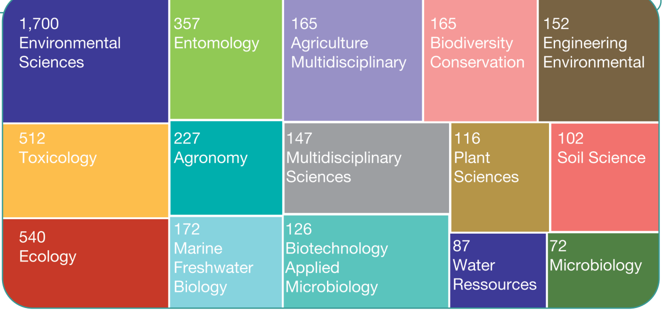
This condensed report is based on the findings described in the CSA extended report, which contains the entire bibliography used in the assessment. It is not cited here, except when the data or examples mentioned are taken directly from a publication.

The bibliographic corpus was compiled by searching the WoS and Scopus bibliographic databases, and the Cairn, Springer and Sage platforms for the humanities and social sciences. This initial selection of articles was then completed according to the experts' disciplinary skills.

The bibliographic search focused on the years 2000-2020, in order to update the knowledge acquired since the 2005 CSA 'Pesticides, Agriculture and the Environment'. The geographical scope of the contamination inventory was limited to France and its overseas territories. For the effects of PPPs on biodiversity, ecosystem functions and services, all knowledge from studies conducted in other countries that could be applied to the French context (e.g. types of climate, PPPs, or organisms) were also examined. The bibliographic search was completed, where necessary, with articles from before this period that are fundamental to the understanding of current knowledge, or when the subjects were insufficiently covered by the literature of the last twenty years. It was also updated during the course of the assessment (year 2021 and early 2022), on the basis of the experts' competence and the bibliographic monitoring carried out on the WoS by the CSA librarians. Additional information was provided outside the academic field, including reports produced by institutions using data sources relating to the monitoring of PPP sales or environmental surveillance. With regard to non-agricultural areas, very little academic work deals specifically with these areas and uses. For this section, we mainly used studies that were not published in peer-reviewed scientific journals. These were carried out, depending on the case, under the aegis of the managers of these areas, local decision-makers or other public authorities.

The total number of references cited was 4,460, of which 14% were literature reviews and meta-analyses. Seventy per cent of these references were published in the last ten years. This bibliography covers a wide range of research areas, as shown by the top 15 research fields in which the 3,343 references in the CSA bibliographic corpus that are published in WoS-ranked journals are classified (Figure 4).

Figure 4. Research fields of the 3,343 references classified in the Web of Science™ (WoS) categories (top 15 categories)



Analysis framework

Comprehensive approach to biodiversity

Biodiversity is considered here in the sense of 'biological diversity' as defined by the Convention on Biological Diversity (CBD; United Nations, 1992) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Biodiversity is also considered in terms of population dynamics and flows, interactions, ecological processes and ecosystem functions.

Addressing biodiversity as a whole raises the question of the delimitation of fields of knowledge. Indeed, living environments are made up of biotic (organisms) and abiotic (e.g. minerals, gases) components organised at different scales (e.g. individual, population, ecosystem), which interact with variable temporal dynamics, and fulfilling functions that result from biological activity that enables them to be perpetuated. The keys to analysing such an ensemble can be broken down by environment, type of organism, type of ecosystem, type of interaction, etc., with each typology having its own advantages and limitations, particularly in terms of disciplinary separation.

In addition to this complexity, PPPs can also be characterised by a wide range of attributes: chemical family (e.g. organochlorines), mode of action (e.g. photosynthesis inhibitors), target organisms (e.g. insecticides), use (e.g. fruit production, cereals), toxicological classification (carcinogenic, mutagenic, toxic to reproduction, or CMR level 1 or 2), regulatory category (e.g. basic substances, of concern, low risk, candidate for substitution), and the regulatory status (approved or not approved), etc.

In order to address the issue of impacts on biodiversity as closely as possible to situations as they occur in reality, the full range of impacts of PPP applications and their consequences was considered in the analysis. The substances were therefore not specifically targeted *a priori* in the literature search. However, in order to answer questions relating to certain substances or themes that have been the subject of specific political initiatives over the last decade (chlordecone, copper, glyphosate, neonicotinoids, endocrine disruptors, pollination, SDHI), the CSA report contains appendices that bring together all of the information on these subjects, based on the analyses carried out by the experts.

Reference framework for ecosystem functions and services

A common framework has been developed to group the ecological processes potentially impacted by PPPs into 12 categories of ecosystem functions (see section 'Consequences for ecosystem functions'), with the initial aim of linking them to the ecosystem services they support. The reference framework used for ecosystem services is the latest version of the CICES (Common International Classification of Ecosystem Services)[12]. This conceptual framework allowed a common vocabulary to be established at the CSA level, facilitating the synthesis of results. It also made it possible to note the difficulty of linking all

12. https://cices.eu/

of the identified ecotoxicological processes with the evaluation of ecosystem services in a comprehensive manner, especially since these two aspects come under different scientific disciplines. The dynamics of the response of ecosystems to the pressures exerted by PPPs, which vary according to time and spatial scales, are therefore difficult to consolidate in the form of impacts measured as a whole on all ecosystem services.

Analysis focusing on studies under realistic environmental conditions

The existence of a regulatory framework for the placing of PPPs on the market leads to the production of scientific knowledge on their ecotoxicity, thus documenting the assessment of the risks that their use may pose to the environment. This abundant body of knowledge is essentially based on standardised experimental approaches, supplemented by the use of numerical models, and forms the basis for regulatory decisions. The scope and limitations of such an assessment framework are themselves the subject of scientific publications that study the inadequacies of these approaches for estimating impacts at the scales of biodiversity and ecosystem services.

To compile the corpus analysed in this CSA, priority was given to studies that were as integrative as possible and as realistic as possible from an ecological perspective. For example, results from single-species tests have not been systematically reviewed, and are only used insofar as they provide explanations for phenomena observed or suspected under realistic environmental conditions.

Thematic breakdown and cross-cutting themes

The thematic breakdown presented in Figure 5 was based primarily on the experts' knowledge, and facilitates the compilation and analysis of the bibliographic corpus.

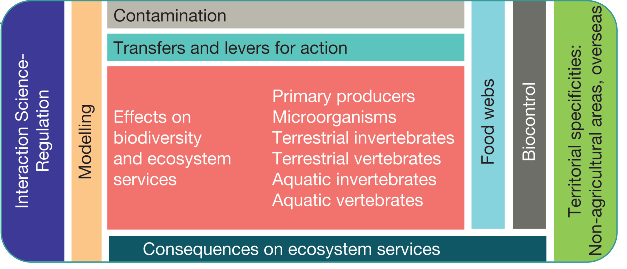
Within the ecotoxicology field, knowledge was analysed by the type of organism (primary producers, i.e. photosynthetic macro- and microorganisms; non-photosynthetic microorganisms; invertebrates; vertebrates), and by the type of environment (terrestrial or aquatic) when this is highly specific (for invertebrates and vertebrates). Focus was also given to the dynamics within food webs, which cross these divisions by type of organism and habitat and play a significant role in both the transfer of substances and the propagation of their effects.

The corpora dealing with contamination, the dynamics of transfer, and the physicochemical transformation of substances, as well as modelling tools, were analysed in a transversal manner. The specificities of biocontrol required a two-pronged approach within this field: in the case of natural substances, they are treated in the same way as other substances, but in a more specific way in the case of living organisms or in studies adopting biocontrol as a separate subject of study (e.g. comparative studies).

As regards non-agricultural areas, knowledge has, as described above, mainly been gathered from non-academic sources, and supplemented by the few scientific studies related to this type of area.

The specificities relating to overseas territories were explored within each of the previously compiled thematic corpora.

Figure 5. Thematic breakdown of the CSA



Ecosystem services are the subject of a specific body of literature, and this was analysed as such. Conceptual framing was conducted in order to establish a relationship between the results from the corpus on ecosystem services and those from the analysis of effects on ecosystem functions (examined in the field of ecotoxicology).

Finally, the field of knowledge addressed in this CSA has the distinctive feature of being partly produced within frameworks standardised by regulations (e.g. studies based on data from monitoring imposed by regulations on the surveillance and protection of biodiversity), or for decision-making purposes within regulatory frameworks (e.g. scientific opinions from EFSA or Anses). These interactions between scientific processes and regulatory approval processes partly underlie the scientific dynamics observed in the corpus of this CSA. A multidisciplinary group, involving researchers in law, sociology, ethnology and ecotoxicology, was dedicated to synthesising the scientific work that examines these interactions between science and regulation, particularly in the field of PPP risk assessment.

Treatment of agricultural practices

This CSA does not address existing tools for limiting the use of PPPs. Topics such as strategies to protect crop health without resorting to PPPs, or the comparison of the impacts on biodiversity of different types of agricultural systems that do or do not use PPPs, are not the subject of this assessment, in order to avoid redundancy with parallel studies. Such complementary analyses have been conducted within the CSA focusing on the natural regulation of pests and diseases, as well as within the *Growing and Protecting Crops Differently* priority research programme. The expert group and corpus topics were not designed to cover these topics, particularly in the field of agronomy, which is not a key element in the approach taken. However, certain methods of using products influence the dispersion dynamics of substances and the exposure of non-target organisms. The available knowledge of how parameters such as application equipment, practices that determine soil conditions, and the adjustments that can be made at the plot and landscape levels influence the impact of PPPs was therefore included in the scope of the study.

1. Preamble regarding the fragmentation of knowledge

Despite the size of the scientific corpus dealing with the impacts of PPPs on biodiversity, ecosystem functions and ecosystem services, an examination of the available knowledge quickly reveals the difficulty of generalising results from knowledge that is particularly discontinuous and heterogeneous. This fragmentation of knowledge is partly linked to the topics studied, whether PPPs or biodiversity, which cover a wide range of entities (e.g. substances, transformation products, species, habitats), many of which are not known or not covered in the scientific literature. It is also linked to the diversity of environmental conditions (e.g. pedoclimatic, hydrological) and practices (agricultural or environmental management), which makes generalisation even more difficult. Finally, the frameworks around the production of science have their own constraints and limits, which are not specific to the corpus analysed here, but which must be considered in the critical analysis of the results.

Patchy and heterogeneous nature

With regard to substances

Approved or previously approved substances are well known because of the regulatory framework. In 2022, approximately 450 substances were approved at the European Union (EU) level[13], of which less than 300 were valid for French territory. These substances are used in the composition of more than 1,500 commercial products whose marketing authorization is granted at national level, and whose sales are subject to mandatory reporting. However, fundamental knowledge of the pressure on ecosystems is still lacking, such as a geographic history of applications, possible fraudulent uses, the extent of transfers of substances and their transformation products in the environment, whether within the same environment, between environments (e.g. from soil to surface water or groundwater, from inland waters to the marine environment), or within or between organisms (e.g. within food webs). There are major differences in data availability between environments and between matrices, particularly depending on whether or not they are subject to regulations that require monitoring to be conducted. Aquatic environments are subject to monitoring of the chemical and ecological quality of water bodies, as required

13. https://ec.europa.eu/food/plants/pesticides/eu-pesticides-database_en (accessed 9/01/2023).

by the European Water Framework Directive (WFD; 2000/60/EC) and the Marine Strategy Framework Directive (MSFD; 2008/56/EC). Despite recent improvements, there are no equivalents for terrestrial and atmospheric environments.

These elements are therefore addressed in the corpus on a case-by-case basis, according to specific research objectives. Thus, the extent of current knowledge remains very uneven depending on the substances considered and the hydro-morphological and geographical contexts in which they are studied (see section "Depending on the context").

The historical perspective is a primary factor in the development of knowledge. This explains the fact that older PPPs, many of which are no longer approved for use today, are better documented than the most recently developed products, for example in the area of biocontrol. Thus, the effects of PPPs are unevenly documented depending on the type of substance, as follows in descending order: organic compounds that are relatively hydrophobic and/or older, inorganic compounds, organic compounds that are less hydrophobic and/or more recently developed, macroorganisms, microorganisms, natural substances, and finally semiochemicals.

A significant knowledge discrepancy can also be seen between the number of substances likely to be found in the environment (those currently on the market and those that were marketed in the past and are persistent, either as such or via their transformation products), those that are looked for, those whose presence is actually detected and those whose effects have been studied.

The spectrum of substances investigated in the environment also varies greatly depending on the matrix concerned. Knowledge of contamination is most abundant in inland waters, followed by marine waters (coastal waters being more closely monitored than offshore waters); there is less knowledge of contamination of the atmosphere and soil. There is also a high degree of variability in knowledge about the contamination of living organisms (biota), with a few taxa, generally used as indicator organisms, being very well studied, while the majority are poorly studied, in a very patchy manner, or not studied at all.

Regarding biodiversity

Biodiversity is a concept that covers a multitude of study areas: genes, species, ecosystems and interactions, many of which are still little known or unknown. Although it is always tricky to assess knowledge gaps in biodiversity, the proportion of described species in relation to the total number of existing species is estimated to be around 20% at best[14]. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), 86% of the world's species and 91% of species in the oceans have not yet been described.

There is no simple indicator for assessing the state of biodiversity. The European WFD and MSFD directives establish monitoring of the ecological status of water bodies, but,

14. https://theconversation.com/biodiversite-combien-de-millions-despeces-61875 (accessed 9/01/2023).