Natural products for biocontrol: Fate in the environment and impact on biodiversity

Laure Mamy, Cédric Bertrand, Bruno Chauvel, M.-F. Corio-Costet, Fabrice Martin-Laurent, Sophie Le Perchec, Marcel Amichot

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Introduction

Introduction

Context

- Preservation of biodiversity and ecosystem services is critical for sustainable development and human well-being
- Unprecedented erosion of biodiversity observed for many years
- Chemical pollution, including plant protection products (PPPs), is one of the main cause of biodiversity decline (IPBES, 2019)

➢ French collective scientific assessment (scientific literature survey): Impacts of PPPs on biodiversity and ecosystem services

Collective scientific assessment
Plant protection products
Biodiversity
Ecosystem services

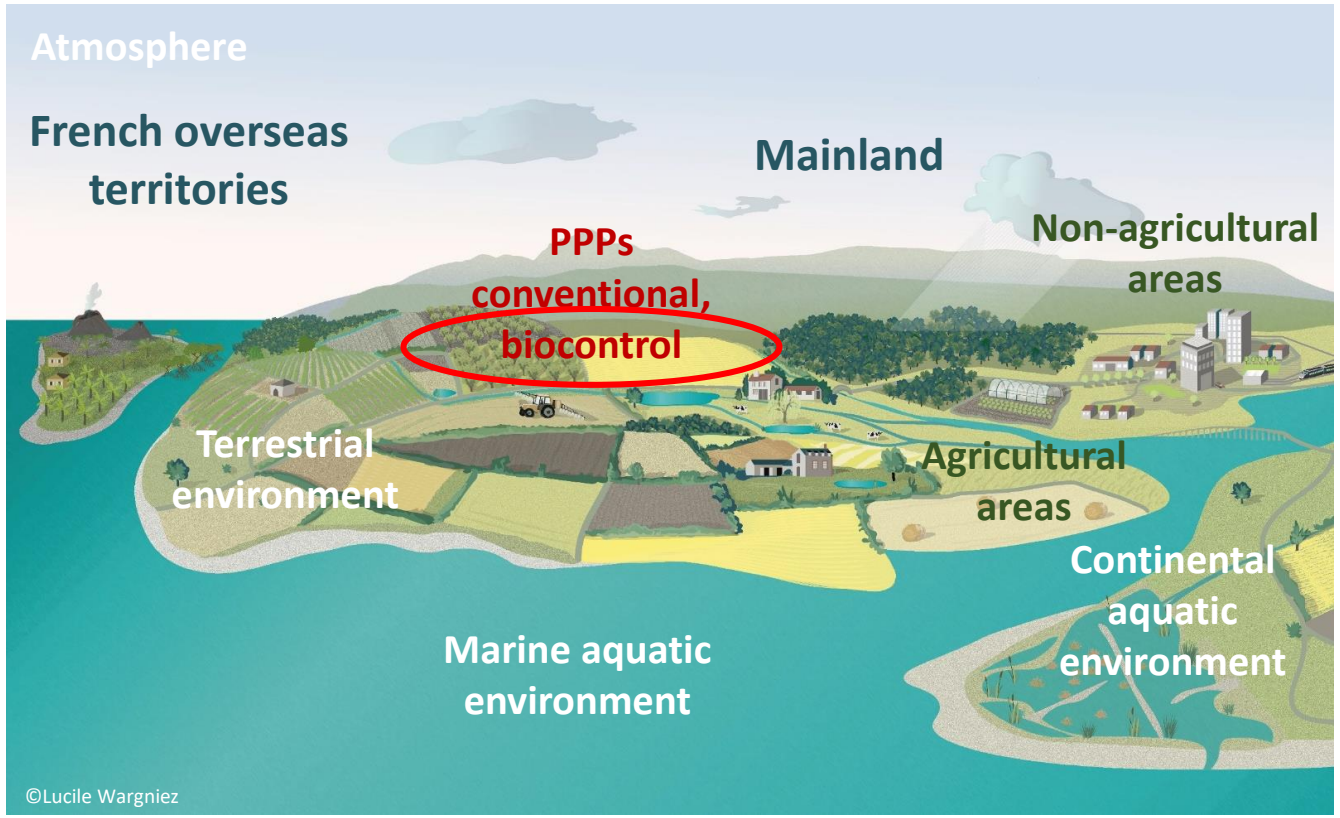
INRAE

Ifremer

https://www.inrae.fr/en/news/impacts-plant-protection-products-biodiversity-and-ecosystem-services-findings-inrae-ifremer-collective-scientific-expert-report

Introduction

Collective scientific assessment on the impacts of PPPs on biodiversity and ecosystem services



- Contamination
- Land use and transfers
- Effects on:
  - Primary producers
  - Microorganisms
  - Terrestrial invertebrates
  - Aquatic inverterbrates
  - Terrestrial vertebrates
  - Aquatic vertebrates
- Propagation
- Ecosystem services
- Biocontrol
- Modelling
- Regulation

- **Biocontrol:** Set of crop protection methods defined as agents and products using natural mechanisms in the context of integrated pest management

Introduction

Objective and approach

Objective

➢ **To determine the sustainability of biocontrol solutions**

Approach

➢ To review:

- The contamination of the environment by biocontrol solutions
- The fate of biocontrol solutions in the environment
- The effects of biocontrol solutions on the biodiversity
- The effects of biocontrol solutions compared to those of conventional PPPs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Biocontrol solutions

Biocontrol solutions

Macroorganisms (examples)

Predators

Parasitoids

Nematodes

Biocontrol solutions

Microorganisms (examples)

Bacteria

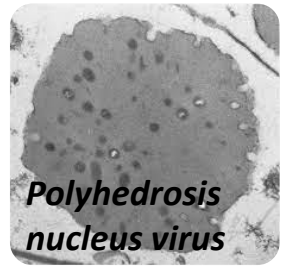
- *Bacillus amyloliquefaciens*
- *Bacillus firmus*
- *Bacillus pumilus*
- *Bacillus thuringiensis* (Bt)
- *Bacillus subtilis*
- *Pseudomonas*

Fungi

- *Beauveria bassiana*
- *Clonostachys rosea*
- *Metarhizium anisopliae*
- *Pythium oligandrum*
- *Saccharomyces cerevisiae*
- *Trichoderma atroviride*

Virus

- *Cydia pomonella granulosis virus*
- *Pepino mosaic virus*
- *Polyhedrosis nucleus virus*



Biocontrol solutions

Natural substances (examples)

Plants

- 6-benzyladenine
- Caprylic acid
- Eugenol
- Fatty acids
- Garlic extract
- Geraniol
- Gibberelins
- Heptamaloxyloglucan
- Maltodextrin
- Orange oil
- Pelargonic acid
- Pyrethrins
- Rape oil
- Terpenoids mixture
- Thymol

Minerals

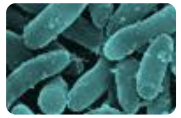
- Disodium phosphonate
- Ferric phosphate
- Iron sulfate
- Kaolin
- Paraffin oil
- Potassium hydrogenocarbonate
- Potassium phosphonate
- Quartz sand
- Sulfur

Animals

- Blood meal
- COS-OGA
- Fish oil
- Sheep fat

Microbial

- Abamectin
- Acetic acid
- Cerevisane
- Diatomaceous earth
- Spinosad

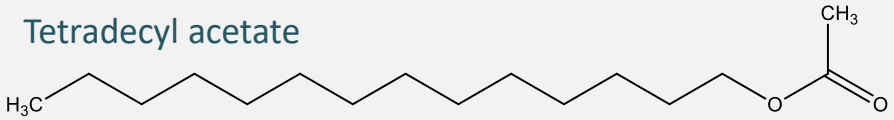


Biocontrol solutions

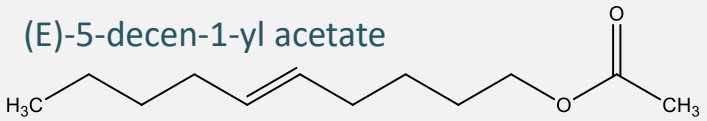
Semiochemicals (examples)

- Straight chain lepidopteran pheromones

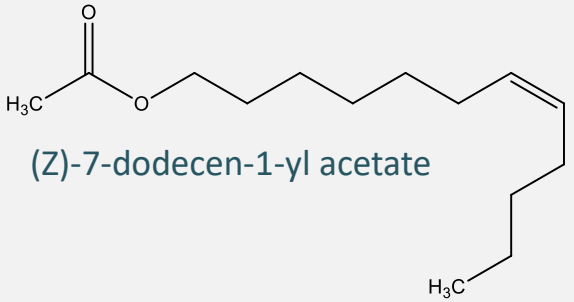
Tetradecyl acetate



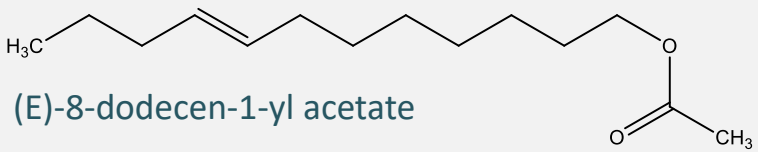
(E)-5-decen-1-yl acetate



(Z)-7-dodecen-1-yl acetate



(E)-8-dodecen-1-yl acetate

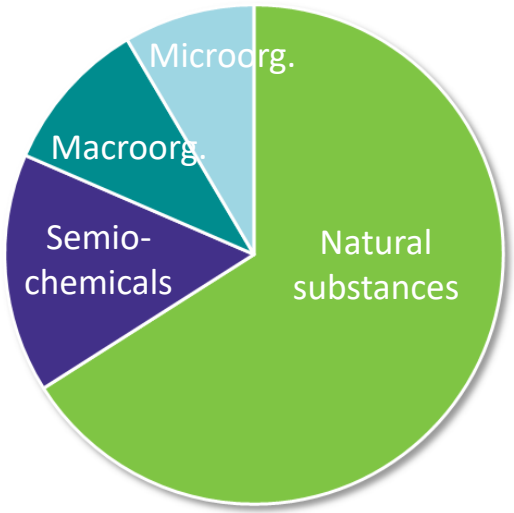


From EFSA (2021)

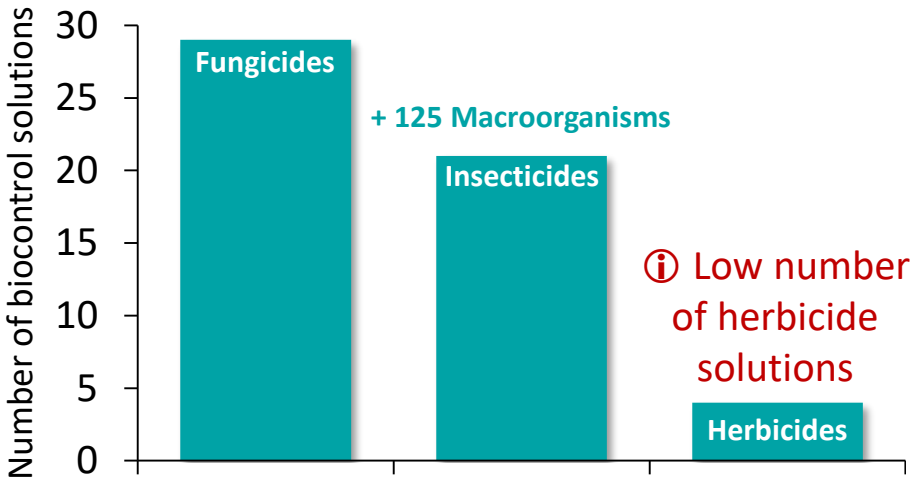
Biocontrol solutions

Example of the France case study

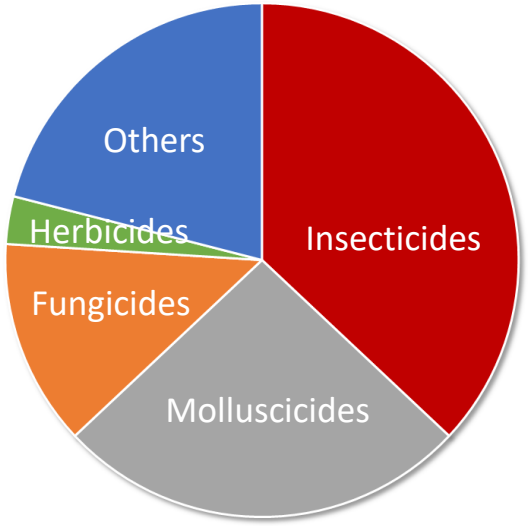
➢ Biocontrol market booming : 12% of PPPs market in 2020, 30% expected in 2030 (IBMA, 2021)



Use of biocontrol solutions
(% market share 2020) (IBMA, 2021)
NB : Sulfur is the most used solution



Number of active substances, micro and macroorganisms species per fungicide, insecticide or herbicide use (DGAL, 2021)



Sales of biocontrol solutions
(% market share 2020) (IBMA, 2021)

Bibliographic corpus

Bibliographic corpus

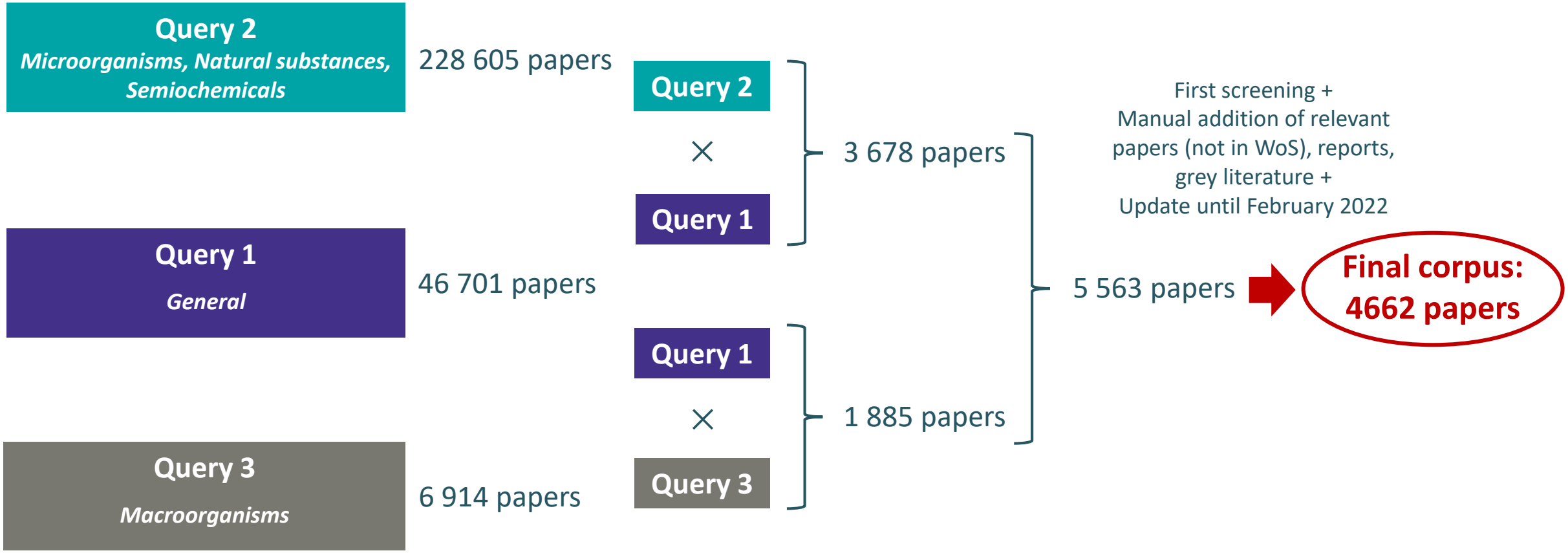
Definition of queries and keywords

Query 1	Query 2	Query 3
General	*Microorganisms, Natural substances, Semiochemicals*	*Macroorganisms*
Unspecific keywords / Biocontrol	French list of biocontrol plant protection products of the Rural Code and Maritime Fishing	French decree Décrets, arrêtés, circulaires TEXTES GÉNÉRAUX MINISTÈRE DE L'AGRICULTURE, DE L'AGROALIMENTAIRE ET DE LA FORÊT anses Macroorganisms notices *Innovations Agronomiques 79 (2020), 425-439* **Macroorganismes de biocontrôle en France, état des lieux** *Biocontrol macroorganisms in France, state of the art* Robin D.C.[1], Marchand P.A.[1]
Biological control Biocontrol Semiochemical Natural extract Plant extract Natural substance Biopesticide, etc.	*Bacillus thuringiensis* *Beauveria bassiana* *Trichoderma asperellum* Straight chain lepidopteran pheromone Abamectin Acetic acid Eugenol Heptamaloxyloglucan, etc.	*Adalia bipunctata* *Bombus terrestris* *Chrysoperla carnea* *Harmonia axyridis* *Leptomastidea abnormis* *Orius laevigatus* *Osmia bicornis* *Trichogramma achaeae,* etc.

ANSES: French Agency for Food, Environmental and Occupational Health and Safety

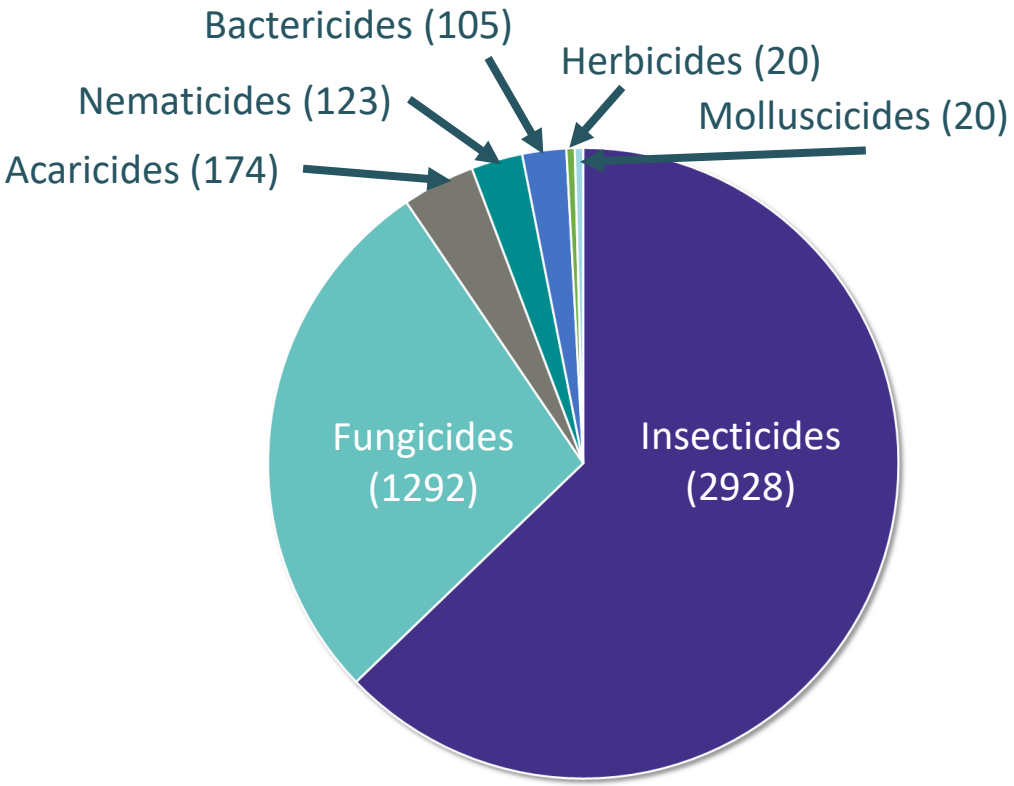
Bibliographic corpus

Selection of papers in the Web of Science™ (WoS) from 2000 to 2020



Bibliographic corpus

Distribution of papers according to the usage of biocontrol products



- Huge number of papers / insecticides, fungicides
- Very low number of papers / herbicides, molluscicides
- Consistency between the number of papers and the sale volumes (France case study), except for molluscicides

Contamination of the environment by biocontrol solutions

Contamination of the environment

- Biocontrol compounds are very rarely searched in the environment
- Some of them are naturally present: fatty acids, potassium hydrogen carbonate, aluminum silicate, sulfur...
  - ➢ Fraction coming from products / native fraction?
- Some compounds have a chemical nature that is not compatible with analytical monitoring: blood meal, fish oil, sheep fat...

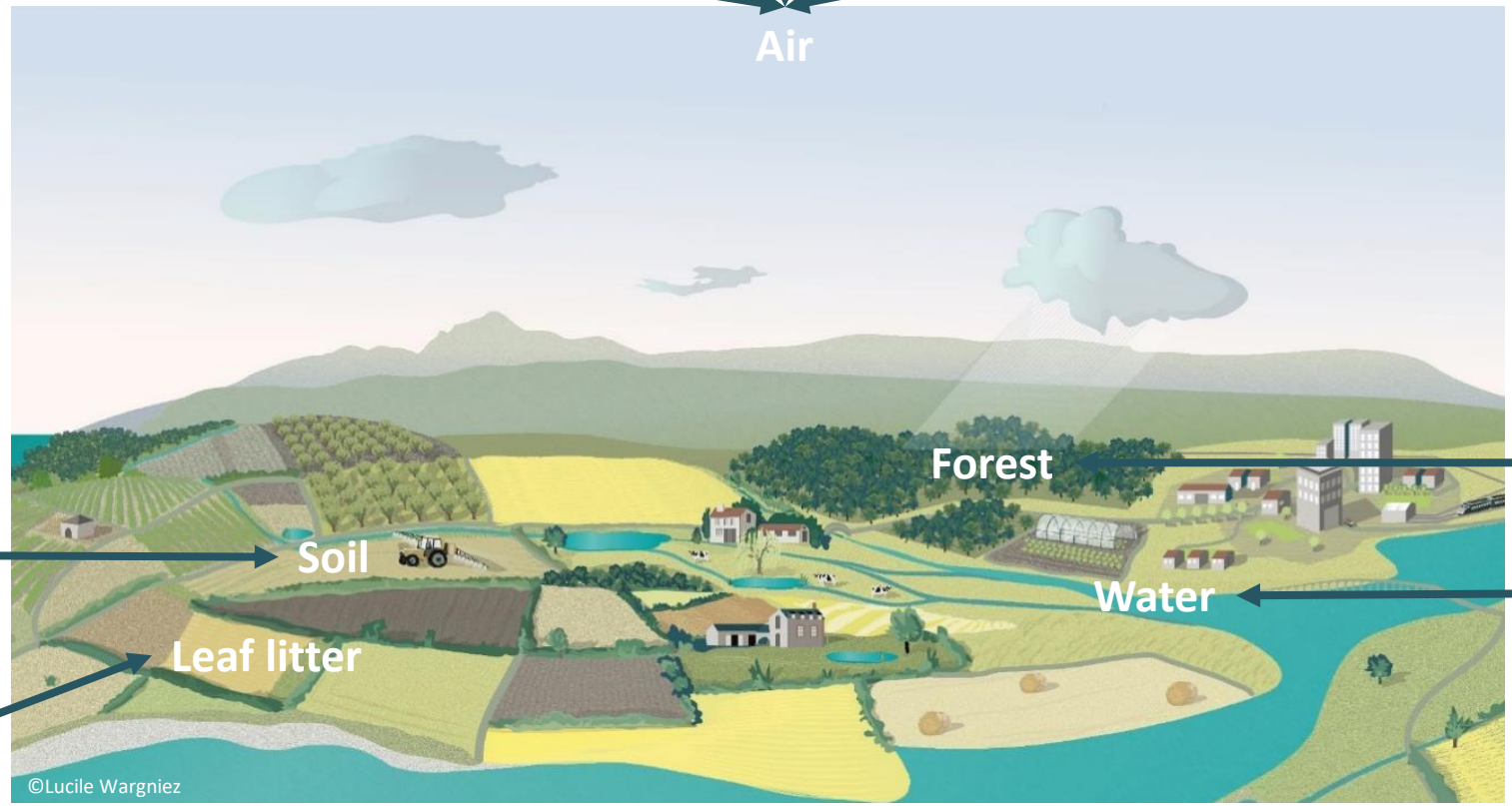
➢ **Very few results for exogenous biocontrol substances that can be measured in the environment**

Contamination of the environment

Pyrethrins < LOQ
(French AASQA, 2011 & 2016)

Abamectin? Analytical problems (ANSES, 2020)

Pheromones detected some hours after dispensers removal in USA
(Koch et al., 2009)



Bt + Cry toxins up to 28 months
(Vettori et al., 2003)

No data

No data

Bt + Cry4Aa and Cry4Ba toxins after several months
(Tetreau et al., 2012)

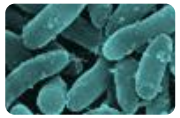
Bt: *Bacillus thuringiensis*
LOQ: Limit of quantification

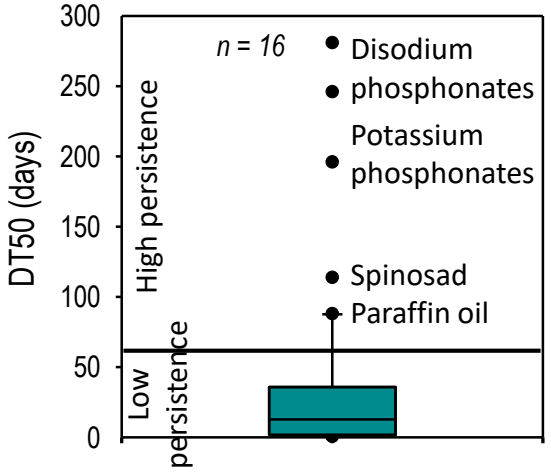
Fate of biocontrol solutions in the environment

Fate in the environment

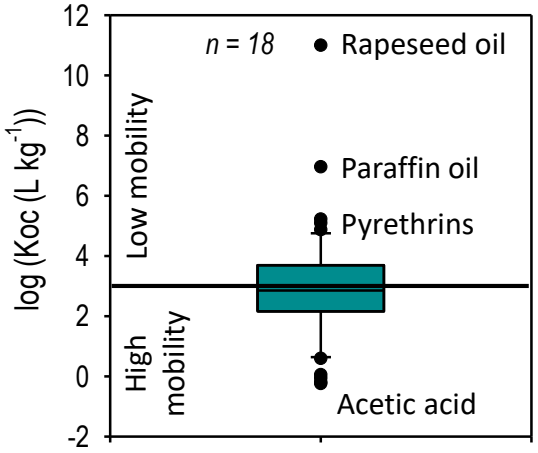
Natural substances





Boxplots of the distribution of DT50 and Koc of natural substances
(From Mamy and Barriuso, 2022)



- Many natural substances have a low persistence in the environment

ⓘ The degradation may produce transformation products (abamectin, spinosad)

- Some substances are immobile contrary to others having high mobility

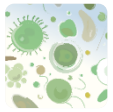
➡ Risk of groundwater contamination

➢ **Lack of persistence and mobility data for several substances**

DT50: Degradation half-life in soil
Koc: Adsorption coefficient in soil

Fate in the environment

Microorganisms, macroorganisms and semiochemicals



Microorganisms

- Fungal-based insecticides are persistent in the environment (Meyling and Eilenberg, 2007)
- Persistence of Bt insecticide several months and years (Tetreau et al., 2012; Bruhl et al., 2020; Liu et al., 2021)
- Fungal-based and bacteria-based fungicides are not persistent (Kohl et al., 2019)

Macroorganisms

- Persistence in the short term well known (efficacy)
- Persistence in the long term?

Semiochemicals

- No data

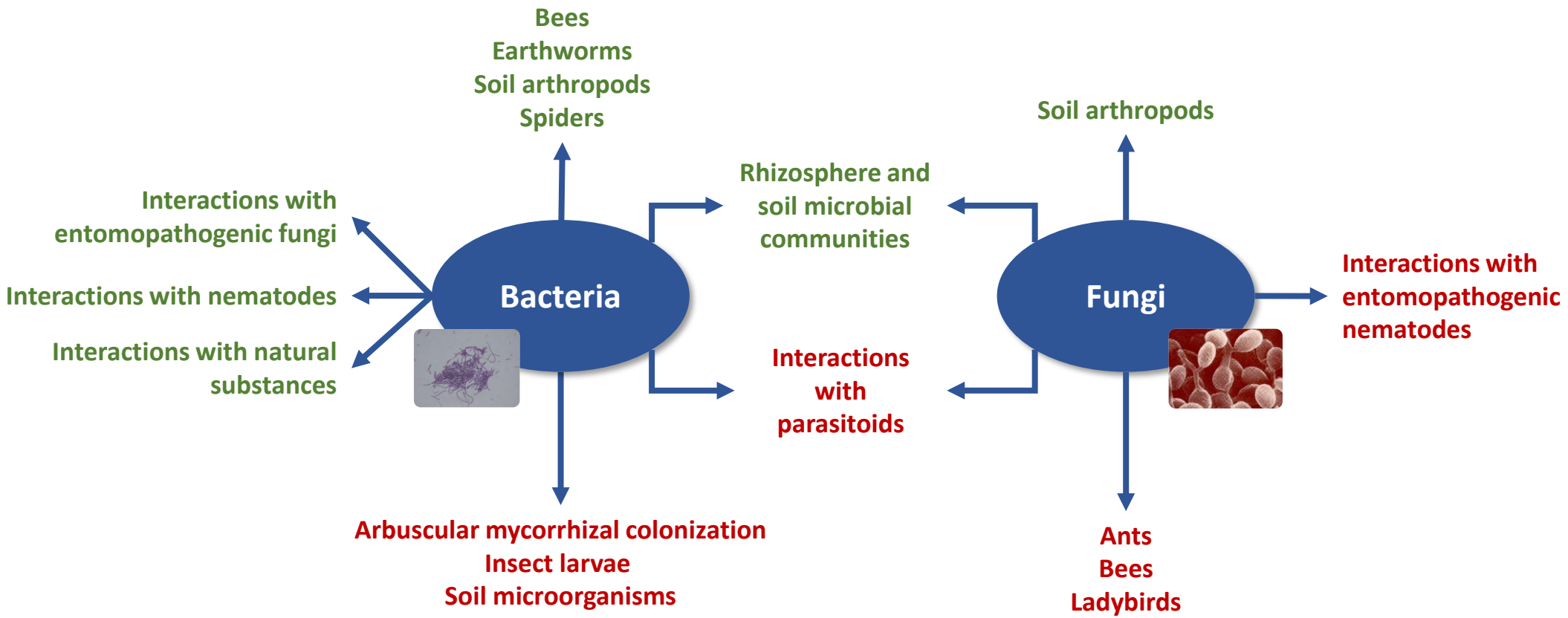
➢ **Lack of data to characterize the fate of microoorganims, macroorganisms and semiochemicals in the environment**

Ecotoxicological effects of biocontrol solutions and impact on biodiversity

Microorganisms

Summary of observed effects

- Most of results for Bt bacteria, some results for *Beauveria Bassiana* and *Metarhizium anisopliae* fungi, no result for virus



Negative effect
No effect

Bt: *Bacillus thuringiensis*

Microorganisms

Example of *Bacillus thuringiensis* (Bt)

Interactions with biocontrol agents

Parasitoids (*Habrobracon hebetor*)
(Oluwafemi et al., 2019)
↘ Emergence rate

Parasitoids (*Trichogramma chilonis*)
(Amichot et al., 2016)
↗ Life duration

Entomopathogenic nematodes
(Lanzoni et al., 2014; Oestergaard et al., 2006)

Entomopathogenic fungi
(Mantzoukas et al., 2013)

Natural substances (Abamectin)
(Zhu et al., 2006)

Predators
(*O. strigicollis*, *S. cantonensis*)

Ecotoxicological effects

↘ **Arthropod food resources for birds**
(Awkerman et al., 2011; Poulin and Lefebvre, 2018)

Soil microorganisms (Ferreira et al., 2003)
↘ **Development of drosophila** (Babin et al., 2020)

Batracian larvae (Weeks and Paris, 2020)
Soil arthropods (Beck et al., 2004)
Spiders (Bajwa and Aliniazee, 2001)

Survival, longevity, pollen consumption and physiology of bees (Dai et al., 2012)

No transfer along the maize-slug-carabid food chain
Reproduction of carabids (Harwood et al., 2006)

➢ **High complexity of interactions between Bt and biocontrol agents and between Bt and other (micro)organisms**

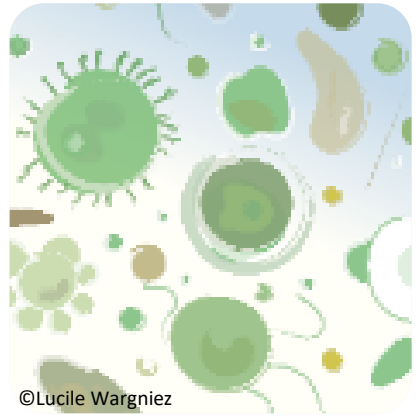
Microorganisms

Main conclusions

- Limited impact of microorganisms on soil micro-biodiversity, except for Bt
- Some effects of fungi on various organisms

➢ **Need of more data:**

- **Impacts of microorganisms on biodiversity**
- **Impacts of virus**
- **Invasion of microorganisms**
- **“Cocktail” effects on local biodiversity**
- **Effects on ecological functions and ecosystem services**



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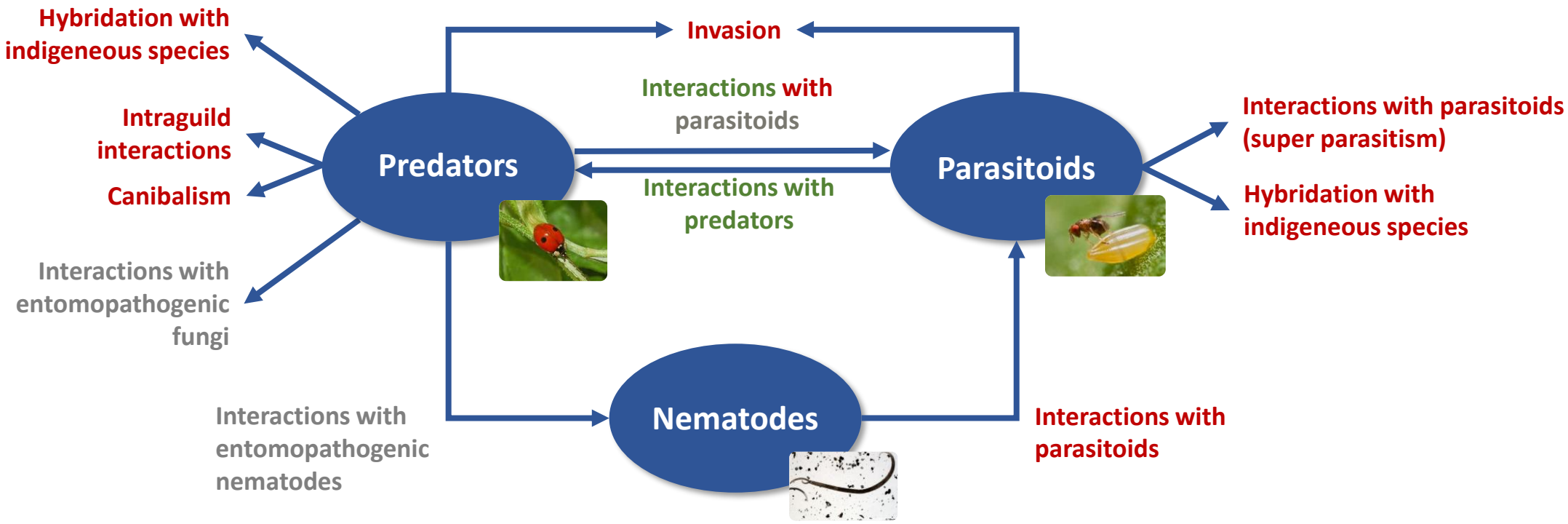
Macroorganisms

Summary of observed effects

- Affect the biodiversity through their mode of feeding, their ability to move and their ability to reproduce



Negative effect
No effect
Positive effect

Macroorganisms

Example of *Harmonia axyridis* predator escape

- Introduction to impose top-down population regulation of pests, in particular aphids

Intraguild predation
(Gardiner and Landis, 2007)

Canibalism
(Rondoni et al., 2012;
Tayeh et al., 2014)

Invasion
(Lombaert et al., 2014)

Decrease in biodiversity of native species
(Li et al., 2021)

Early reproduction and during a longer time
(Tayeh et al., 2015)

➢ **Illustration of what should not be done in biocontrol**

Negative effect
No effect
Positive effect

Macroorganisms

Main conclusions

- High complexity of modes of action
- Interactions among them or with local organisms
- Direct interactions: predation, parasitism, hybridation
- Indirect interactions: competition for resources
- Change in host or preys

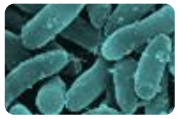
➢ **“Cocktail” effects on local biodiversity?**

➢ **Effects on ecological functions and ecosystem services?**

Natural substances

Summary of observed effects



- Most of results for abamectin, spinosad and pyrethrins

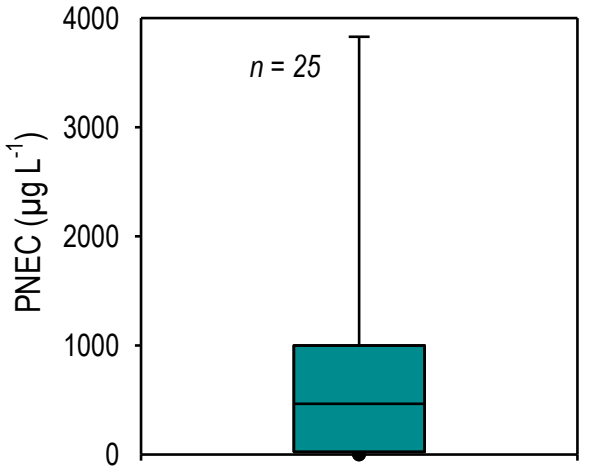
ⓘ **Similar modes of action as conventional PPPs**

- **Observed ecotoxicity of natural substances, especially abamectin and spinosad**

Natural substances

Main conclusions

- In general, natural substances have a low ecotoxicity
- But, some of them have high ecotoxicity (abamectin, spinosad...)
- Lack of data for numerous substances



Boxplots of the distribution of PNEC of natural substances
(From Mamy and Barriuso, 2022)

➢ **Need of more data:**

- **Impacts of natural substances on biodiversity**
- **Chronic effects at low doses**
- **"Cocktail" effects on local biodiversity**
- **Effects on ecological functions and ecosystem services**

PNEC: Predicted No Effect Concentration

Semiochemicals

- **No data!**

- Comparison of the effects of biocontrol solutions with those of conventional PPPs

Effects of biocontrol solutions / conventional PPPs

- Biocontrol solutions seem to have lower ecotoxicity than conventional PPPs, but there are some exceptions

➢ **Need of more data**

Conclusion

Conclusion (1/2)

➢ **Very few results in the literature**

Microorganisms

- High persistence of some insecticides (Bt), low persistence of fungicides
- Some observed effects
- Change in soil biodiversity?
- Invasion of non native species?

Natural substances

- Low persistence in the environment
- Low ecotoxicity / conventional PPPs
- ⓘ Abamectin, spinosad, pyrethrins
- Contamination?

Macroorganisms

- Direct effects: predation, hybridation
- Indirect effects: competition / resources
- Decrease in local biodiversity (*H. axyridis*)
- Persistence in the long term?

Semiochemicals

- ?

Bt : *Bacillus Thuringiensis*

Conclusion (2/2)

- Contamination?
- Chronic effects?
- “Cocktail” effects?
- Effects on ecological functions and ecosystem services?
- Nanoparticules?
- Risk assessment and regulation?
- Management of potential invasion?
- Biocontrol / conventional PPPs?

➢ **Biocontrol is a promising alternative to conventional PPPs, but it depends on the type of solution (and lack of herbicide solutions)**

➢ **Numerous research still remains to be done**

Ackowledgements

- Scientific Committee of the 5th Congress on Natural products & Biocontrol
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