Ubuntu serious game during the Biosefair workshop on science and participatory research.

BIOSEFAIR
Metaprogramme

INRAE

BIOSEFAIR: diversity in biodiversity projects

Results of research supported by the BIOSEFAIR 2021–2026 metaprogramme

Coordination: Sylvie Vanpeene and Isabelle Avelange (BIOSEFAIR project managers)

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After five years of operation, the Biosefair meta-program has played a major role in fostering new interdisciplinary research areas and collaborations within INRAE's research units. Thanks to project support and the events that have been organized, a scientific community is taking shape, particularly through the involvement of all students and thesis candidates, whom we thank here by highlighting the results achieved. An analysis of these advances outlines INRAE's unique contribution to addressing challenges related to biodiversity loss and the enhancement of ecosystem services. It is clear that the research topics cover a wide range of issues and subjects. The diversity presented in this booklet is a major asset when connections are forged between these different advances: this is what Biosefair aims to contribute to by fostering exchanges between topics that are sometimes very distant from one another.

To bring this scientific community to life and generate the collective added value expected from these exchanges, we obviously need the commitment and dedication of those involved in the supported projects. We would like to thank them here. The success of the thematic workshops clearly demonstrates this motivation and desire to break out of the usual silos. Careful guidance is also needed to help facilitate these opportunities for exchange. The Biosefair steering committee plays an essential role in this regard. Thank you to its members for their consistent and constructive involvement in bringing to life and implementing the many ideas aimed at fostering an environment conducive to creative research.

The large organization that Biosefair has become would not be what it is today without the constant dedication of two people who will soon be moving on to other endeavors and enjoying a well-deserved rest. I would like to take this opportunity to thank Christine Argillier and Sylvie Vanpeene, who have contributed so much to Biosefair, giving it its warm and welcoming "atmosphere" while always promoting scientific and collective interests. Biosefair, like the other nine metaprograms, owes a great deal to the work of the metaprogram coordination unit (Isabelle Maillet, Oana Vasiliu, and Gwladys Medelice), which, though less visible to the community, is essential–particularly for team funding.

The Biosefair project is entering its final phase; a new project manager, Isabelle Avelange, will take the lead, and further results will enrich the already impressive collection presented here. Summaries, new directions for the future, and practical applications will undoubtedly round out the project in the near future. You will be invited to participate. The best is yet to come... Stay tuned

Marc Deconchat on behalf of the Metaprogramme leadership team

Overview

Overview of the achievements of the Biosefair meta-program and the results of the supported projects (2021–2025)

The decline in biodiversity is one of the major global changes currently posing a serious threat to the living conditions of human societies by disrupting ecosystem services. INRAE is particularly concerned by these issues given the nature of its research. New interdisciplinary approaches could complement and enrich the scientific work already being carried out by INRAE teams. This is the goal of the Biosefair metaprogram. After five years of activity, Biosefair can now take stock of its achievements.

Summary of Results by Priority Area[1]

The projects selected by Biosefair fall under the three priority areas outlined in the framework (Figure 1). Priority Area 3 is the least addressed, both among the selected projects and those submitted. The steering committee therefore focused the design of the flagship SALUD project on this area.

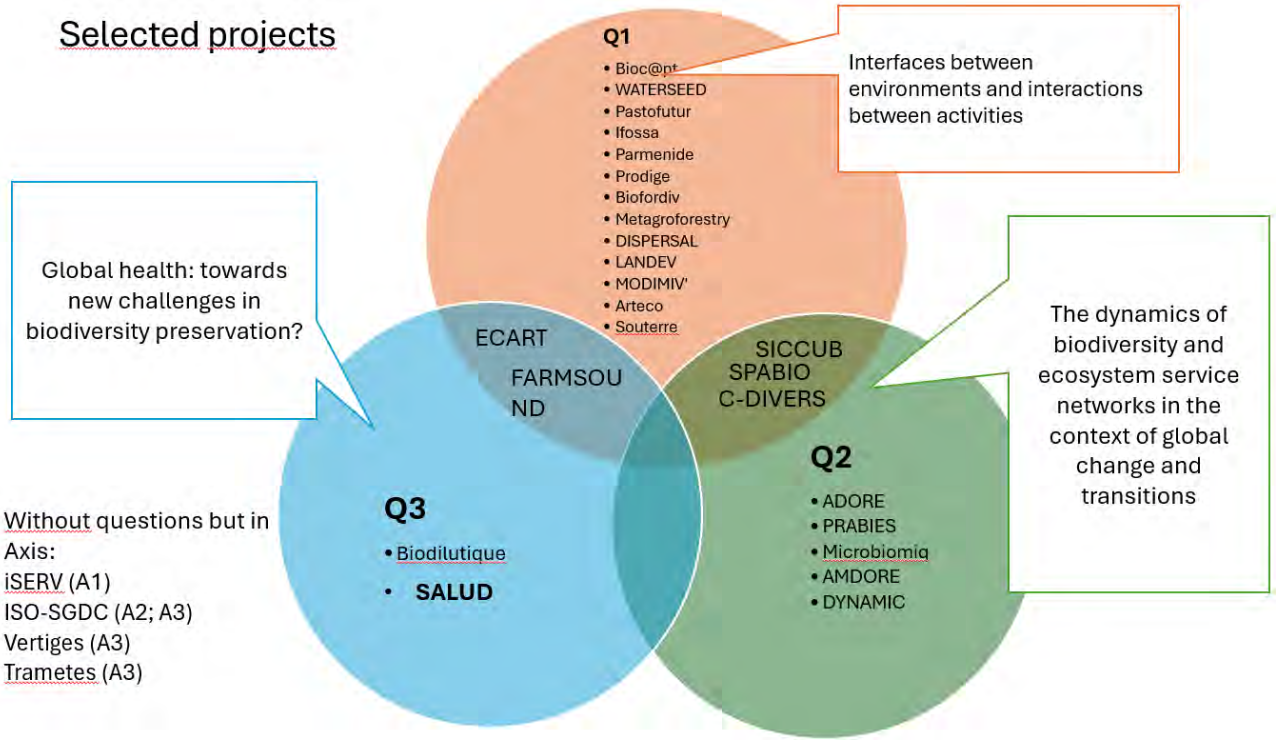


Figure 1: Breakdown of projects selected by Biosefair across the three priority areas. Area 3, on global health, is significantly underrepresented compared to the other areas.

Q1 – How do the interfaces between environments and the interactions between activities influence biodiversity and ecosystem services?

The first priority question aims to advance research on biodiversity and ecosystem services at the interfaces between land-use types, activities, and organisms. Although these questions are not new, Biosefair had identified significant potential, which was confirmed by the diversity of the projects.

Several projects proposed conceptual advances. The MetaEcoServ consortium, through a literature review, formalized the contribution of meta-ecosystems to understanding the spatial distribution of services in hydrosystems, clarifying their

[1] Some projects are cited as examples in the text, without claiming to be exhaustive.

assumptions and limitations. The BECO project uses the concept of the "common good" to model the interactions between beekeeping, agriculture, and conservation of wild bees, exploring potential tensions surrounding floral resources.

Most projects focus on the links between interfaces, the spatial and socio-technical heterogeneity of territories, and service networks. Particular attention is paid to interactions among actors from different socio-economic sectors to overcome sectoral divides (BECO, LANDEV, PRABIES, PASTOFUTUR projects; SEINARIOS thesis). The subjects of study vary (forest, grassland, agroforestry, and water bodies) and, in terms of functions, there is a slight emphasis on pollination, carbon and nitrogen cycles, and soil biodiversity.

Although often aimed at proof of concept, the projects involve operational stakeholders to develop management solutions. The SPABIO project, which combines economic and ecological models for invasive alien species, shows that early eradication of water primrose in Brière can be counterproductive; only actions in heavily infested areas improve the situation. The ECOSYSTEMIX thesis evaluated agroecological scenarios (species selection) to optimize ecosystem services, suggesting the promotion of grass–legume mixtures for carbon sequestration and weed control.

Method development is a cross-cutting objective that, in this context, focuses on characterizing biodiversity at ecological interfaces. The projects incorporate environmental DNA, automatic recorders, trapping, remote sensing, and citizen science. The PARMENIDE project exemplifies this cross-disciplinary approach: passive acoustic recorders for birds also generate ethnographic data on landscape perception. Although challenging, the analysis of sonograms provides novel functional insights. A vast network for monitoring acoustic biodiversity has been established, but data is accumulating faster than analytical capacity can keep up. Finally, it is worth noting that few studies specifically target the characterization of ecosystem services, a topic that remains under-explored.

Q2. What are the dynamics of ecosystem service networks in the context of global changes and in response to the steering actions undertaken for transitions?

Given the often-static nature of research on ecosystem services and the context of climate change, Biosefair aimed to address the issue of their dynamics. However, the lack of data likely limited the number of projects that actually addressed this issue.

The temporal dimension was addressed in a few projects, though rarely at the core of the issues. It is taken into account through phenotypic plasticity (MICROBIOMIQ: 15-month monitoring), environmental determinants (SICCCUB: comparison of images from 1850 to the present), or adaptive management (ADORE: 3 years of monitoring). Nevertheless, limited data availability and shallow temporal depth restrict the scope of analyses on the dynamics of functions and services.

Two projects, however, examine the temporal dimension through projections in the context of climate adaptation. The PRABIES project, combining a systems approach with modelling, simulates the impact of adaptation practices on grassland services in the Massif Central. The results indicate that it is essential to carefully consider fertilization to preserve species richness and the diversity of services. The C-DIVERS project, based on surveys of farmers in Brittany, analyzes the socio-economic determinants of the adoption of crop diversification. Researchers point to a shift in the drivers of adoption: by 2040, agronomic management will become the primary determinant, surpassing perceived risks and economic considerations. Crop diversification will then emerge as a key lever for pest management, reducing inputs, and animal feed. In this research, ecosystem services (carbon sequestration, water filtration, crop protection, etc.) are consistently considered as long-term levers.

Q3. Global health: new challenges for biodiversity conservation?

Despite efforts to promote and foster research and discussion on the role of biodiversity in "One Health" or "global health" approaches, and the organization of a two-day interdepartmental workshop on the "One Health" topic in 2024, few projects have truly embraced this priority. However, BIODILUTIQUE is testing the hypothesis that increased species diversity within host and tick communities leads to a dilution of Borrelia spp. and, consequently, a reduced likelihood of transmission of

these bacteria to humans. Furthermore, the flagship SALUD project, which aims to better understand how the health of forest ecosystems directly or indirectly influences human health, will help advance this issue.

Advances that could potentially be leveraged by local stakeholders or public policymakers

Many projects involve non-academic partners, sometimes as early as the project's co-development phase (SPABIO, ECART). The initiatives undertaken bring together various stakeholders, primarily land managers (conservatories of natural or botanical areas, the National Forestry Office, regional nature parks) or stakeholders responsible for implementing public policies (Chambers of Agriculture, Water Agencies, ANSES, OFB, local authorities), involved at varying levels (ranging from defining project objectives to simply reporting results, including support or joint field interventions). The actions are primarily aimed at generating new knowledge that can, in the short or long term, be leveraged to support public policies (e.g., management of invasive or heritage species). Several projects have produced or plan to produce tools that can be utilized by non-academic stakeholders. The serious game AGORAPI is used to engage local stakeholders in addressing the competition for floral resources between wild and domestic bees with a view to improving the management of agricultural land (BECO). The Ministry of Ecology has taken an interest in the discussions on Environmental Performance Bonds led by the LANDEV project. There have been several collaborations with companies, particularly on projects to develop biodiversity sensors.

Some of these initiatives contribute to agroecological transitions in crop farming, livestock farming, and among fishermen and beekeepers, but the preservation of biodiversity appears to be cited more frequently as the motivation for these collaborations. From the outset, Biosefair has established collaborations with the DAPP (Directorate for Public Policy Support), which provides feedback on responses received to calls for proposals. This special relationship should help better integrate these non-academic collaborations into the broader scope of INRAE's efforts to achieve policy-relevant research outcomes.

Biosefair's Activities

Biosefair Community Statistics

Biosefair has attracted many scientists, and the community continues to grow, with more than 30 new members joining each year over the past two years.

- 380 colleagues submitted a research proposal or a thesis for Biosefair funding, and after selection, 300 received funding;

- 510 colleagues have submitted a research proposal or thesis and/or participated in an in-person event organized by Biosefair (Meetings, Workshops);

- 670 colleagues have submitted a research proposal or thesis and/or participated in an in-person event (Meetings, Workshops) and/or attended a webinar organized by Biosefair.

The mailing list includes 400 contacts (internal and a few external).

Colleagues from the ECODIV, ACT, AQUA, and AGROECOSYSTEM departments account for 70% of the community that submitted projects or theses (Figure 2). Nevertheless, all divisions are represented in the submissions.

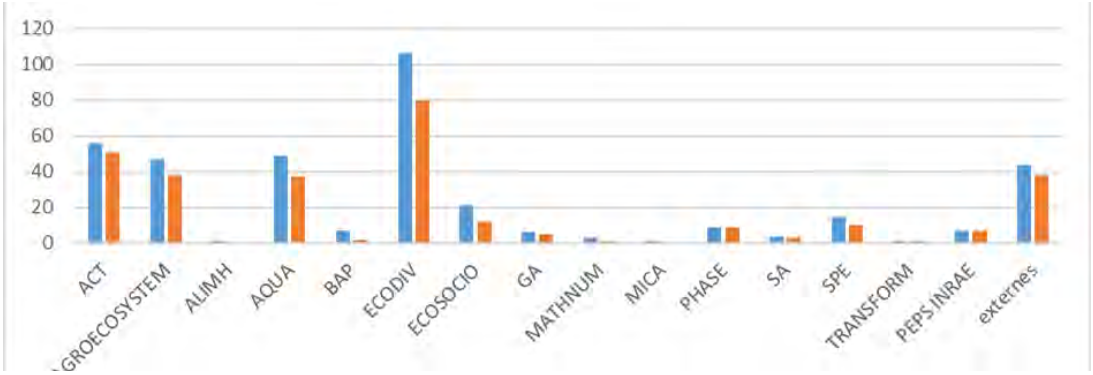


Figure 2: Breakdown of INRAE researchers who have submitted a project or thesis by department (excluding AMI 2026). Caption : blue : submitted projects – orange : funded projects

Since 2021, Biosefair has organized 3 Plenary Meetings (community-wide gatherings) and 5 thematic workshops. The workshop topics were determined based on the expectations expressed by colleagues during the plenary meetings.

Plenary Meetings	Thematic Workshops
Lyon – October 18–19, 2021	Innovative inventory methods – Lyon – September 7–8, 2022
Orléans – October 17–19, 2022	Remote sensing – Montpellier – November 14–15, 2023
Lyon – November 15–16, 2024	Humanities and Social Sciences – Lyon – April 4–5, 2024
Lyon – May 21–22, 2026	Interfaces – Lyon – November 24–25, 2025
	Participatory and Research Science – Montpellier – March 23–24, 2026

Funded Projects

The success of the calls for expressions of interest demonstrates the appeal of the meta-program, despite the relatively modest funding amounts offered and the lack of opportunities to hire staff on fixed-term contracts or postdocs (Figure 3).

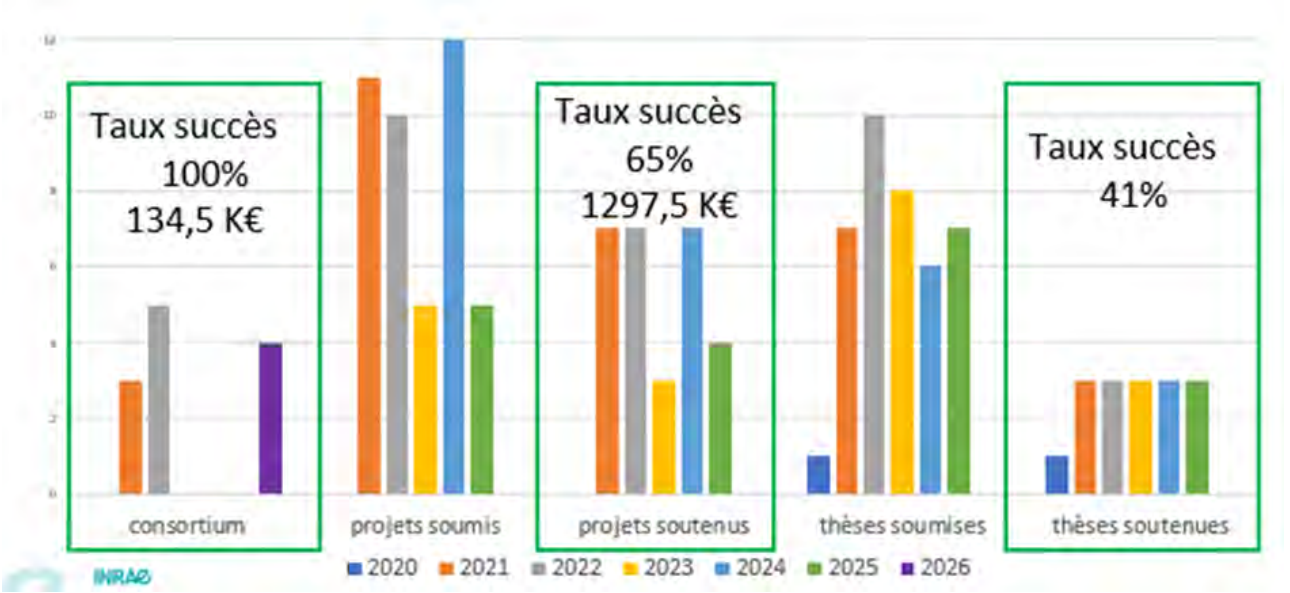
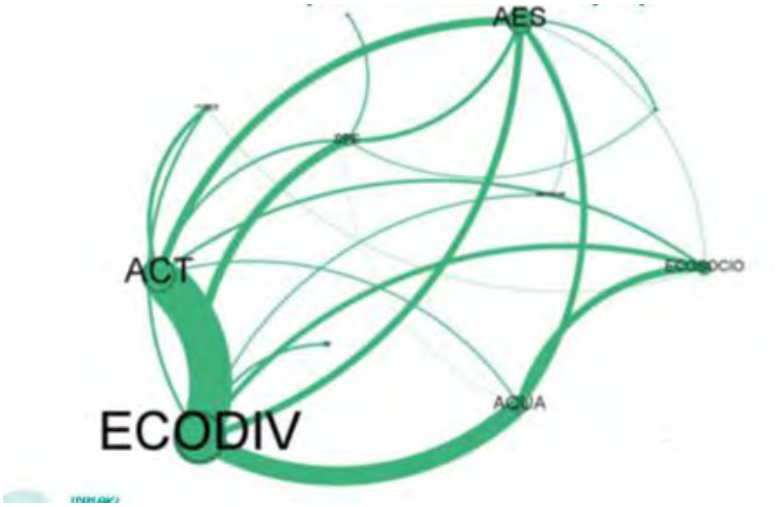


Figure 3: Number of submissions and success rates for calls for proposals and applications for doctoral grants

To date, we have supported: 28 exploratory projects, 23 of which have submitted their final reports; 1 flagship project and 11 consortia, 7 of which have submitted their final reports; and 16 theses, 6 of which have been defended.

All funded research tracks and theses are featured in an article on the Biosefair website (under "Our Actions"). Upon completion, they are supplemented by an article (under "Our Results") presenting a summary of the findings and a more comprehensive document (scientific report).

Most projects involve colleagues from 3 to 4 units, with a median of 7 participants from 2 or 3 departments (Figure 4). The flagship SALUD project brings together 29 participants from 10 units across 3 departments (ECODIV, ACT, and SA) and 2 co-supervising institutions (ONIRIS and AgroParisTech).



Caption : Gephi tool – font size of the division name based on the number of colleagues involved – line thickness based on the number of joint projects between the two linked divisions

Figure 4: Relationships between divisions in the projects (data 2024)

Productions

The Hal Biosefair collection automatically harvests publications deposited on HAL that mention support from Biosefair. It should be noted that project leaders do not systematically deposit the internship reports (primarily M2 theses) that contributed to the projects. Sixteen projects have already had articles published; 9 of them have published 1 or 2 articles to date, and 5 have published 3 or more, for a total of 33 published articles so far. Excluding projects that concluded at the end of 2025, only 2 projects currently have no planned academic output. About forty articles have been published, either directly related to the projects' results or defended theses, or because broader collaborations have utilized data produced during the project. About twenty articles are reported as in preparation in the end-of-project reports.

Figure 5: Word cloud generated from thesis and project titles (through AMI 2024)

Completed researches

Metaprogram
BIOSEFAIR

ADORE *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Biodiversity
Farm
Adaptative management
Ecological engineering
Result-based approach

Thematics involved
Agroecology
Agronomy
Animal and plant ecology
Functional ecology
Water management
Ornithology
Design sciences
Zootechnics

Divisions involved
ACT
AGROECOSYSTEM
AQUA

INRAE units involved
UE Saint-Laurent-de-la-Prée
UMR SADAPT
UR EABX
UE FERLus
UMR AGRONOMY

External partnership
An ornithologist
Charente fishing federation

A dashboard for implementing an adaptive management approach on a farm based on a "results-oriented" approach

The implementation of an adaptive biodiversity management approach, in collaboration with stakeholders, was tested on INRAE experimental sites. ADORE shows mixed results depending on the target species. It also highlights the influence of the farmer's personal background on the choice of target species and the role of their training in their perception of the approach. Translating a framework for action into a dashboard is a useful tool for facilitating the implementation of this type of approach. A survey of farmers highlighted the factors to be taken into account when applying it in real-world farming conditions.

ADORE – Tools for restoring biodiversity on farms: application of a results-based approach

The latest IPBES report (2022) makes the alarming observation that biodiversity continues to decline globally. In agricultural areas, the intensification of practices is the main pressure associated with this decline. Numerous initiatives have been launched in Europe to support farmers who are motivated to welcome rich biodiversity onto their farms. The CAP's Agri-Environmental Measures (AEMs) are 'action-oriented' and come with financial incentives for farmers who commit to 'good' practices. However, their effectiveness is controversial. As these approaches are mainly guided by a 'means-based approach', some scientists suggest that they should be clearly geared towards delivering concrete results. In other words, payments should be conditional on the achievement of results. Shouldn't we take a different approach to preserving biodiversity? Wouldn't it be better to think and act in a 'results-based approach'?

Approaches

In the field of water quality, an adaptive management approach based on results has been successfully tested in a catchment area involving several dozen farmers. ADORE sought to adapt this method to the service provided by agriculture to biodiversity at the farm level of the INRAE research farm in Saint-Laurent de la Prée (located in the marshes of Rochefort-sur-Mer, in Charente-Maritime).

The multi-year approach consists of a series of annual cycles comprising four steps: 1. implementation; 2. monitoring of target species, their habitats and the agricultural practices carried out; 3. collective analysis of results and lessons learned; 4. redesign of the project for the following year.

For the 11 'target' species selected, the expected abundance of the species, the habitat required for that species and, finally, the practices proposed to achieve this habitat and abundance were defined. This action plan was translated into dashboards that display the initial action plan, organise the observations to be made (monitoring) to determine the results obtained and the practices actually implemented, analyse these results and, in particular, understand why the expected results were not achieved, if applicable.

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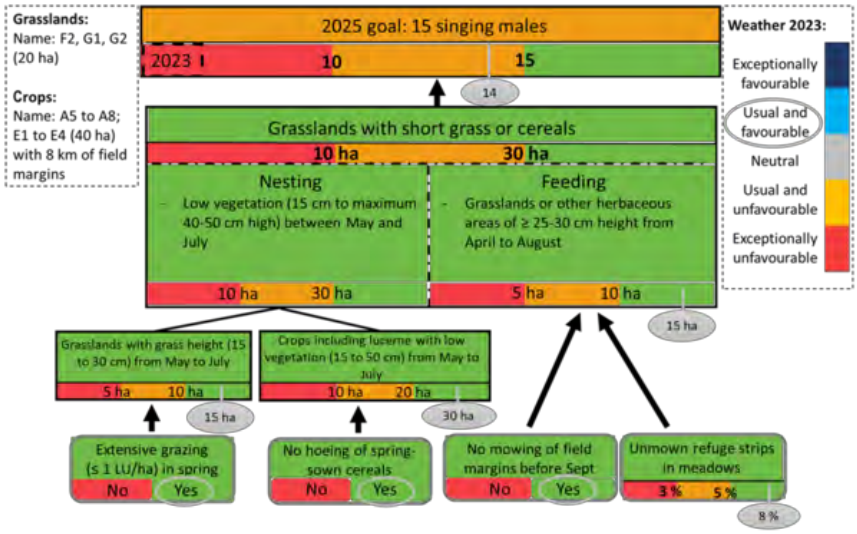
Results

First results from the research farm

ADORE has enabled analysis of the first three years of implementation of the approach on the farm (2021, 2022 and 2023), which shows varying results depending on the target species:

- Very rapid success for the skylark by leaving unmown strips in grasslands or alfalfa fields.
- Not many lapwings despite a favourable habitat, probably due to the general evolution of the populations of this migratory bird.
- For the reed warbler, neither the desired habitats nor the expected abundance could be achieved.



Example of the 2023 results dashboard for the skylark. A green box means that the result has been achieved, while an orange box means that it is moderately satisfactory.

Results of the farmer survey: consideration of biodiversity

Biodiversity is not seen as an economic asset for farming: in general, farmers do not expect it to add value to their income.

The farmer's personal background (their training) seems to influence the nature of the biodiversity taken into account ("ecosystem" versus a few species perceived as being of functional interest or not) and to be a strong factor in the level of reasoning behind practices to conserve biodiversity.

If biodiversity conservation is to be integrated as an objective of farming (at the same level as production), farmers will need to acquire knowledge and re-contextualise it. However, moving from "imposed" biodiversity to "appropriate" biodiversity requires the ability to observe it and to have management indicators to support action.

Original results production

Sketchnote – Préserver la biodiversité sur les fermes : et si nous pensions et agissions dans une logique de résultats ?

Publications

Durant, D., Farruggia, A., Grimonpont H., Reau R. Results-based approach for biodiversity management at the farm scale: proposal for a new method.

Daphné Durant, Nathalie Lemaire, Alexandre Teynié, Éric Kernéïs, Raymond Reau. Préserver la biodiversité sur les fermes : et si nous pensions et agissions dans une logique de résultats ?

Metaprogram
BIOSEFAIR

AMDORE *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Biodiversity
Farm territory
Adaptive management
Collective approach
Indicators

Thematics involved
Ecology
Agronomy
Animal Physiology
Management Sciences
Animal Science

Divisions involved
ACT
ECODIV

INRAE units involved
UE PAO
UMR PRC
UE Saint-Laurent-de-la-Prée
UMR SADAPT

Tools Involving farmers from the very outset of a "results-oriented" approach

AMDORE, building on ADORE, aimed to organise participatory workshops and then implement a results-oriented approach at two pilot sites. AMDORE demonstrated a shift in stakeholders' perceptions of biodiversity and a change in attitude towards it, moving from viewing biodiversity as a nuisance to a more positive outlook. The actions defined by the group will be sustained following the numerous positive outcomes.

AMDORE – Tools for restoring biodiversity on farms: improving a results-driven approach

Halting the erosion of biodiversity in agricultural environments requires the development of approaches and tools that enable farmers and agricultural collectives to take ownership of this issue and manage it more effectively. The ADORE project developed a biodiversity management approach for farms that gave a free hand in deciding what they wanted to do to conserve/promote biodiversity, steering these projects with a "results-based approach". However, the dissemination of this method could be limited by 1) the commitment of farmers or agricultural collectives to the approach and objectives of biodiversity conservation/restoration and 2) the choice of the most relevant indicators for monitoring the results of actions taken to conserve/restore biodiversity.

The AMDORE project proposed to take this approach further by addressing the methodological elements that enable biodiversity management to be positioned as an objective for farmers or agricultural collectives. In particular, it sought to test methods for integrating a collective design stage for biodiversity issues.

Approaches

The project was set up within Experimental Animal Physiology Unit of Orfrasière (UEPAO, INRAE Centre Val de Loire, Nouzilly site). Two teams participated in the process, which was structured in three iterative stages based on the KCP (Knowledge-Concepts-Proposals) method.

In the first stage, each team member explained the concept of biodiversity in his/her own way, and then a collective choice was made regarding the biodiversity elements to be worked on.

In the second stage, a workshop was held to share knowledge on the biodiversity elements selected in stage 1 and to discuss the knowledge, leading to the selection of actions to be taken, objectives for the year and measures to be implemented by the teams themselves.

The third stage involves reviewing the results observed, analysing the results in relation to the objectives set, and defining new objectives and actions for the coming year.

This iterative approach was implemented over two consecutive years for one team and over a single year for the other.

For the first team, the biodiversity targeted focused on species considered harmful (coypu, corvids, flies/horseflies and wasps, etc.), heritage species (swallows and bats), ecosystem functions (degradation of organic matter and shade on pastures) and overall biodiversity by increasing the mowing height of pastures. For the other, the objectives chosen were to assess soil biological activity in five plots and to establish flower strips.

Results

Most of the selected actions have been carried out and monitored: morning and evening counts of the number of coypu seen on a grazing plot; installation of swallow nesting boxes under a straw shed and monitoring of their presence/absence in the nests; installation of bat nesting boxes and monitoring presence/absence of droppings; measurement of mowing height and recording of damage to wildlife, installation of LEVAbags to measure soil biological activity.

The project has had numerous benefits for biodiversity conservation at the INRAE site in Nouzilly and contributes to the site's CSR approach. Several biodiversity initiatives will be continued: installation of nesting boxes for swallows and bats, increasing mowing height, commitment of teams to a micro-copse planting project, planting of flower strips.

Initial findings suggest that the approach to promote ownership requires certain initial conditions, in particular the presence of a network engineer and shared leadership within the group. Nevertheless, it seems that the proposed method is at least changing perceptions of biodiversity, as can be seen from the evolution of the vocabulary used by participants. Biodiversity has thus become a unifying force for the team.

AMPLI GAMMA *Consortium results*

CONSORTIUM
2022-2023

Prospects for scientific research into the relationship between landscape and biodiversity

The literature review carried out by AMPLI GAMMA identified key research issues relating to geographical contexts, ecosystems and taxonomic groups in relation to the link between landscape heterogeneity and biodiversity.

AMPLI GAMMA – Landscape planning and gamma multi-diversity

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Keywords:
Spatial heterogeneity
Landscape mosaic
Biodiversity
Multifunctionality

Thematics involved
Ecology

Divisions involved
ACT
AGROECOSYSTEM
AQUA
ECODIV
MATHNUM
SPE

INRAE units involved
UR LESSEM
UMR BAGAP
UMR DYNAFOR
UR EFNO
UR PSH
UMR ABSYS
UMR LISAH
UR EABX
UREP
UMR LISC
UMR SAVE

External partnership
ECOBIO University of Rennes 1;
University of Jyväskylä (Finland)

In a global context of loss and fragmentation of natural habitats, changes in land use and management practices, one question is central to understanding and analyzing the role of management types on biodiversity in our anthropized landscapes and proposing ways of organizing the landscape that are more favorable to biodiversity. What is the link between the heterogeneity of composition and configuration of the landscape mosaic and specific and functional multi-taxonomic diversity at different spatial scales?

Approaches

To provide an overview of the current state of knowledge on this issue, a systematic review of the relationship between landscape heterogeneity and biodiversity was conducted in accordance with current standards. The objectives of this review are as follows:

1. to explore and analyze, based on the results of empirical field studies, the relationship between landscape heterogeneity and diversity (HD relationship), focusing on the nature of the relationship (positive, negative, bell-shaped curve);
2. to analyze which factors in the study, whether methodological (e.g., quality of the sampling plan, sample size) or ecological (landscape context of the study, type of heterogeneity, level of biodiversity analyzed), can explain the variability of this relationship.

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Results

Two successive sorting and extraction phases resulted in the selection of 159 references and 3,523 elementary results from the 2,605 references initially identified.

The studies were conducted mainly in four geographical contexts (% relative to the number of elementary results): Spain (19 %), Europe (15 %), France (13 %), and Germany (12 %). The ecosystems sampled were predominantly agricultural (72 %), with the remaining cases covering multiple environments (14 %), forests (8 %), or aquatic environments (5 %).

The taxonomic groups studied were mainly birds (22 %), plants (17 %), bees (14 %), butterflies (8 %), carabids (7 %), hoverflies (3.1 %) and mammals (2.3 %), with other taxonomic groups (reptiles, amphibians, mollusks, fish, annelids, springtails, arachnids, bacteria, fungi, protists) each accounting for less than 1 % of observations.

The HD relationship analyzed is very often insignificant (75.6 %), with positive relationships (16.7 %) being more frequent than negative relationships (5.6 %). Bell-curve relationships (Hmax) are anecdotal (0.6 %).

Scientific perspectives

Additional data is currently being collected and further analysis will enable the initial results to be refined.

The results obtained so far are interesting and enable us to identify the main gaps in research on the HD relationship in terms of the taxonomic groups studied, the type of heterogeneity, the type of landscape sampled, and the geographical context.

The systematic review will make it possible to assess the extent to which recommendations to increase crop and agricultural practice heterogeneity at the landscape level (composition heterogeneity) and reduce plot size (configuration heterogeneity) can be transposed to other types of landscapes, particularly forests, aquatic environments, and mixed landscapes.

CONSORTIUM
2021-2023

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Keywords
Floral resources
Beekeeping
Agriculture
Common good
Competition among bees
Serious games

Thematics involved
Agroecology
Beekeeping
Landscape ecology
Human geography
Participatory action research

Divisions involved
ACT
ECODIV

INRAE units involved
UMR DYNAFOR
UR ABEILLES ET ENVIRONNEMENT

External partnership
ITSAP-Bee Institute
SENS Joint Research Unit - Knowledge, Environment and Societies
Cévennes National Park

A serious game to develop collective management of floral resources

Viewing floral resources as a common good that could be subject to competition, BECO supported the development of a serious game to initiate collective discussions between beekeepers and managers. It highlights that a 'frugal' agricultural system is most conducive to this resource.

BECO – Bees and consultation. Reconciling beekeeping, agriculture and biodiversity: floral resources seen as a common good to be managed collectively

With the evolution of farming practices, climate change, and the increasing number of beekeepers and hives, tensions have been emerging in rural areas over floral resources (nectar, pollen) used by bees. Long considered unlimited, these resources now appear to be subject to competition–both interspecific, between wild and managed bees, and intraspecific, between managed bee colonies. This shift invites us to consider floral resources as a common good that requires collective management, involving not only beekeepers and biodiversity managers but also farmers, who shape landscapes and whose practices influence the availability of these resources. The BECO project aimed to better understand the interactions between beekeeping, agriculture, and wild bee conservation at the landscape level, through the lens of the floral resources used by bees. It focused on a mountain area, the Cévennes National Park, and supported emerging processes of dialogue and collective action on these issues.

© INRAE - Cécile Barnaud

Approaches

To advance understanding of these challenges and their associated socio-ecological systems, BECO developed a transdisciplinary approach that combined:

- Spatial ecology to measure and characterize competition between bees over floral resources,
- Landscape ecology to assess the impact of farming practices on landscapes and floral resources,
- Social sciences to understand and facilitate social interactions around the management of this common good,
- Participatory approaches involving local actors from the Cévennes National Park to co-produce actionable knowledge.

Two PhD theses were carried out within the project, in partnership with the Cévennes National Park.

- Léo Mouillard-Lample's thesis (defended in December 2023), focused on competition between wild and managed bees, examined interactions between beekeeping and wild bee conservation, starting from the question: to what extent is it relevant to view floral resources as a common good?

- Gabriel Gonella's thesis (defended in January 2025), centered on interactions between beekeeping and farming through floral resources, sought to identify barriers and levers for creating agricultural landscapes rich in floral resources that support beekeeping.

Results

From an ecological perspective, field surveys suggest that competition between bees does indeed occur in the study area–meaning that floral resources can be considered common goods in ecological terms. From a social perspective, while most beekeepers report not perceiving such competition, interviews show that representations are evolving, and some beekeeping practices are starting to limit competition. A role-playing game (Agorapi serious game) was developed and tested in the Cévennes National Park to foster collective reflection among beekeepers and land managers on innovative, collaborative ways to manage floral resources at the landscape scale.

The analysis of semi-structured interviews with beekeepers and farmers in Mont Lozère shed light on beekeepers' rationales, the floral resources they rely on, and the impacts of farming systems on these resources. The floral resources used by beekeepers are threatened by dominant agricultural development trends–intensification of farming practices in cultivated areas and extensification of grazing in rangelands. By contrast, "frugal" farming systems–based on low inputs, modest investments, and labor-intensive practices such as intensive use of pastures–prove to be the most favorable to floral resources.

The social dimension of beekeeper–farmer interactions (mutual representations, relationships) reveals that they mainly interact around access to floral resources through the search for hive locations, and very little around the production of these resources.

A simplified and transferable version of the AGORAPI game is currently being developed for dissemination to potential users (nature managers and beekeeping organizations).

Publications

Mouillard-Lample, L., Gonella, G., Decourtye, A., Henry, M., Barnaud, C. (2023) Competition between wild and honey bees: Floral resources as a common good providing multiple ecosystem services. *Ecosystem Services*, 62, pp.101538

Gonella, G., Leoni, E., Mouillard-Lample, L., Aubron, C., Decourtye, A., Deconchat M., Barnaud, C. (2024) Beekeeping and agropastoralism interactions through floral resources in the French Mount Lozère. *Agronomy for Sustainable Development*, 44 (5), pp.49

CONSORTIUM
2021-2022

A non-lethal method using environmental NDA to identify bees from foraged flowers

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Keywords
Environmental DNA
Bees
Pollinated flowers
Proof of concept

Thematics involved
Molecular and genomic biology
Landscape ecology

Divisions involved
BAP
GA

INRAE units involved
UMR DYNAFOR
UMR GenPhySE

BEEDET has demonstrated, under controlled conditions, that it is possible to detect bee species (both wild and domestic) that have visited flowers by identifying the DNA they leave behind whilst foraging. The established proof of concept must now be optimised for real-world conditions.

BEEDET – Identification of wild bees and honey bees using non-lethal molecular methods

There are more than 20,000 species of wild bees worldwide and nearly 1,000 in France, playing an essential role in the pollination of wild and cultivated plants. This wide diversity of bee species, all differing in terms of morphology, mobility, floral preference, nesting sites and flight period, are collectively irreplaceable but unfortunately threatened pollinators. It is therefore important to assess the factors such as agricultural practices or land management, having an impact on the health of domestic bees (e.g. resistance to varroa mites) but also on the abundance and diversity of wild bees. The decline of pollinating insects is now a proven fact reported in media and scientific journals. To halt this rapid and massive disappearance of pollinating insects, various actions have been taken in France, such as the Pollinators Plan (plan pollinisateurs) (2021-2026), and in Europe with the drafting of Article 8 of the European Commission (June 2022), which provides for "the obligation to reverse the decline of pollinators and achieve an upward trend in pollinator populations until satisfactory levels are reached. This obligation will be based on the implementation of a method for monitoring pollinators".

However, at present, inventories and monitoring of pollinating insects face significant methodological barriers due to a lack of specialised entomologists and reliable, standardised methods for identifying species. In addition to the institutional obligations, there is also a strong societal demand for monitoring pollinator populations in different environmental contexts, using methods that preserve living specimens.

In this context, we have proposed developing a non-lethal protocol based on eDNA amplification and sequencing, that can be easily replicated by institutes or conservation associations to identify wild bees from the traces such as hairs, faeces or saliva, they leave on flowers when foraging.

Lithurgus cornutus femelle

© Remi-Rudelle

Approaches

The experimental setup consisted in four strawberry plants, commonly used as pollinometers, placed in insect-proof enclosures or exposed to the open air for three days.

- In condition A, the strawberry plants enclosed with four bees that had been caught in a net, photographed and identified. These were from species *Antophora plumipes, Andrena sp.* and *Lasioglossum sp.*
- In condition B, the plants were exposed to the open ai
- In condition C, the strawberry plants were not in contact with pollinating insects, being protected by nets.

After three days, the flowers were harvested individually, then frozen and stored at -20 °C before DNA extraction from traces.

	A	B	C
Exposition conditions	**Exposure to the 4 bees captured**	**Open air exposition**	**No insecte contact**
Time exposition	3 days	3 days	3 days
Strawberry plants	4	4	4
flowers number harvested / plant	10	10	10

Results

Optimisation of DNA extraction and amplification conditions

- Development of a protocol for extracting DNA from traces of insects deposited on flower
- Definition of 16S minibarcode amplification conditions suitable for several genera, starting from very small amounts of potentially degraded DNA.
- Optimisation of MiSeq sequencing conditions (read depth, cost).

Bioinformatic data processing

Prior to metabarcoding identification from our partially degraded DNA from environmental samples (eDNA), a reference barcode database for wild bees in the Occitanie region. Minibarcodes (250 bps insect 16S) had been built.

Two of the species introduced manually in condition A were detected: *Antophora* and *Andrena* (A). However, several species of wild bees belonging to different genera, as well as sequences from other pollinating insects such as hoverflies (*Philantus*), were also detected.

Sequences were detected under conditions C, in which the plants were protected from insects from the environment. This could be due to the fact that the strawberry plants used in this experiment came from external nurseries, where insects were present.

We also found a lot of contamination from Homo sapiens and unsurprisingly sequences corresponding to 16S DNA from strawberry plants. For further work, the effect of these contaminations will need to be limited, for example by using blocking oligonucleotides to reduce the amplification of contaminations.

The proof of concept is conclusive: under controlled conditions, it is possible to detect the passage of insects from foraged flowers.

Publication

Marquisseau, A., Canale-Tabet, K., Labarthe, E., Pascal, G., Klopp, C., Pornon, A., Escaravage, N., Rudelle, R., Vignal, A., Ouin, A., Ollivier, M., Pichon, M. (2025) Building a reliable 16S mini-barcode library of wild bees from Occitania, south-west of France. *Biodiversity Data Journal*, 13, pp.e137540

Metaprogram
BIOSEFAIR

BIOC@PT *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Image sensors
Automation
Metabarcoding
Forest biodiversity
Agrilus
Bryophyte

Thematics involved
Forest biodiversity
Entomology
Artificial intelligence
Metabarcoding
Bryophyte taxonomy
Robotics

Divisions involved
ECODIV
ECOSOCIO
PHASE

INRAE units involved
UR EFNO
UMR HERBIVORE
USC Ecodiv-Rouen
UR P2E
UMR SADAPT

External partnership
Laboratory IRBI Joint Research Unit CNRS – University of Tours - Institute of Research on Insect Biology

New tools for automatically assessing beetle populations in forests

BIOC@PT has tested and adapted a prototype photographic beetle sensor and developed and trained a neural network for the automated visual recognition of these insects. It has proven effective, achieving 90% recognition accuracy for *Agrilus* and *Scolytus* species.

BIOC@PT – Automatic Forest Biodiversity Sensors

For several decades, due to the rapid and alarming decline in biodiversity, monitoring environmental changes has become a crucial issue. Traditional methods of biodiversity monitoring are no longer adequate, and it is necessary to consider automating the collection of samples using images, videos, and sounds.

Thanks to advances made over the last decade in the fields of genomics, computer science, and artificial intelligence, sensors can now be combined with environmental DNA barcoding, visual recognition, and autonomous sound recognition technologies to identify or count species.

© INRAE - Christophe Bouget

Approaches

The BIOC@PT project explored new ways of acquiring biodiversity data that are faster and less costly than traditional morphological identification in the laboratory, by automating field surveys (using sensors) and species identification (using artificial intelligence techniques applied to photographic recognition), with a threefold focus on biomonitoring, biodiversity monitoring and the study of spatiotemporal patterns of biodiversity. This exploratory approach involved two important and relatively poorly understood forest taxonomic groups (insects and bryophytes) and could be adapted to other groups.

Bryological and mycological studies

A feasibility test of autonomous visual recognition using deep learning was conducted on photos of bryophyte spores, sampled in the forest by actively aspirating airborne particles with an automatic Cyclone Sampler sensor. We developed a CNN-type algorithm capable of discriminating between" spore"-type objects and built a photo bank of diaspores from 54 species of bryophytes, including species recorded by naturalist inventory at the aspiration sampling sites.

Prototype photographic entomological sensor

A prototype automatic camera trap insect sensor was developed and tested in the forest on a group of wood-boring beetle species (buprestes *Agrilus sp.*). In collaboration with Cap2020 for the mechatronic engineering of the sensor (housing, backlit optical sensor, communication, backup, energy autonomy), we transformed a green Lindgren trap, selective for buprestes, into a prototype selective, non-destructive, automatic and connected photographic sensor.

Autonomous visual recognition of photos of *Agrilus* beetles

The medium-term goal is to develop an automatic camera trap with an embedded photo processing algorithm. At BIOC@PT, we worked on an automatic laboratory sorting tool capable of automatically recognising (classification by deep learning) beetles photographed in the laboratory, in order to automate the processing of samples from conventional traps.

Results

Bryological and mycological studies

Based on the training data, the overall recognition rate is insufficient, ranging between 63 % and 80 %, and the average sensitivity and accuracy are low for all species, with frequent confusion between certain species.

Prototype photographic entomological sensor

Remote updating of the script controlling the regular frequency of shots and remote transmission of images are operational. The geometry of a new camera chamber, with an anti-return collar, optimised after observing the behaviour of trapped insects, has been integrated into version 2 of the Cap2020 sensor housing and successfully tested in the forest in the summer of 2024 (photo).

Autonomous visual recognition of *Agrilus* beetle photos

A custom neural network was created and trained to distinguish between classes (species) in a training photo library consisting of several thousand images of the seven main regional species of the *Agrilus* genus and one invasive exotic *Agrilus* species. Eight species of bark beetles were then added. The neural network performs well in distinguishing between taxa. With the expanded training photo library, the overall recognition rate reaches 90 %.

The algorithm trained with the laboratory photo library proved capable of distinguishing between *Agrilus* species in photos taken with the field sensor, even though the latter is of lower optical quality than the digital laboratory microscope.

Publications

Le Borgne, H. & Bouget, C. (2023) Suivis de biodiversité par la reconnaissance automatique des espèces sur photographies: perspectives et défis. *Naturae*, 6, pp.75-96

Le Borgne, H. & Bouget, C. (2023) Suivis acoustiques de biodiversité : perspectives et défis en milieu continental terrestre. *Naturae*, 8, pp.129-150

Le Borgne, H. & Bouget, C. (2024) La reconnaissance des espèces basée sur l'ADN: applications, perspectives et défis en milieu continental terrestre. *Naturae*, 3, pp.31-67

Caruso, V., Shirali, H., Bouget, C., Cerretti, P., Curletti, G., de Groot, M., Groznik, E., Gutowski, J.M., Pyliatuk, C., Plewa, R., Roques, A., Sallé , A., Sweeney, J., Wührl, L., Rassati, D. (2026) Image-based recognition using advanced neural networks can aid surveillance of *Agrilus* (Coleoptera, Buprestidae) jewel beetles. *NeoBiota*, 105, pp.319-336 (accepted 23/01/2026)

Metaprogram
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BIODILUTIQUE *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Biodiversity
Eco-epidemiology of tick-borne diseases
Eco-Health
Landscape
Zoonosis

Thematics involved
Agroecology
Population dynamics
Eco-epidemiology
Ecology and systematics of ticks
Community ecology
Landscape ecology
Spatial ecology
Epidemiology
Geomatics
Data management
Host-parasite interactions
Molecular methods
Dynamic modelling
Sociology

Divisions involved
SA
SPE

INRAE units involved
BIOEPAR Joint Research Unit - Biology, Epidemiology and Risk Analysis in animal health
USC CEBC - Résilience

In large woodlands, ticks are more numerous, and birds and roe deer play a role in harbouring Borrelia

BIODILUTIQUE confirms the role of landscape characteristics in tick abundance: in large wooded areas, ticks are more numerous on vegetation. The overall prevalence of Borrelia spp. is 8.2%. Birds play a more significant role as reservoirs for Borrelia than small mammals. Roe deer density influences tick population dynamics.

BIODILUTIQUE – Biodiversity, dilution effect and tick-borne diseases: analysis of the relationship between prevalence of pathogens, tick and host diversities along a landscape gradient

The links between biodiversity and health represent a frontier in science where the concept of the dilution effect plays a central yet still debated role. Tick-borne diseases, which are often zoonotic, provide a particularly relevant pathosystem for exploring this concept. The Biodilutique project explored the links between the biodiversity of host and tick communities and the diversity of pathogens transmitted by these ticks, with a particular focus on bacteria of the genus Borrelia responsible for Lyme disease.

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Approaches

BIODILUTIQUE investigated the roles of woodland, grassland and cropland on the diversity of vertebrates and ticks, as well as on the prevalence of the pathogens they carry. Tick collection and camera monitoring were carried out at 62 landscape plots distributed across two landscape gradients of woodland and grassland proportions within the Plaine & Val de Sèvre Study Area.

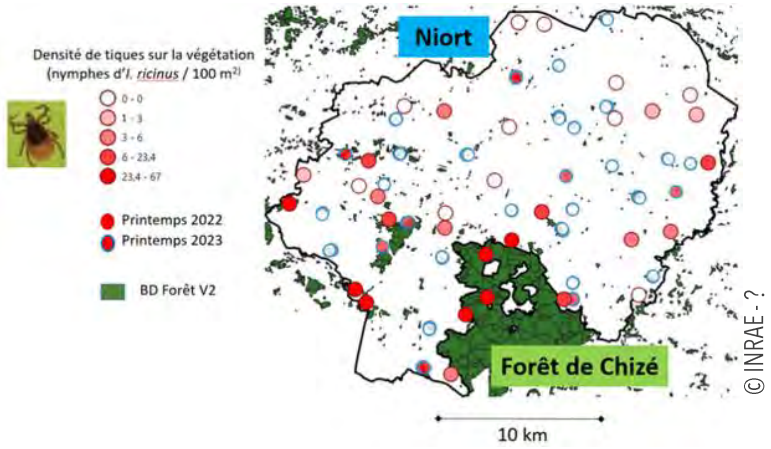
In the springs of 2022 and 2023, 4,546 ticks were collected, of which 4,386 were found on vegetation, 71 on small mammals and 89 on birds.

In total, seven tick species were identified, of which 90.1% were *Ixodes ricinus*, a generalist species capable of biting humans, and 9.2% were *Ixodes frontalis*, a species specialising in birds (passerines – Turdidae and Corvidae – and Columbidae).

Captures of small mammals (n=271) revealed the presence of six species, the three most abundant being the common shrew (50.2%), the common vole (34.2%) and the field vole (10%). Analysis of data from camera traps (n=723 videos) placed in the windows revealed the presence of 10 species of wild mammals and various species of birds.

Results

The highest tick densities were observed in the largest wooded areas, whereas smaller wooded areas, particularly those located in less wooded patches and less connected to other wooded areas, had lower or even zero densities.



Analysis of tick DNA revealed an overall prevalence of *Borrelia* of 8.2%, of which 3.2% corresponded to two species of *Borrelia* whose main reservoirs are birds, and 2.2% to a species of *Borrelia* whose main reservoirs are small mammals. Furthermore, these ticks collected from vegetation were also carriers of zoonotic pathogenic bacteria and protozoa.

Analysis of DNA extracted from biopsies of small mammals (n=80) revealed the presence of bacteria of the genera Bartonella (37.5%) and *Ehrlichia* (1.2%), *Neoehrlichia mikurensis* (1.2%) and the apicomplexan protozoan Hepatozoon sp. (33.7%). Among the *I. ricinus* ticks collected from birds (n=66), 51.5% were infected with *B. garinii* or *valaisiana*.

A multi-host, multi-pathogen mechanistic model was developed. A sensitivity analysis highlights the very significant influence of roe deer density; although roe deer are not suitable hosts for the multiplication of *Borrelia*, they play an important role in tick population dynamics. Birds appear to play a more significant role than small mammals as reservoirs for these pathogens.

A PhD thesis co-funded by Biosefair is continuing this research.

Metaprogram
BIOSEFAIR

BIOFORDIV *Project results*

EXPLORATORY PROJECT

2023-2025

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Keywords
Biodiversity indicator
Metabarcoding
Environmental DNA
Interdisciplinarity

Thematics involved
Entomology
Ornithology
Botany
Community ecology
Eco-acoustics
Molecular systematics
Forest management/biodiversity interactions

Divisions involved
ECODIV

INRAE units involved
UMR DYNAFOR
UMR RECOVER
URFM
URZF

External partnership
Conservatory of natural areas Occitanie
National Center for Forest Property (CNPF)

Innovative methods for assessing biodiversity show that forest biodiversity depends, in particular, on past forest management

BIOFORDIV has demonstrated the varying influence of forest management history and biogeographical factors on biodiversity and the structure of communities across several taxonomic groups (saproxylic beetles, birds, vascular flora). Passive acoustics and environmental DNA are innovative and promising methods for conducting such biodiversity monitoring.

BIOFORDIV - Taxonomic, functional and phylogenetic diversity of forest biocenoses along a gradient of naturalness

The forest ecosystems of Occitanie (France) are located at a biogeographical crossroad between Atlantic and Mediterranean climatic influences, making them and their associated biodiversity particularly vulnerable to climate change and its functional consequences for biocenoses. The conservation of biodiversity in natural ecosystems depends partly on the development of faster, less costly and non-lethal tools for monitoring and quantifying biodiversity. New monitoring tools can help to provide indicators of the resilience potential of forests to environmental change, which can be used to implement biodiversity-friendly forest management practices.

The BIOFORDIV project aims to analyze the response of forest biodiversity to the history of silvicultural management and the naturalness gradient of ancient native fir forests, using a multi-taxonomic and interdisciplinary approach. It comes at a time of high societal and operational expectations regarding sustainable forest management and biodiversity conservation, particularly in mountain ranges with contrasting histories of exploitation.

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Approaches

The work was carried out in two mountain ranges in the Pyrenees, Canigou and Burat, within beech and fir forests representative of three categories of forest corresponding to a gradient of anthropization: (i) currently exploited production forests, (ii) formerly exploited forests that have been left to evolve freely for at least 50 years, and (iii) old forests with very few traces of exploitation, dating back more than 100 years. BIOFORDIV relied on the study of three complementary indicator groups (forest birds, saproxylic beetles, and vascular flora) to characterize biodiversity in different dimensions (taxonomic, functional, and phylogenetic) and analyze its determinants.

Biological communities and environmental components were characterized using standardized inventories, coupled with the evaluation of innovative biodiversity monitoring methods, such as passive acoustics, automated data analysis, and molecular tools based on environmental DNA (eDNA). Comparison with conventional methods allowed for testing their complementarity, performance, and operational limitations.

Results

Biological communities respond differently to forest management history. At the multi-taxonomic level, species richness appears to be determined mainly by the specific context of each forest, while community composition, abundance, and certain aspects of diversity are strongly influenced by the degree of naturalness and maturity of the stands. This is the case, for example, with saproxylic beetle communities (which live on dead wood), which are clearly structured by silvicultural history, highlighting the importance of habitat quality and continuity rather than just the quantity of resources. The richness, abundance, and phylogenetic diversity of bird communities increase with the structural complexity of stands and the density of tree microhabitats, which have been identified as key elements. The vascular flora reveals significant differentiation between mountain ranges and a marked influence of local conditions, while highlighting a floristic specificity associated with old-growth forests.

Innovative approaches have proven their value. Passive acoustics, coupled with the BirdNET automated identification tool, has shown performance comparable to standardized listening points. eDNA analyses detected a significant proportion of insect species and genera identified morphologically, as well as species complementary to conventional approaches, and provided access to fungal diversity that had previously been poorly documented.

Overall, BIOFORDIV highlights the importance of integrating qualitative indicators of forest structure, such as dendro-microhabitats and ecological continuity, into forest assessment and management. The project thus reinforces recommendations in favor of silvicultural practices aimed at preserving or enriching these elements, including in production forests. The results and limitations identified have directly led to the development of the SALUD project (2025–2029), which extends BIOFORDIV by broadening the spatial scope and the taxa studied, and by integrating a "One Health" approach in order to strengthen the scientific and operational scope of the work.

Metaprogram
BIOSEFAIR

C-DIVERS *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Diversified cropping system
Hedgerow
Farmer decision
Interdisciplinarity

Thematics involved
Landscape agroecology
Systemic agronomy
Rural economics

Divisions involved
ACT
AgroEcoSystem
AQUA
EcoSocio

INRAE units involved
UMR BAGAP
UMR SAS
UMR SMART

Partners
Institut Agro Rennes-Angers, campus de Rennes

Contribution of low-input, diversified cropping systems and hedgerows to sustain agroecosystem multifunctionality in crop-livestock production

C-DIVERS demonstrates the complex effects of crop diversity and hedgerows, at both the local and landscape scales, which do not, on their own, facilitate all the outcomes required for the development of multifunctional agroecosystems. However, the presence of a hedgerow at the edge of a plot does promote certain ecological (pollination) or agronomic (agricultural production) outcomes. In the long term (15 years), plant diversification becomes a key factor in pest management, reducing the use of chemical inputs and improving livestock feed.

C-DIVERS - Contribution of low-input, diversified cropping systems and hedgerows to sustain agroecosystem multifunctionality in crop-livestock production

A transition toward sustainable and resilient agricultural systems, which combine biodiversity conservation with enhanced ecosystem services, is necessary. Diversified, low-input cropping systems (i.e., systems designed with a high level of crop diversity in rotation and reduced use of pesticides and nitrogen fertilizers) and hedgerows are identified as potential means of making this transition. However, significant knowledge gaps persist regarding their respective contributions to promoting agroecosystem multifunctionality. The spatial scales–field or landscape–at which the effects of diversified, low-input cropping systems and hedgerows operate, as well as the factors that hinder or facilitate their adoption by farmers, are also insufficiently understood to date.

In the context of mixed farming systems in Brittany, the objective of the C-DIVERS project was twofold:

- first, to explore the effects of crop diversity, the use of inputs (pesticides and nitrogen fertilizers) and hedgerows at the field and landscape scales on the agroecosystem multifunctionality;
- second, to explore the barriers and drivers to the implementation of diversified, low-input cropping systems and hedgerows within farms.

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Approaches

The initial hypotheses of the C-DIVERS project were as follows:

- Cropping systems with high level of crop diversity in rotation and low levels of chemical inputs, with hedgerows bordering fields, as well as a heterogeneous landscape context (high crop diversity and hedgerow density) combined with low pesticide use (large areas of organic farming) promote high agroecosystem multifunctionality;
- The barriers and drivers of plant diversification (i.e., the implementation of diversified rotations, the establishment or maintenance of hedgerows) differ depending on the time scale considered and on the socioeconomic and technical determinants behind these barriers and drivers;
- The opportunity cost (i.e., a way of assessing the economic barriers and drivers of plant diversification) is, in the long term, unfavorable to hedgerows due to their high maintenance costs.

In order to test these three hypotheses, the following approaches were used:

1. An assessment was conducted of the environmental (seven functions), agronomic (one function), and socioeconomic (two functions) performances underlying the agroecosystem multifunctionality of winter cereal fields with varying levels of crop diversity in rotation and contrasting landscape contexts;
2. A comprehensive survey was carried out based on the results of a prospective external study prior to the C-DIVERS project; the aim of the survey was to identify the socioeconomic and technical determinants acting as barriers and drivers for the adoption of diversified cropping systems and the establishment or maintenance of hedgerows in the short and long term;
3. An economic assessment was made of the long-term opportunity costs of establishing or maintaining hedgerows on a farm, according to different valorisation scenarios (it was not possible to make this assessment for the implementation of diversified cropping systems).

Results

The results showed that the levels of crop diversity and the presence of hedgerows, whether at the local or landscape scale, do not promote all the performances expected for the development of multifunctional agroecosystems. However, they highlight that the presence of a hedgerow at the field border promotes specific ecological (pollination) and agronomic (agricultural production) outcomes. Furthermore, the reduction of pesticide use at the local scale could be beneficial for biodiversity conservation. However, the spatial diversity of crops within landscape mosaics appeared to reduce the regulation of crop pests in crops, possibly due to dilution effects.

With regard to socioeconomic and technical determinants, the results of this project showed that, in the short term, farm characteristics (e.g., perceived risks and personal norms expressed by farmers) are decisive for plant diversification, along with market-related costs and benefits and agronomic management considerations. Factors external to the farm, including public policies and the configuration of supply chains, have been demonstrated to exert influence. Conversely, access to technologies and consumer behaviour, often mentioned in the literature, have not been pointed as significant determinants during our survey. Over the long term (15 years), the results showed that factors related to agronomic management outweigh perceived risks and market-related considerations: plant diversification emerges as a strategy that facilitates pest management, reduced dependency on chemical inputs, and enhances livestock feed autonomy. However, the calculation of opportunity costs over a 25-year period for hedgerows showed that no valorisation scenario can fully offset the loss of productive area converted into hedgerows compared to specialized dairy farming. Among the options considered, enrolment in the CAP second pillar agri-environmental scheme (MAEC “Biodiversity”) appeared to be the most profitable in terms of return on investment and opportunity cost.

Metaprogram
BIOSEFAIR

CONTICOMIC *Consortium results*

CONSORTIUM
2021-2022

Drivers for research into microbial biodiversity in the soil-aquatic continuum within agroecosystems

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Keywords
Soil-aquatic continuum
Agrosystem
Microbial biodiversity
Coalescence
Interface

Thematics involved
Aquatic and terrestrial microbial ecology and ecotoxicology
Molecular biology
Biostatistics
Biogeochemical cycles

Divisions involved
ACT
AGROECOSYSTEM
AQUA
ECODIV
MATHNUM
SPE

INRAE units involved
UR RIVERLY
UMR AGROECOLOGIE
UMR CARRTEL
UMR EMMAH

External partnership
LECA CNRS

By focusing on the concepts of "coalescence" (encounters between different communities) and "functional continuum" in the case of microbial communities present across the aquatic-terrestrial environmental continuum, CONTICOMIC has identified the limitations of current studies on these topics, as well as the needs in terms of concepts, methods and skills/disciplines required to advance research in this field.

CONTICOMIC - Assessment of the scientific challenges to better understand the role of the soil-water continuum in maintaining functional microbial biodiversity in agroecosystems

Taking into consideration the environmental continuums, including the interface zones, to study and manage ecosystems is gradually gaining interest in both scientific and operational spheres. In this context, the role of the soil-water continuum in maintaining biodiversity and ecosystem functions and services is increasingly questioned. However, this role is still very little studied, especially because of the compartmentalization of research by type of environment (e.g. soil vs surface water vs sediment) as well as of conceptual and methodological scientific limitations (including in terms of experimental set-ups that integrate terrestrial and aquatic compartments).

Agroecosystems, which carry high socio-economic stakes, are ecosystems that illustrate the importance of the soil-aquatic continuum, due to the close links between watersheds and adjacent aquatic environments, particularly in headwater sections. While these links are relatively well studied in terms of chemical transfers (e.g. nitrates, phosphates and pesticides), little attention is paid to biological exchanges between soil and aquatic environments. In agroecosystems, microbial communities are present in all environmental compartments, where they contribute to various ecological processes that contribute to a wide range of ecosystem functions and services.

Thus, these are study models that seem particularly well suited to addressing this type of issue, drawing in particular on the emerging concept of 'coalescence'.

In this context, ContiComiC aimed to conduct a collective reflection on the concepts of 'coalescence' and 'functional continuum' in agroecosystems and the approaches/methods to be developed to explore these concepts based on the study of microbial biodiversity and certain services it supports.

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Approaches

A working seminar held on 24 and 25 November 2021 brought together eight participants representing four INRAE research units/joint research units (RiverLy, Agréocologie, CARRTEL, EMMAH) and one non-INRAE joint research unit (LECA).

The seminar was divided into four working sessions, which respectively enabled participants to:

- Define the scientific framework and place the concept of microbial coalescence in the context of the soil-aquatic environment continuum.
- Identify the main scientific issues surrounding this concept.
- Take stock of the existing literature on the subject and conduct a critical analysis.
- Define the main conceptual and methodological needs and list the skills/disciplines to be mobilised.

Results

In addition to the importance of considering the various interface zones between environmental compartments, one of the main challenges identified concerns the need to better understand how coalescence processes in interface zones influence the ability of newly formed microbial communities to fulfil their ecological role, based on the functions to which they contribute.

The parallel literature review showed that few studies take into account coalescence processes along the soil-aquatic environment continuum. Furthermore, all the studies reviewed have methodological limitations (choice of spatial and temporal sampling strategy, failure to take the functional dimension into account), which make it difficult to assess the influence of this continuum on the structural and, above all, functional characteristics of microbial communities. On the other hand, recent methodological developments, particularly in the fields of "omics", bioinformatics and biostatistics, make it possible to envisage the implementation of new approaches that are particularly suited to the study of microbial coalescence processes at different environmental interfaces in agrosystems, addressing this from a taxonomic, structural and functional perspective.

Discussions and collective reflections also clearly highlight the need to mobilise a wide range of interdisciplinary skills in order to truly understand the role of the soil-aquatic environment continuum in maintaining functional microbial biodiversity in agroecosystems. The disciplines to be mobilised (apart from microbial ecology) include, but are not limited to, hydrology, pedology, modelling (of flows), bioinformatics, biostatistics and functional ecology.

Metaprogram
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DIMIVEA *Consortium results*

CONSORTIUM
2022-2023

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Keywords
Modeling
Carbon and nitrogen fluxes
Microbial and plant diversity
Soil

Thematics involved
Modelling
Microbial ecology
Plant-soil microorganism relationships

Divisions involved
ECODIV
AGROECOSYSTEM

INRAE units involved
UMR UREP
UMR IAM
UMR AGROÉCOLOGIE

External partnership
CREA Research Centre for Agriculture and Environment (Italy)
CNRS LIEC (Interdisciplinary Laboratory of Continental Environments)

Improving the accuracy of coupled simulations of carbon and nitrogen fluxes in agroecosystem soils

Focusing on carbon sequestration and biomass production, DIMIVEA has developed, based on existing models, a simulator that takes microbial and plant diversity into account to calculate carbon (C) and nitrogen (N) fluxes in soils. It provides a more accurate representation of coupled C-N cycles by incorporating an explicit and dynamic representation of biodiversity. This led to the MODIMIV project and the MODIMIR thesis, which aim to further improve the simulator.

DIMIVEA - Microbial and Plant Diversity in Multi-Species Agroecosystems - Modelling Relationships

Biogeochemical modeling is used to assess the impact of agricultural activities and climate on carbon cycles and ecosystem nutrients as well as associated services or di-service, such as biomass production, emissions/carbon storage and nutrient retention. From a perspective of agroecosystem, DIMIVEA is interested in the physico-chemical and biochemical characterization of soil, the functional diversity of plant and microbial communities and the definition of indicators of ecosystem services in order to better simulate the provision of ecosystem services.

DIMIVEA aimed to model community biodiversity dynamics to better simulate the provision of ecosystem services. The project sought to go beyond current simplified models by integrating biological diversity into explicit and dynamic simulators.

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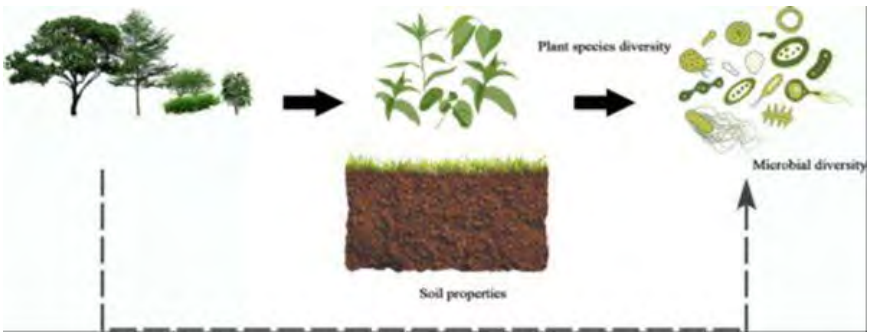

By focusing on the characteristics of plant and microbial communities in mixed vegetation cover, the consortium aims to provide a conceptual framework to extend the potential of models for reliable estimation of ecological processes supporting ecosystem services provided by these covers. Advancing towards the creation of explicit, dynamic, and integrated simulators of microbial and plant diversity, DIMIVEA represents a new paradigm that acknowledges the interconnected aspects of biological diversity in agroecosystem modelling studies.

Results

DIMIVEA, focused on understanding interactions between plant and microbial diversity in multi-species ecosystems, established conceptual bases by progressively integrating plant diversity dynamics into simulation models. These include a new integrated prototype aiming to simulate interactions among C-N flows, climate, and agricultural practices, while introducing plant diversity into C-N flow models. The prototyping approach sought to develop a dynamic conceptual framework linking biological diversity and biogeochemical fluxes, considering biomass, biogeochemical structure, and interactions with soil microorganisms.

The developed simulator offers a more accurate representation of C-N coupled cycles in agroecosystems, moving beyond usual simplified schemes by integrating explicit and dynamic biodiversity representation. Initially focused on carbon sequestration and biomass production, the project used coupled models ModVege (plant) and SYMPHONY (microbial).

Identified gaps in root representation, phenological dynamics, C/N ratio, and other processes will require parameter calibration to improve model accuracy. The dynamics of the C-N ratio and allocation within plants also play a crucial role to be explored

Scientific perspectives

The results and questions that emerged following the DIMIVEA project motivated the implementation of the exploratory MODIMIV project ("Modeling relationships between microbial and plant diversity in multi-species agroecosystems") and the MODIMIR thesis ("Modeling the effects of microbial diversity on the regulation of carbon and nutrient cycles in agroecosystems").

Metaprogram
BIOSEFAIR

DISPERSAL *Project results*

PATHFINDER PROJECT

2024-2025

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Keywords
Pastoralism
Natural and cultural heritage
Sociality
Biodiversity
Zoochory

Thematics involved
Behavioural ecology
Botany
Entomology
Geography

Divisions involved
ECODIV
GA

INRAE units involved
UR EFNO
UE P3R

External partnership
Centre-Val de Loire Nature Conservancy
UMR CITERES - INSA Centre-Val de Loire
Unité Biodiv'AG – University of Angers
Laboratoire d'éco-entomologie (environmental consultancy services)

Give preference to mixed flocks of sheep to limit the spread of exotic plants in their fleece

DISPERSAL shows the epizoochorous potential of sheep. Along the banks of the Loire river, sheep grazing pressure rapidly reduces food availability and necessitates frequent movement of flocks, thereby increasing the potential for seed dispersal. Sheep social behaviour influences seed transport, the presence of lambs reduces seed retention time, particularly that of an invasive alien species which is very common along the banks of the Loire river. Sheep grazing maintains a rich community of dung beetles.

DISPERSAL - Plant dispersal mediated by sheep pastoralism on the banks of the Loire River

The Loire carries sediments laden with seeds from native and exotic plants, which are deposited during flood and recedeing waters cycles on the river floodplains. At the interface between aquatic and terrestrial environments, DispersaL has investigated the impact of sheep grazing (as part of the Pasto'Loire initiative) on areas managed by the CEN (Conservatoire des Espaces Naturels) Centre Val de Loire. The focus was put on the ecological processes associated with the presence of domestic herbivores on the spatial and temporal dynamics of the flora in grazed areas, in particular herbivory and zoochorous dispersal. Certain benefits of sheep grazing are well established, notably the maintenance of open habitats and the risk reduction of log jams, but the potential risks associated with the spread of exotic plants within areas renowned for their biodiversity, in landscapes designated as UNESCO World Heritage sites, are much less so.

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Approaches

DISPERSAL assessed riverine inputs across various components of the flora: the soil seed bank, the local expressed flora, the grazed flora and the flora dispersed by sheep. In parallel, and on the same sampling plots, the entomofauna associated with pastoralism and involved in the recycling of organic matter was studied over two annual cycles.

In addition to in situ observations, an experiment was conducted under controlled conditions with Romane breed ewes and ewe lambs reared at the INRAE P3R experimental unit in Osmoy. It tested the effect of animal sociality on the epizoochorous dispersal of *Xanthium strumarium*, an invasive alien species found along the banks of the Loire river. We assessed the effect of the ewe-to-lamb ratio within the group on the retention time and dispersal distance of this plant.

Results

Cocklebur Xanthium strumarium, an invasive alien species found along the banks of the Loire river, produces fruits with hooks that facilitate their epizoochorous dispersal (though they can also float and be carried downstream). Its fruits were found in the fleeces of the majority of the sheep studied (18 out of 24 fleeces). Experiments with ewes and ewe lambs have also shown that these fruits can be dispersed over significant distances (several kilometres). The conditions are such that sheep grazing on sites where this plant is established act as vectors for the species' spread, and that, particularly as they move along grazing routes, this plant can invade the landscape.

The more ewe lambs there are in the flock, the shorter the retention times and the shorter the dispersal distances of the fruits. The social behaviour of ewe lambs (more contact with other animals and more individual grooming) causes the fruits to detach more quickly from the fleece or be transferred to other sheep with poorer fruit adhesion. From a practical perspective, managing mixed flocks comprising both adults and young tends to reduce the dispersal distances of this plant's fruits.

In the 24 fleeces studied, 35 different species were identified (between 3 and 13 different species and between 8 and 377 diaspores of a single species per fleece). These results confirm the high epizoochorous potential of sheep.

The floristic study conducted shows that sheep exhibit little food selectivity, with grazing having a significant effect, leading to a reduction in biomass (coverage by species), maximum plant height, species density and diversity. The stocking density present in each of the enclosures over a period of around ten days exerts grazing pressure that very rapidly reduces food availability and therefore requires regular movement from grazed areas to ungrazed areas.

The study of the soil seed bank (carried out by UMR Citeres) identified 117 taxa capable of germination. Five species account for more than half of the germinations (*Portulaca oleracea*, *Urtica dioica*, *Lindernia dubia*, *Digitaria sanguinalis* and *Cyperus fuscus*) and very few exotic species were detected.

The expressed local flora differs from the soil seed bank, but seed fall helps to explain part of the expressed flora.

The presence of sheep grazing along the banks of the Loire maintains rich communities of dung beetles (39 species identified, some of which are subject to protection status) involved in the recycling of organic matter.

Publication

Roux, A., Balson, C., Audiguier, M., Battista, M., Marcon, D., Pays, O., Baltzinger, C. (2026). Age ratio in groups of a social ungulate affects epizoochorous dispersal and diaspore exchanges, *Oikos*, e11894

Metaprogram
BIOSEFAIR

DYNAMIC *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Common birds
Landscape
Farming systems
Collective water management
Marais poitevin

Thematics involved
Agronomy
Agro-ecology
Ecology
Geomatics
Hydrology

Divisions involved
ACT
ECODIV

INRAE units involved
UE Saint-Laurent-de-la-Prée
UMR SADAPT
UMR DYNAFOR

External partnership
UMR CESCO - OFB/MNHN
Marais Poitevin Public Agency
Vendée Chamber of Agriculture

Poitevin Marshland, agricultural landscapes that have remained stable since 2010 and bird communities shaped by water levels and farming practices

DYNAMIC demonstrates that the stability of crop rotations and semi-natural landscape components in the Marais Poitevin is largely linked to the soil and climate constraints of the various sites. Bird communities are shaped by agricultural practices in floodplains and croplands.

DYNAMIC - Recent changes in bird communities in relation to the dynamics of farming systems and landscapes in marshlands

For several decades, changes in agriculture across Europe – including both intensification and abandonment depending on the geographical context – have been partly responsible for a significant shift in biodiversity, with bird populations in agricultural environments being particularly affected (an overall loss of 48% of European populations over 30 years).

Spatial scales, ranging from the farm to the landscape, are recognised as being particularly important to consider in the context of agroecological transitions and the reconciliation of agricultural production with biodiversity conservation. However, few studies have examined the joint evolution of agricultural systems and biodiversity at these scales.

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Approaches

Dynamic explores, within the agroecosystems of the Marais Poitevin, how bird communities have evolved over more than a decade at three sites, particularly in relation to changes in agricultural systems. These sites, each covering approximately 1,000 ha, feature varying proportions of grassland and managed crops (100% grassland, 50-50 grassland–crops, and 100% crops). They have already been monitored during two periods (2010–2012 and 2022–2023) for their bird populations and the cropping and livestock systems implemented by around thirty farmers.

The DYNAMIC project aimed to:

- Supplement the ecological data required to analyse variations in bird communities, particularly in relation to changes in water levels;
- Update the mapping of crop rotations and semi-natural features;
- Propose a method for analysing the joint variations in landscape, agricultural and bird community components.

Results

Analysis of crop rotation data and the semi-natural components of the landscape reveals a high degree of stability in the agricultural landscapes across the three monitored sites between the two periods. Given the soil and climate constraints at the various sites and existing regulations, grasslands exhibit a high degree of stability (due to the waterlogged nature of the soils). Conversely, climatic constraints and soil conditions limit the scope for crop

diversification within the cultivated area. Crop rotations remain dominated by durum wheat, sunflowers and maize, with a high degree of uniformity in the practices applied across the different crops.

Specific studies were carried out to model water levels in the floodplains of the three sites for the two periods under study. Using satellite imagery, a digital elevation model and direct field surveys, it was possible to identify the flooded areas and the water levels in the plots for the year 2025. Climate changes (distribution and intensity of rainfall) do not allow the DTM to be extrapolated for previous years.

For both periods analysed, bird communities show a high degree of structure across the three study sites. The 'grassland' site features communities dominated by waterbirds and species specialised in grassland habitats. The 'mixed' site hosts communities specialising in open agricultural habitats and grassland species, with a heterogeneous internal structure. The 'crops' site is predominantly home to species specialising in open agricultural habitats.

Metaprogram
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ECART *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Green tree retention
Microclimate
Tree crown
Biodiversity
Tree dieback

Thematics involved
Micrometeorology
Community ecology
Forest ecology
Bryology
Mycology
Forest ecophysiology

Divisions involved
AGROECOSYSTEM
ECODIV
PHASE

INRAE units involved
UR EFNO
URZF
UMR BIOGECO
UMR ISPA
USC Ecodiv-Rouen
UE PAO

External partnership
National Forestry Office (ONF)
National Center for Forest Ownership (CNPF)
Forest Health Department (DSF)

New methods for describing the vertical distribution of microclimates and communities developing on tree trunks

ECART has tested a system for measuring microclimatic variables and a tool for collecting spores in the canopy. These data have been used to investigate the factors influencing the distribution of this biodiversity within trees. Initial results show distinct associations of bryophyte species between the upper trunk, the base of the trunk and the rest of the crown, as well as a negative effect of tree decline on bryophyte richness in the upper part of the tree

ECART - Do retention trees remain efficient for forest biodiversity conservation in a climate change context?

Retaining perennial habitat trees that have been spared from logging is recommended to promote forest biodiversity. Ongoing climate change is exposing these trees to increased stress (drought, heat waves, pests, and herbivores), leading to dieback, particularly in regeneration gaps. Managers are questioning the effectiveness of retention trees in these situations: can associated forest species fulfill their niche if the tree dies quickly?

At the forest-atmosphere interface, tree crowns are the first to be exposed to sunlight: from above if they are in a closed stand, and over their entire height if they are isolated or on the edge of the forest. Their defoliation may alter the spatial structure of the forest microclimate. We hypothesize that the partially defoliated crowns of dying trees reduce the buffering effect of forest cover on the microclimate of the understory, as well as the temperature and humidity differences between the inner and outer crowns.

The project aims to:

- Describe the stratification of microclimates and communities in trees (little-known aspects in tree crowns),
- Identify the factors that may influence this stratification, with hypotheses on the health status, species, position of the tree in the center or edge of the island, and size of the island,
- Carry out the methodological developments necessary for acquiring canopy data.

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Approaches

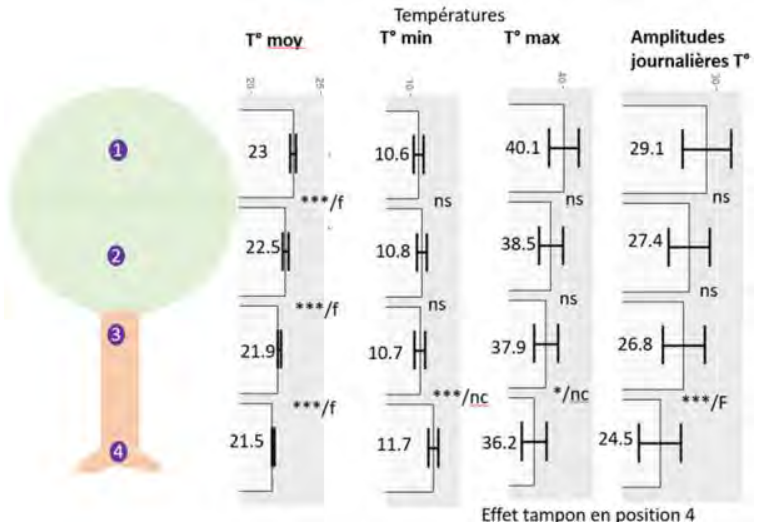
The project is based on three ecological questions and three methodological questions.

From an ecological perspective, how are micrometeorological variables (air temperature and relative humidity) and epiphytic biodiversity (bryophytes, lignicolous fungi) structured in the canopy and on the trunk, depending on whether the oak trees are healthy or dying (question E1), on sessile oaks vs. pedunculate oaks (question E2), on sessile oaks at the edge vs. in the center of the block, and depending on the size of the block (question E3)?

From a methodological point of view, data acquisition required the prototyping and deployment of a system for measuring microclimatic variables at eight points on the tree along a double vertical gradient (four points along the trunk) and horizontal gradient (four points in the crown, two in the inner crown and two in the outer crown). This autonomous system measured and transmitted data remotely once every hour for a year: the DC prototype, a wired system based on the daisy-chaining principle, was deployed on all sampled trees (question M1) and compared on one of the trees with the wireless mPi solution (question M2). Finally, a test of automatic bryophyte and fungus spore sensors, potentially useful for canopy inventories, was carried out as proof of concept (question M3)

Preliminary results

Health gradient data were collected in 2024 on six pairs of healthy/dying oak trees in closed mature stands (Vierzon and Tronçais state forests). Question E2 will be addressed using bryological data from the trunk base only. Data on 20 trees in the center or on the edge of islands is currently being collected (2025-2026) in the Vierzon, Orléans, and Saint-Palais state forests. The micrometeorological variables for 2024 were analyzed using generalized linear models with mixed effects (effects of position in the tree, health status, or their interaction), as was bryological richness (effects alone or in interaction with position, health status, and micrometeorological variables). The composition of bryophyte communities was analyzed using canonical correspondence analysis.



These initial results were discussed on December 3, 2025, at a workshop bringing together project partners, forest managers (4 CNPF, 2 DSF, 7 ONF), other researchers from INRAE (URFM, ISPA, PIAF, LESSEM) and other institutes (EDYSAN laboratory – University of Picardie). The contributions of the various disciplines made it possible to identify valuable insights, areas for improvement (experimental design, formulation of hypotheses, or data processing methods), gaps (variables not taken into account in the sampling), and resources to be mobilized. Many issues remain to be studied in order to assess how climate change and tree decline influence the effectiveness of retention practices and identify the most appropriate practical recommendations.

Metaprogram
BIOSEFAIR

IFOSSA *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Agroforestry
Functions
Soil
Networks

Thematics involved
Agronomy
Ecology of interaction networks
Microbial ecology
Invertebrate ecology
Tree ecophysiology
Soil functions
Microfauna
Macrofauna
Plant phenology

Divisions involved
AGROECOSYSTEM
BAP
SPE

INRAE units involved
UMR ECO&SOLS
UE DIASCOPE
UMR DGIMI
UMR PHIM

A comprehensive inventory of biodiversity and soil functions in agroforestry

IFOSSA compared the biodiversity present in an experimental agroforestry system across four land-use scenarios (agricultural control, forestry control, and two agroforestry scenarios: linear under-canopy and cultivated alley). It provides an inventory of the faunal groups present during the growing season (several hundred taxa). At the same time, soil functions (weed and pathogen control, organic matter dynamics and structural stability) were analysed according to these land-use treatments.

IFOSSA - Distribution of interaction networks and functions in a spatially heterogeneous system, case of agroforestry

Agroforestry, broadly defined as the presence of trees in agricultural landscapes, is an example of mixed farming that increases "planned biodiversity". Thanks to their perennial structures, these trees create a microclimate that varies over time, leading to changes in the associated biodiversity and the activity of organisms through habitat diversification. However, few studies have looked at the effects of agroforestry on soil organisms and the functions they perform.

The main hypothesis is that introducing trees alters the spatial structure of fields in ways that enhance biodiversity and multifunctionality in agricultural landscapes.

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Approaches

This study was carried out at the DIAMs trial (Mediterranean Agroforestry under Water Constraints), located South of Montpellier at the INRAE experimental station UE Diascope (Mauguio). The experimental design covers 5 hectares and follows a factorial layout with three blocks. Each block compares three treatments: forest plantations (black locust, *Robinia pseudoacacia*), an agroforestry system, and arable crop plots. Within the agroforestry system, two main habitats are distinguished: tree rows with associated grassy strips and inter-row cultivated alleys. Crops (rotations of cereals and legumes) are managed under conventional low-input practices. The site is fully instrumented, enabling continuous monitoring of radiation at the soil surface, soil temperature and moisture at different depths, root growth, and soil solution nutrient concentrations. Four treatments are studied: arable control (C), forest control (F), and, within agroforestry, tree row (AF-LSA) and cultivated alley (AF-C).

In each treatment and block, five georeferenced sampling points were selected, providing five field replicates to capture variability. In total, sixty measurements per variable (biodiversity, function) were obtained.

Biodiversity was assessed through multiple approaches: environmental DNA metabarcoding (bacteria, fungi, protists), Baermann funnel extraction (nematodes), Macfadyen method (microarthropods), soil hand-sorting (macroinvertebrates), pitfall traps (surface-dwelling macroarthropods), pan traps (flying arthropods in the canopy), leaf dissection (foliar arthropods), camera trapping (mammals), photographic surveys (pollinators).

Multifunctionality was measured through :

- weed seed predation assays (seed cards),

- soil suppressiveness against root-knot nematodes (Meloidogyne javanica) in laboratory assays,
- litterbag experiments assessing decomposition of black locust litter,
- soil aggregate stability (mean weight diameter of macroaggregates after wet sieving),
- monitoring of crop growth and yields, as well as black locust growth and resource allocation strategies.

Results

Biodiversity

Morphological and molecular identification characterized communities of soil engineers, surface-dwelling macroarthropods, free-living and parasitic nematodes (plant-feeding and entomopathogenic), fungi and bacteria (both free-living and nematode-associated), weeds, and aerial invertebrates (herbivores, predators, parasitoids). Several hundred taxa were identified, providing an almost exhaustive inventory of taxa and trophic groups present during the growing season (some protocols were repeated three times in spring). Key findings include:

- **Herbivory by mammals.** Rabbit activity-density was higher in agroforestry plots than in monocultures.
- **Flying insects.** Invertebrate diversity was higher in the presence of trees than in cultivated areas. However, more individuals were collected in pan traps from monocultures than from forest plantations, with agroforestry showing intermediate values. Trophic group composition shifted with land use and across the growing season.
- **Surface macrofauna.** Tree presence did not affect the abundance and diversity of surface-dwelling invertebrates, unlike findings from the literature where agroforestry often enhances soil organism diversity.
- **Free-living nematodes.** Monocultures showed higher diversity of herbivores and lower diversity of predators compared to other treatments.

Soil functions

Interaction networks were reconstructed from field observations, either directly (bipartite interactions) or inferred by combining co-occurrence data with trophic knowledge bases on soil organisms. Structure and composition of reconstructed networks were analyzed in relation to agroforestry spatial organization. Highlights include:

- **Weed regulation.** Seed predation was highest in arable controls (~70 %) and lowest in forest controls (~30 %). Late-winter granivore activity (mainly Carabidae) was greater in arable plots than in agroforestry or forest treatments, likely reflecting species selection.
- **Suppression of phytoparasitic nematodes.** Greater suppressive capacity was observed in samples from vegetated plots compared to monocultures.
- **Insect control:** Agroforestry appears to have a positive impact on the life cycle of entomopathogenic nematodes, which are key organisms in soil food webs.
- **Soil structural stability.** Water infiltration rates were significantly higher under tree rows compared to inter-row alleys, highlighting the positive role of tree rows in field hydrology. Soil structural stability and infiltration rates were strongly correlated with soil organic carbon, underlining the structuring role of organic matter status for other soil functions.

These results still require further integration, particularly to link biodiversity and functional patterns in agroecosystems. Some findings are already published or in press, while others will not be published but will serve as a basis for broader reflections on biodiversity assessment in diversified agroecosystems under Mediterranean climate constraints.

Publications

Masson, A.-S., Bouton, F., Bellafiore, S., Aribi, J., Marsden, C., Hedde, M., Trap, J. (2025) Soil fauna in agroforestry contributes to the suppressiveness to plant-parasitic nematodes: a case study in a Mediterranean area. *Applied Soil Ecology*, 208. pp.105962

Vion–Guibert, L., Marsden, C., Degrune, F., Forest, M., Henon, N., Masson, A.-S., Notton, D, Orrière, S., Trap J., Verheyde, F., Versavel, C., Vignac, P., Hedde M. (2026) Mediterranean alley–cropping agroforestry modifies arthropod temporal dynamics with divergent effects on trophic groups. *Agriculure, Ecosystems & Environment*, 397.

Metaprogram
BIOSEFAIR

iSERV *Project results*

EXPLORATORY PROJECT

2023-2025

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Keywords
Intraspecific diversity
Restocking
Nutrient cycle
Biomass production
Economic assessment

Thematics involved
Evolutionary and functional ecology
Population genetics
Metabolic theory of ecology
Economic evaluation
Environmental chemistry
Fish management and ecology
Scalimetry

Divisions involved
AQUA
ECODIV
ECOSOCIO

INRAE units involved
UMR CARRTEL
UMR DECOD
UMR RECOVER
BETA

External partnership
SETE CNRS
Fishing federation Haute-Savoie
Approved Association for Fishing and the Protection of Aquatic Environments - Annecy

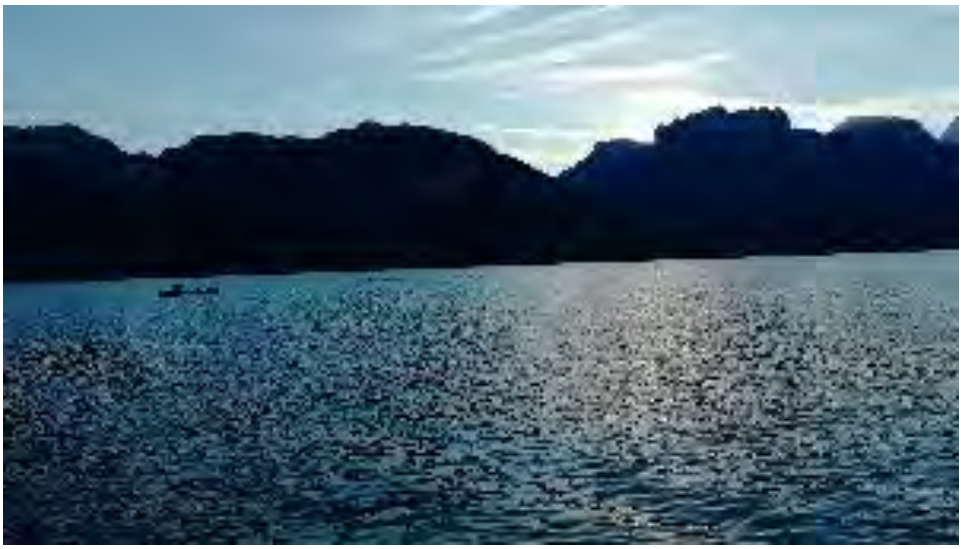
Fish restocking has an effect on the population and functioning of lakes

iSERV has shown that the current population of Arctic char in Lake Annecy relies predominantly on restocking. The results suggest that the origin of the fry influences temperature tolerance. They show that char alters the structure of aquatic communities, though with little effect on the functioning of the lake. Restocking could therefore alter the lake's ecosystem services. Potential conflicts between users are identified when they are asked about their preferred management of the lake.

iSERV - Relationship between intraspecific diversity and ecosystem services: role of fish stocking practices

Intraspecific diversity plays a major role in ecosystem functioning. However, it is strongly affected by human activities. For example, freshwater fish are subject to pressure from climate change, fishing, pollution and management practices such as restocking. These species support major ecosystem services, such as fish production, nutrient regulation and water quality. Changes in their intraspecific diversity could therefore have significant ecological and socio-economic consequences.

This project investigated the effects of Arctic char (*Salvelinus umbla*) restocking practices in alpine lakes on the links between intraspecific diversity and ecosystem services. Restocking can alter intraspecific diversity, indirectly affecting fish biomass and nutrient cycling, which are important services for fisheries and water quality. Nevertheless, the links between fish management practices and ecosystem services remain largely unexplored.



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Approaches

The iSERV project consisted of three components in order to:

- Link intraspecific diversity resulting from restocking to the nutrient cycle (regulatory service) at the individual and ecosystem scales using a mesocosm approach;
- Quantify *in situ* the effects of restocking on genetic diversity and fish biomass production (production service);
- Quantify the local population's preference for char conservation strategies.

Results

Studies conducted in Lake Annecy show that the current Arctic char population is highly dependent on stocking, as naturally reproduced individuals are very scarce. Fish from local fish farms and naturally occurring individuals had very similar genetic structures, growth rates and phenotypic traits, suggesting a close relationship between these origins. In contrast, fish from Lake Geneva fish farms were slightly genetically differentiated and showed higher growth rates. Despite contrasting stocking intensities, individuals from both fish farms contributed comparably to the population, indicating that the origin of stocked fish may influence their survival and contribution to total biomass, a key service for fisheries.

Laboratory experiments have revealed functional differences depending on the origin and date of spawning of the fish, particularly in terms of zooplankton consumption and ammonium excretion, with contrasting thermal responses. These variations suggest that restocking could alter the nutrient cycle and trophic functioning of the lake, particularly in a context of global warming.

Finally, a mesocosm experiment showed that Arctic char influence the structure of aquatic communities through top-down effects on zooplankton and that differences between origins could alter the abundance of certain taxa present in the community. The overall effects on ecosystem functioning were moderate. Overall, the project highlights that restocking practices affect intraspecific diversity and, possibly, associated ecosystem services.

The socio-economic component of iSERV analysed public preferences regarding the management of recreational uses and fish stocks in Lake Annecy (through a stakeholder workshop and a survey of around 1,000 people). The results highlight a significant willingness to pay for tighter control of lake use and, in particular, for restocking strategies based on local genetic resources. However, fishermen and non-fishermen have different expectations regarding the regulation of usage and management strategies, which confirms the potential for tension between different user groups and highlights the importance of taking this diversity of preferences into account in public decision-making.

Metaprogram
BIOSEFAIR

ISO SGDC *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Genetic diversity
Taxonomic diversity
Lake
Macrophytes
Management

Thematics involved
Bioinformatics
Molecular biology
Community ecology
Population genetic
Taxonomy

Divisions involved
AQUA
ECODIV

INRAE units involved
UR EABX
UMR BIOGECO

External partnership
National Botanical Conservatory South Atlantic
SIAEBVELG : management union of the Carcans-Hourtin and Lacanau lakes and Natura 2000 site coordinator
Community of Communes of the Great Lakes: Natura 2000 site coordinator
Black Pond National Nature Reserve: protected area manager
Landes Nature Association: Natura 2000 site coordinator

New genetic markers for identifying heritage plant species from the Aquitaine coast - ISO SGDC

To contribute to the conservation of nine heritage plant species found in the lakes of Aquitaine (Isoetes), ISO-SGDC has developed genetic markers and a protocol for genotyping them with high precision using high-throughput sequencing. The routine implementation of this method will enable a detailed characterization of plant genetic diversity.

ISO SGDC - Relationship between taxonomic and genetic diversity of aquatic plants in lakes of the Atlantic coast

The role of genetic diversity in maintaining species diversity and ecosystem functioning is now widely recognised. In the face of environmental change, this diversity contributes significantly to the resilience of ecosystems and the adaptive capacity of species. Integrating genetic diversity within species is therefore essential in order to implement management and conservation measures. The lakes and ponds of the Aquitaine coastline, ecosystems that are unique on a national and European scale, are home to significant plant biodiversity that is now seriously threatened. While the taxonomic diversity of these communities is well known, knowledge of their genetic diversity is currently non-existent. However, improving this knowledge seems essential for better management of these ecosystems, particularly for their heritage species. Joint analysis of the relationships between species genetic diversity within a community and taxonomic diversity of communities (species–genetic diversity correlations) provides a better understanding of how communities function and the processes responsible for the assembly of their species. Studying these two levels of diversity also makes it possible to assess whether the taxonomic diversity commonly used in conservation practices adequately takes into account the evolutionary processes revealed by genetic diversity.

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Approaches

To this end, nine species belonging to the "isoetid" communities of five water bodies on the Aquitaine coast were sampled: Lobelia dortmanna, Littorella uniflora, Baldelia ranunculoides, Myriophyllum alterniflorum, *Juncus bulbosus, Schoenoplectus pungens, Eleocharis multicaulis, Phragmites australis* and *Chara fragifera.* In total, more than 4,000 individuals were collected from all the water bodies during the spring of 2022 and 2023. Around a hundred genetic markers (microsatellites) were identified and developed for each species.

Results

ISO-SGDC has enabled the development of genetic markers and a protocol for genotyping them with high precision using high-throughput sequencing. One of the challenges was to identify experimental conditions suitable for the diversity of the plant species studied.

Analysis of the genetic structure of the different species revealed varying levels of genetic diversity depending on the species. Overall, the most common species possess greater genetic diversity, whereas rare and threatened species exhibit lower diversity. A regional pattern of diversity was highlighted for certain species, with strong genetic differentiation despite geographical proximity. A pattern of isolation by distance was identified for all species, but with varying intensity across taxa, reflecting contrasting dispersal capabilities.

Analysis of species-genetic diversity correlations (SGDC) reveals a marked scale dependence for all eight species. In *B. ranunculoides* and *S. pungens*, the correlation is entirely driven by environmental factors (lake surface area, hydraulic connectivity, natural cover). For the other species, the results suggest that local demographic processes and regional dispersal constraints structure biodiversity in a decoupled manner.

These results demonstrate that dispersal limitation and environmental filtering processes act jointly to structure the biodiversity of coastal lakes in Aquitaine. The conservation of habitats of Community interest (3110) requires a balanced approach combining local management of habitat quality and regional management of functional connectivity.

This project is eagerly awaited by managers, particularly the South Atlantic National Botanical Conservatory (CBNSA), as part of the coordination and implementation of the national action plan for these species.

This work is a continuation of the multi-partner project Vigie Lacs (https://www.biodiversite-nouvelle-aquitaine.fr/connaitre/enjeux-de-territoire/le-projet-vigie-lacs/).

A thesis supported by Biosefair was associated with this project: ISOTÉIDES - The biodiversity of Aquitaine's coastal lakes is shaped by the limited dispersal capacity of species and environmental filtering mechanisms – see p. 76

Publication

Debailleul, E-M., Jamoneau, A., Lepais, O. (2026) Genetic diversity of aquatic macrophytes in Aquitaine lakes. *Conservation Genetics*, 27 (1), pp.20

Metaprogram
BIOSEFAIR

LANDEV *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Contract
Property
Land
Environment
Agriculture

Thematics involved
Sociology
Geography
Law
Economics
Ecology

Divisions involved
ACT
AgroEcoSystem
BAP
ECODIV

INRAE units involved
UMR SADAPT
UMR BAGAP
UMR Innovation
UMR AGROÉCOLOGIE
UMR SMART

External partnership
Federation of conservatories of natural areas

Are environmental easements (ORE) a suitable mechanism for protecting ordinary nature?

LANDEV has shown that, thanks to their flexibility, environmental easements appear to be a suitable tool for protecting land whilst maintaining agricultural activity in the long term. However, most of the operators surveyed consider that the ecological benefit of compensatory OREs is low. This study highlights the current limitations of OREs, but also shows that they contribute to the diversification of responsibilities and stakeholders, to cooperation and to the development of expertise

LANDEV - Land property and EnVironmental contracts in agriculture

Faced with the erosion of biodiversity, public policies have set an ambitious agenda, as illustrated, for example, by France's national biodiversity strategy. This strategy sets out a plan for the protection and restoration of ecosystems, with the aim of establishing protected areas covering 30% of the country, including 10% of high-level protection. In this context, public environmental policies are reflected in increasingly diverse and sophisticated contractual tools, most of which have a direct or indirect impact on land ownership rights, which need to be documented empirically.

The objective of our exploratory project is to study how land ownership influences contractual practices within the framework of these contracts and to propose a reflexive analysis of contract terms and specifications with an environmental focus when they impact the rights of the landowner, as the main manager (landowner-farmer or non-farmer landowner of natural areas that are not used for agriculture) or as the lessor of a farm tenant. The project is based on the observation that contractual practices affecting landowners, both public and especially private, are still insufficiently documented.

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Approaches

Among the various contractual objects identified as areas of investigation when the research project was designed, the LANDEV project team focused on an exploratory study of practices relating to real environmental easements (ORE), due to the sharp acceleration of these local initiatives over the last three years. The research focused on identifying and analysing case studies relating to real environmental obligations, in partnership with organisations particularly involved in the governance of these contractual initiatives, in particular the French Office for Biodiversity and the Federation of Nature Conservatories. One of our objectives was to analyse the construction of specifications and the variability of contractual obligations identified through case studies, focusing on the assumptions that guide their adoption, the known inflections in the negotiation process and their expected impact on natural environments and the multifunctionality of landscapes. We also aimed to assess how the stakeholders involved perceived the tool, with a view to explaining the degree to which it has been adopted and mobilised by them.

From a social science perspective, we focused on the profile of the landowners involved, the multi-stakeholder governance of contractual arrangements, and the geographical characteristics of the areas concerned. From an ecological science perspective, we examined the nature of the contractual commitments, taking into account the types of natural environments concerned and the conservation or restoration actions envisaged.

Results

The conservation easements studied contribute to broadening and diversifying the range of actors involved in the preservation of natural environments. In some cases, they enable the mobilisation of private landowners, notaries, and nature conservation associations.

Work carried out on the methods of involvement of local authorities shows that conservation easments are used in this context to serve a variety of strategies: protecting biodiversity, but also preserving the quality and quantity of water resources, and supporting local agricultural projects based on public land ownership.

Finally, we analysed the influence of conservation easements on the territorial governance of ecological compensation. We highlight the ambivalent role of this legal tool: it brings innovation in terms of duration, contractualisation and diversification of actors, but is also limited by ecological gains that are still perceived as low by most of the stakeholders surveyed. This legal tool has certain limitations related to the ability of stakeholders to make a long-term collective commitment and to manage potential difficulties, such as tensions between parties, the disappearance of stakeholders, the effects of climate change, or other unforeseen events.

Despite these limitations, these contracts encourage cooperation and sometimes promote the emergence of new skills among private landowners, associations and local authorities in the field of nature conservation and restoration.

CONSORTIUM
2022-2023

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Keywords
Meta-ecosystem
Socio-hydrosystem
Ecosystem services

Thematics involved
Agroecology
Community and landscape ecology
Trophic ecology
Functional ecology
Ecohydrology
Eco-evolutionary dynamics
Continental hydrosystems, lakes, rivers, esturaries
Hyporheic zones
Macroecology
Biodiversity modelling

Divisions involved
AGROECOSYSTEM
AQUA
ECODIV
MATHNUM

INRAE units involved
UR RiverLy
UR HYCAR
UR EABX
UMR CARRTEL
UMR LISC
UMR LISAH
UR DECOD

External partnership
IEES - Institute of ecology and environmental sciences of Paris - National Center for Scientific Research
MARBEC - Marine biodiversity exploitation and conservation - University of Montpellier
CESCO - Center for Ecology and Conservation Sciences - National Museum of Natural History
SETE - Theoretical and Experimental Ecology Station - National Center for Scientific Research
University of Floride

Application of the meta-ecosystem concept to the services provided by water systems

METAECOSERV has published a conceptual article published in the journal Bioscience, titled "Integrating the meta-ecosystem framework into the dynamics of ecosystem services in socio-hydrosystems."

METAECOSERV - The concept of metacommunities as a tool for understanding and managing ecosystem services in hydrosystems

Freshwater ecosystems, which serve as biodiversity hotspots and key providers of ecosystem services, are among the most threatened ecosystems on Earth. Management measures for these ecosystems have traditionally been designed at the local scale, based on the concept of ecological niche, without necessarily accounting for landscape variability in action plans–a factor that has often limited the success of these measures. Today, our understanding of how biodiversity and ecosystem services are organized within these dynamic environments has advanced considerably, particularly thanks to the emergence of the concepts of metacommunities and metasystems, which formalize the processes and dynamics operating at different spatiotemporal scales of communities and ecosystems. The meta-ecosystem framework, which focuses on the flows of organisms, matter, and energy between ecosystems at different spatial and temporal scales, offers valuable tools for more holistic ecosystem assessments. However, the contribution of these concepts to the field of aquatic ecosystem services has not yet been formalized, tested, or translated into management tools.

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METAECOSERV has adapted the contributions of meta-system theory and its corollaries to the understanding and management of ecosystem services supported by water systems, with the aim of better understanding the links between biodiversity and ecosystem services and their spatio-temporal organization within landscapes. This work has identified relevant spatial scales for managing hydrosystems in the context of global change. Indeed, better integration of the regional ecological processes involved in the spatio-temporal organization of biodiversity into management practices will enable the effective conservation and restoration of biodiversity and associated ecosystem processes in a changing global environment, particularly in the face of extreme events (floods, droughts, storms) that repeatedly alter the physical and ecological connectivity of hydrosystems.

Results

METAECOSERV has published a conceptual article on the value of studying hydrosystems within a meta-ecosystem framework. Such a unified framework is essential for understanding how ecosystem services are influenced by the spatiotemporal dynamics of organisms, matter, and energy, enabling us to better understand how changes in one part of the hydrological system translate into changes in other parts. The proposed framework also helps identify synergies and trade-offs between ecosystem services and the influence of environmental conditions. Finally, this unified framework enhances our ability to inform decision-making, design adaptive management strategies that account for changing environmental conditions–particularly in the context of climate change–and mitigate social inequalities.

Publication

Truchy, A., Eme, D., Jabot, F., Vinatier, F., Jamoneau, A., Petit, E.J., Villeneuve, B., Carassou, L., Datry, T., Jeliazkov, A. (2025). Integrating metaecosystem framework with ecosystem service dynamics in sociohydrosystems. Bioscience, 76, pp238-253

Metaprogram
BIOSEFAIR

METAGROFORESTRY *Project results*

EXPLORATORY PROJECT

2023-2025

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Keywords
Agroforestry
Meta-ecosystem
Nitrogen
Spatial distribution
Tree-crop interaction

Thematics involved
Theoretical ecology
Ecological modelling
Flow modelling
Mathematical modelling
Ecology of meta-ecosystems
Study of microfauna
Macrofauna and soil functions

Divisions involved
AGROECOSYSTEM
ECODIV
MATHNUM

INRAE units involved
UMR ECO&SOLS
UMR MISTEA
UMR ABSys

External partnership
IEES - Institute of ecology and environmental sciences of Paris - National Center for Scientific Research

The spatial organisation of the agroforestry system influences the nitrogen cycle

A meta-ecosystem model has been developed to study nitrogen fluxes in agroforestry systems (AFS). Its application at the DIAMS experimental site has shown that the spatial organisation of the AFS, in interaction with agricultural practices, strongly structures the distribution of nitrogen stocks and fluxes between landscape sub-units, with consequences for crop production and the system's ability to limit nitrogen losses through leaching.

METAGROFORESTRY - Influence of the management and spatial arrangement of agroforestry systems on nitrogen recycling: a meta-ecosystem modeling approach

Agroforestry systems (AFS) combine trees, crops and/or pastures in order to optimise agricultural production while improving the provision of ecosystem services. Their functioning is based on complex interactions between plant and soil subunits, the intensity of which depends closely on the spatial organisation of the system and the associated agricultural practices. Among the key processes governing these interactions, the nitrogen cycle plays a central role in plant productivity, soil fertility and the sustainability of AFAs.

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This project was based on the hypothesis that the spatial arrangement of the sub-units of an agroforestry system, combined with management practices, is a major lever for influencing nitrogen flows, distribution and conservation within the system, via mechanisms of complementarity and transfer between sub-units. The main objective was to develop a modelling framework to jointly analyse the effects of spatial organisation and agricultural practices on nitrogen dynamics and to assess their consequences on plant production and system fertility.

Approaches

To achieve this objective, the project employed a modelling approach based on the concept of a meta-ecosystem, explicitly representing the various sub-units that make up an agroforestry system (trees, crops, herbaceous cover) and the nitrogen flows that connect them. The SAF is thus described as a set of ecosystems interconnected by material flows, the intensity of which depends on both spatial configuration and management practices

A dynamic mathematical model, based on a system of differential equations, was constructed to describe nitrogen stocks and flows within each sub-unit and between sub-units. The spatial parameters of the model correspond to the relative areas of the subunits and their functional overlap zones, defined by the spatial distribution of tree litterfall and the horizontal and vertical distribution of tree root systems. These overlaps determine the intensity of nitrogen transfers between subunits, particularly via litter inputs and competition for soil resources.

The model also incorporates the presence of deep tree roots, representing a "safety net" effect whereby trees can capture nitrogen that has leached into deeper horizons and contribute to its redistribution to surface layers via litter. Agricultural practices (sowing, harvesting, fertilisation, residue management, tree pruning) are incorporated in the form of disturbances to stocks and flows, in order to represent the managed and temporally structured nature of SAF.

The model was applied to a Mediterranean agroforestry system studied at the DIAMs (Mauguio) experimental site. Its parameterisation was based on existing data, supplemented by new field measurements of the nitrogen content of different plant biomasses in the system's subunits. These measurements provided information on the nitrogen content of the system's various plant components and enabled the orders of magnitude to be integrated into the model

Results

The results show that the spatial organisation of the SAF, in interaction with agricultural practices, strongly structures the distribution of nitrogen stocks and flows between sub-units, with consequences for plant production and the system's ability to limit nitrogen losses through leaching. Beyond the case study, the project provides a generic and transferable modelling framework for exploring scenarios for the management and spatialisation of SAF, contributing to a better understanding of the biogeochemical functioning of these complex agroecosystems.

Metaprogram
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MICROBIOMIQ *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Aquatic microbial communities
Metomics
Microbial biodiversity
Ecosystem functions
Ecotoxicology

Thematics involved
Algal composition analysis
Lipid analysis
Multi-omics statistical analyses
Physico-chemical measurements
Metabolomics
Metagenomics

Divisions involved
AQUA
ECODIV

INRAE units involved
UR EABX
UMR BIOGECO

The photosynthetic activity of aquatic microbial biofilms subjected to chemical stress varies over time

The combination of metagenomic and meta-metabolomic analyses deployed in MICROBIOMIQ has characterised aquatic microbial biofilms in terms of biodiversity, function, variation over time and response to chemical stress (herbicide pollution). The metadata collected will subsequently support the development of management tools for biomonitoring water quality.

MICROBIOMIQ - Multiomic approach to characterize the link between the structural biodiversity and the microbial activity along the natural evolution of periphytic biofilm

Periphytic microbial communities are complex assemblages of micro-organisms (algea, bacteria, fundi, cyanobacteria, protozoa) that are attached to immerged substrates (inert or alive) in most of aquatic ecosystems. These communities play a tremendous role in ecosystems functions and associated services (e.g. primary production, biogeochemical cycles).

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In the global change context, one major challenge for human and environmental health is to better understand the response of microbial communities to multiple stressors in terms of acclimation, adaptation and resilience in order to preserve ecosystem function and services. In particular, as regard chemical contamination of aquatic systems, one major goal is to characterize how the natural fluctuation of the structural biodiversity and microbial community functioning due to environmental changes might modulate their sensitivity to the chemical stress.

In this context, the omics methods and their combination pave the way to new perspectives in microbial eco(toxi)cology to tackle the knowledge gap. Among others, these omics encompass:

- Metagenomic allowing to explore simultaneously the diversity of species within a microbial community and its functional potential (gene reservoir);
- Untargeted meta-metabolomic providing a comprehensive picture of the microbial activity in response to the environment by analyzing all the small molecules from biochemical reactions within the community.

MICROBIOMIQ aims to better understand the link between the microbial activity (i.e. metabolome), the structural biodiversity (diversity of species and genes) and the sensitivity to the chemical stress associated to natural fluctuation in the species composition and the functioning of periphytic communities due to changing environmental conditions along the year. Thus, through the combination of metagenomic and meta-metabolomic on periphyton, this project will focus on the modulation of the photosynthetic function that is strongly involved in primary production and overall biogeochemical cycles.

The outcomes of the project will allow to better understand the adaptive mechanisms (e.g. phenotypic plasticity) in the sensitivity of ecosystem functions (i.e. photosynthesis) to the chemical stress and their time sequence. The collected data would be further used to support the development of management tools in a water quality biomonitoring purpose.

Approaches

MICROBIOMIQ combines in situ investigations (longitudinal monitoring over 15 months – one measurement per month in a pond) with laboratory experiments (monthly acute exposures), based on a multidisciplinary approach that integrates metagenomics, meta-metabolomics, measurements of photosynthetic activity and the physico-chemical characterisation of the environments. The combination of these methods provides an innovative and precise understanding of the interrelationships between changes in environmental factors, taxonomic diversity, microbial activity and photosynthetic function, as well as their sensitivity to chemical stress under natural and controlled conditions, supported by bioinformatics approaches.

In situ sampling measured the taxonomic structure, microbial activity and photosynthesis of periphyton in parallel with monitoring of water physico-chemistry and meteorological conditions.

On a monthly basis, a portion of the collected periphyton was exposed to a model herbicide (terbuthylazine) for 4 hours to determine the community's sensitivity at the molecular/biochemical (metabolomic) level and at the physiological/functional (photosynthetic yield) level.

A four-week exposure experiment was conducted in channels using periphyton collected from the same pond. The taxonomic composition, microbial activity and photosynthetic activity of the periphyton were measured at the start of the experiment and then after 24 hours, 72 hours, 1, 2, 3 and 4 weeks, alongside monitoring of the water's physico-chemical parameters.

Results

No correlation was found between taxonomic diversity and metabolic diversity, indicating a certain degree of asynchrony between structural biodiversity and functional biodiversity (Q1). However, alpha taxonomic diversity was found to be correlated with temperature variations: the diversity of all taxa (presence/absence) decreases with temperature, whilst that of typical and dominant taxa increases with temperature. The predominant role of temperature in taxonomic structuring is highlighted, whilst microbial activity appears to be influenced by a greater number of factors, particularly nutrients (SO4, NO3) (Q1).

In parallel with these dynamics in community structure and function, a change in sensitivity was observed at the metabolome level, whilst the sensitivity of photosynthetic function remained relatively stable (Q2).

MICROBIOMIQ highlights significant heterogeneity in the metabolome's response to terbuthylazine in terms of the number of metabolites, response profiles and metabolite classes, suggesting that toxicity pathways may vary over time. These results suggest that similar physiological responses may arise from various molecular pathways.

The project's findings enhance our understanding of the link between natural changes in microbial biodiversity and the functioning of periphytic aquatic communities, as well as their sensitivity to chemical stress. This new knowledge is an essential prerequisite for establishing models capable of predicting, in the context of global change, the evolution of ecosystem functions and associated services based on the measurement of biodiversity descriptors (eDNA) and/or metabolomic descriptors. Thus, the metadata collected in this project will subsequently support the development of management tools within the framework of a biomonitoring approach to water quality.

A thesis related to the project was completed by Arthur Medina (defended in December 2024) – Metabolomic analysis of the relationship between agricultural chemical stress and its impact on photosynthesis within freshwater biofilms

Publication

Medina, A., Eon, M., Mazzella, N., Bonnineau, C., Millan-Navarro, D., Moreira, A., Morin, S., Creusot, N. (2024). Sensitivity shift of the meta-metabolome and photosynthesis to the chemical stress in periphyton between months along one year and a half period: Case study of a terbuthylazine exposure. Science of the Total Environment, 957, pp177681

Metaprogram
BIOSEFAIR

MODIMIV *Project results*

PATHFINDER PROJECT

2024-2026

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Keywords
Sustainable agroecosystems
Microbial and plant biodiversity
Multi-species covers
Fluxes and synchronisation
Modelling

Thematics involved
Ecology
Agronomy
Applied mathematics

Divisions involved
ACT
AgroEcoSystem
AQUA
EcoSocio

INRAE units involved
UREP
UMR SADAPT
UMR EMMAH
UR P3F

External partnership
CREA Research Centre for Agriculture and Environment, Italy
CREA Research Centre for Animal Production and Aquaculture, Italy
LIEC - CNRS
VetAgroSup Campus Agronomique de Clermont-Ferrand

Modelling the relationship between microbial and plant diversity in multi-species agroecosystems

The MODIMIV project aims to model the relationships between microbial and plant diversity in multi-species agroecosystems, particularly grasslands, in order to improve the simulation of carbon (C) and nitrogen (N) flows and better synchronise nutrient supply and demand. The initial objective was to overcome the limitations of existing models, which often incorporate biodiversity in an implicit or simplified manner, by developing explicit and dynamic simulators capable of representing biotic interactions.

MODIMIV - Modelling the relationship between microbial and plant diversity in multi-species agroecosystems

The central hypotheses are that interactions between plant diversity (e.g. grasses and legumes) and soil microbial diversity play a key role in regulating biogeochemical cycles. Grasslands, which cover about 40 % of the Earth's surface, can act as carbon sinks or sources. Processes such as biological nitrogen fixation via legume-rhizobium symbiosis or root dynamics influencing organic matter decomposition contribute to better nutrient synchronisation, reducing losses and improving productivity.

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Approaches

The methodological approach is based on combining existing models: ModVege for plant growth, CoSMo for plant species dynamics, and SYMPHONY for soil microbiology. Several M2-level internships have enabled the development of specific modules:

- Integration of nitrogen fixation by legumes, based on functional traits such as specific leaf area and leaf lifespan,
- Addition of a root compartment to simulate exudate flows and root mortality, with adjustments to the C/N ratio,
- Analysis of the distribution of functional traits at different spatial scales using the DRY database.

The work is based on numerical simulations, literature reviews and data from field experiments, in particular UREP devices on innovative plant covers such as agroprairies.

Results

The main results include a prototype integrated model of root dynamics, enabling the simulation of new flows, such as the growth gain attributable to biological nitrogen fixation. Functional trait analysis highlights intraspecific variability influencing functional diversity at scales ranging from square metres to ecoregions, with covariations structured by aridity gradients.

Finally, a position paper (Rodríguez et al., under review) compiles more than 300 references and a glossary of 40 terms. It proposes a roadmap for integrating microbial and plant biodiversity into biogeochemical models.

The MODIMIR thesis supported by Biosefair builds on this work: Modeling the effects of microbial diversity on the regulation of carbon and nutrient cycles in agroecosystems – see p. 96

Metaprogram
BIOSEFAIR

PARMENIDE *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Biodiversity
Ecoacoustics
Heterogeneity
Soundscape
Permanent grassland

Thematics involved
Agroecology
Biodiversity
Eco acoustic
Landscape ecology
Entomology
Geomatics
Ornithology

Divisions involved
ECODIV
ACT
PHASE

INRAE units involved
UMR DYNAFOR
UMR BAGAP
UE ST LAURENT DE LA PRÉE

External partnership
Laboratoire LADYSS CNRS
SETE Moulis CNRS University of Toulouse
University of Stirling, United Kingdom, Scotland
ISPRA, Italy

The recorded acoustic diversity is linked to the natural character of the landscapes

PARMENIDE shows that the degree of naturalness of a landscape promotes acoustic diversity. In particular, landscape mosaics that are not highly fragmented and contain a high proportion of permanent grassland, as well as landscapes where management practices are becoming more extensive (particularly organic farming), very clearly promote biophony.

PARMENIDE – Farmland mosaic landscapes and novel indicators of ecoacoustic diversity

Temperate rural landscapes have undergone profound changes since the post-war period due to the combined effects of climate and land-use changes. To better quantify the underlying socio-ecological dynamics, there is a need for integrative metrics that capture the complexity of the relationships between agricultural practices, landscape heterogeneity and biodiversity. The acoustic component of biodiversity has seen significant conceptual and methodological advances with the emergence, over the past decades of landscape ecoacoustics and the use of acoustic diversity metrics that allow for the simultaneous quantification of sounds of biological origin (biophony) and anthropogenic origin (anthropophony). In the PARMENIDE project, we tested the hypothesis that the acoustic diversity of rural landscapes would be correlated to the compositional and configurational heterogeneity of landscape mosaics and enhanced by production systems tending towards the extensification of management practices (notably organic farming).

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Backgrounds and challenges

To test this hypothesis, we gathered a large-scale sample of long-term study sites in France drawn from the networks of INRAE sites (Sebiopag, UREP, UE St Laurent de la Prée), CNRS (Armorique, Arc Jurassien and Pyrénées-Garonne LTERs) and Regional Natural Parks (Baronnies Provençales, Pyrénées Ariégeoises). By combining approaches from ecoacoustics and landscape ecology, we tested the effect of the proportion of different types of land use cover (biological or non-biological, perennial or non-perennial) in the landscape on indices of acoustic diversity, as well as the effect of the degree of naturalness of the surrounding landscape at multiple spatial scales extending up to 1 km around the recorders.

Results

At the national level, our results show that landscape heterogeneity and the shift toward large-scale extensification of farming practices are key factors in acoustic diversity. In particular, the amount of permanent grassland, the extent of organic farming in the landscape, and the degree of naturalness promote biophony, whereas techno-anthropophony dominates in the most fragmented rural landscapes.

At the regional level, we observe that the effects of organic farming practices and landscape heterogeneity can vary depending on the local composition of bird communities–as measured by the acoustic complexity of bird choruses– in response to agricultural practices stemming from the locally dominant production systems within the landscape.

These results open new perspectives for the study of the acoustic diversity of mosaic farmland landscapes, within which the multiplicity of sound sources makes their analysis both complex and integrative of socio-ecological dynamics.

The perspectives of the PARMENIDE project are currently being explored within the framework of its follow-up Biosefair project, FARMSOUND, in which we are expanding the response metrics to include those derived from bird acoustic communities identified via deep learning (BirdNET) and the geomatics variables to include those describing historical landscapes before and immediately after post-war agricultural land consolidation.

These two approaches also make it possible to significantly expand the interdisciplinary scope of the research undertaken within PARMENIDE by emphasizing the integration of concepts and methods from geomatics and artificial intelligence with those already employed from landscape ecology, ecoacoustics, and agroecology.

Publication

Barbaro, L., Sourdril, A., Froidevaux, J., Cauchoix, M., Calatayud, F., Deconchat, M., Gasc, A. (2022) Linking acoustic diversity to compositional and configurational heterogeneity in mosaic landscapes. Landscape Ecology, 37 (4), pp.1125-1143

Metaprogram
BIOSEFAIR

PASTOFUTUR *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Interdisciplinarity
Modeling
Participation
Multifunctionality
Sociology
Ecosystem services

Pastoralism

Thematics involved
Ecology
Economics
Geomatics
Computer science
Pastoralism
Organizational sciences
Zootechnics

Divisions involved
ACT

INRAE units involved
UR LESSEM
UMR MoÏSA
UMR SELMET

External partnership
Laboratoire Sens (Knowledge, Environment and Societies) CIRAD

A pastoral ecosystem better understood by the various stakeholders and new tools for collective management

PASTOFUTUR has identified the stakeholders and interactions involved in pastoral activities and characterised the multiple uses of the land in question. It has highlighted measures conducive to their collective management and developed tools to support the collective approach.

PASTOFUTUR - Analysing pastoral livestock farming through its multifunctionality and associated ecosystem services to strengthen public action

Pastoral activity is currently the subject of much debate regarding its future forms, its place within territories and its role in socio-ecosystems. This is particularly true in Mediterranean mountain regions, which in recent decades have shifted towards a residential and tourist economy and are facing rapid forest expansion as well as the effects of climate change.

Pastoral activities are carried out in areas that are most often subject to multiple uses. They must contend with potentially contradictory demands: maintaining food production, contributing to the conservation of iconic species, managing natural risks, and controlling landscape dynamics in areas at the interface between agricultural lands, grasslands and forests.

Approaches

The INRAE and CIRAD research collective conducted a participatory research project in the Alpes-Provence-Verdon Community of Municipalities to help identify actions that would promote the long-term preservation of pastoral activities in the region in conjunction with other existing activities.

This research alternated between individual interviews with stakeholders, institutions and groups concerned with the future of pastoral farming in the region and workshops involving a wide range of stakeholders to enable the co-construction of strategies that could facilitate the articulation between multiple uses in the territory.

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Results

The main results obtained during PASTOFUTUR are organised around the four following dimensions:

Identifying the stakeholders and interactions at stake around pastoral livestock farming activities

Identifying, describing and analysing the interactions between pastoralism and a diversity of human and non-human actors, as expressed by livestock farmers in individual interviews, highlights different visions of the profession of livestock farmer or of shepherd.

Workshops with local farmers and shepherds enabled these interactions to be validated, prioritised and qualified from the perspective of those involved in livestock farming. Points of convergence emerged, such as the shared difficulty of grazing in forests, but a diversity of views was expressed on other topics. For example, the relationship with protected flora was viewed positively by some, while others saw it as a complex constraint to be integrated into herd management.

Characterising multiple uses of areas used for pastoral activities

Two thematic focus areas made it possible to characterise the compromises or ways in which pastoral activities and other activities are coordinated in silvopastoral areas and on mountain pastures frequented by people engaged in tourism and recreational activities.

Silvopastoral areas: supporting pastoralism and forestry

Stakeholders have diverse expectations regarding silvopastoral environments, each prioritising specific ecosystem services linked to their use(s). However, a shared interest in landscape aesthetics could be an interesting starting point for future collaborative work. Certain levers for better coordination of multiple uses (e.g. shared land management tools, financial support for stump grinding operations, etc.), also integrating biodiversity issues (e.g. prior agreements on grazing schedules, phasing of work, etc.) have been identified.

Summer pastures: coexistence of livestock farming with tourism and recreational activities

Interviews and a participatory workshop highlighted a profound crisis in the local socio-ecosystem centred on the implementation of herd protection measures associated with the return of the wolf and the risk of predation. Relationships between stakeholders in the area appear to have changed profoundly, accompanied by a questioning of traditional trades and activities and impacting the perceived collective identity of the area.

Identify measures conducive to collective management of the environment

During group workshops, two ideas emerged: i) the desire to build a realistic and attractive image of the region, better integrating existing activities and communicating more effectively with tourists from outside the region; ii) the need to share space more effectively. Explaining the reasons behind the practices and rules in place could encourage their acceptance and compliance, and thus possibly favour more appropriate behaviour from a variety of stakeholders.

Developing tools to support the collective approach

A prototype multi-use model has been developed that allows the spatial intersections between activities to be visualised. In the medium term, this opens up the possibility of developing a tool for facilitating discussion around the rules for implementing various management options and their link to changes in the landscape.

Metaprogram
BIOSEFAIR

PRABIES *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Climate change
Mitigation
Hazards
Biodiversity metrics
"Climate Adaptation Service"

Thematics involved
Agroecology
Botany
Ecology of plant communities
Livestock economics
Zootechnics

Divisions involved
ECODIV
ECOSOCIO
PHASE

INRAE units involved
UREP
UMR HERBIVORE

External partnership
National Botanic Conservatory of the Massif Central

Optimising fertilisation to preserve grassland biodiversity and multifunctionality in the context of rising temperatures

Through statistical modelling, PRABIES demonstrated the existence of complex interactions between practices (fertilisation, stocking density), temperature and biodiversity, which impact the provision of service packages (provisioning, regulating and cultural). It has also shown that livestock farmers' climate change adaptation strategies influence whether grasslands are maintained or converted into forage crops or temporary grassland.

PRABIES - How livestock farming practices 'transform' grassland biodiversity into bundles of ecosystem services

Understanding the link between biodiversity and the level of ecosystem service supply is complex. The relationship is not linear or unidirectional and it can be influenced by climate variables. We studied this relationship through adapted statistical models, in a grassland context.

The project investigated how biodiversity, assessed using various metrics (species richness, functional diversity, evenness and rarity), is 'transformed' into effective ecosystem service packages through relevant agro-pastoral practices. For example, grasslands provide numerous ecosystem services such as fodder production, the maintenance of habitats for pollinators, or open and varied landscapes. PRABIES placed particular emphasis on the climate change adaptation service, i.e. the ability of ecosystems to adapt to climate change and variability, by analysing the buffering of hazards enabled by grassland plant diversity and the ability of plant communities to reassemble to provide a relevant bundle of ecosystem services under a new climate.

Approaches

PRABIES aimed to describe the impact of climate change adaptation practices on the supply of ecosystem services (ES) in grassland environments, to assess whether adaptation practices have a positive or negative effect on biodiversity, and the related ecosystem services.

PRABIES made it possible to describe the complex interactions between these factors through the use of structural equation modelling (SEM), a statistical tool for assessing the strength and significance of variables in direct and indirect interactions.

This tool was applied to a dataset of 100 permanent grassland plots in the Massif Central according to an altitude and latitude gradient, including management data and proxies for three types of ecosystem services (provisioning, regulating, and cultural).

PRABIES also collected information through interviews with 15 dairy farmers in the Massif Central about their strategies. These interviews described the role of permanent grasslands in the livestock feeding system and their management, and in particular fertilization. They also made it possible to characterize farms where more than 75% of the crop rotation included forage crops. On some of these farms, farmers felt ready to face a new climate.

© INRAE - Frédéric Joly

Results

Direct effects of climate change on permanent grasslands

The SEM showed that at an average temperature of 6.7°, multifunctionality was proportional to fertilization, whereas at an average temperature of 12.2°, the relationship between multifunctionality and fertilization took the form of a bell curve. This curve indicates that at 12.2° multifunctionality peaks at 70 kg of N per hectare. These patterns can be explained by the fact that multifunctionality is positively correlated with biodiversity and that biodiversity is more or less promoted by fertilization, depending on the temperature (due to processes of more or less strong competition between plant species).

Livestock farmers' climate change adaptation strategies

Adaptation strategies modulate:

- The maintenance of permanent grasslands by livestock farmers who view them positively, in a climate that is not very dry or cold;
- The conversion of permanent grasslands to forage crops or temporary grasslands by farmers who view them negatively, in hot and dry climates
- Adaptation strategies do not involve the level of fertilization.

Changes in multifunctionality resulting from a rise in temperature

Simulation of changes in multifunctionality resulting from a 1.5 °C rise in temperature within a sample of permanent grasslands representative of forage systems shows that:

- The degradation and conversion of permanent grasslands do not affect the same systems.
- Some systems limit both phenomena, by purchasing more forage and concentrates per livestock unit (LU) and selling less milk per unit of area (ha) than others.

A thesis related to the project was completed by Lucie Allart (defended in June 2024) – Maintaining the multifunctionality of permanent grasslands and adapting forage systems to climate change in the Massif Central

Publications

Allart, L., Dumont, B., Joly, F., Mosnier, C., Alvarez, G., Galliot, J.-N., Luna, D., Pottier, J., Gross, N. (2024). Species richness: A pivotal factor mediating the effects of land use intensification and climate on grassland multifunctionality. *Journal of Applied Ecology*, 61(5), pp.1053-1066

Dumont, B., Carrère, P., Farruggia, A., Allart, L., Oostvogels, V.J., Ripoll-Bosch, R. (2026) Biodiversity in the grass-based systems of Massif Central PDO areas. *Innovations Agronomiques*, 104, pp.25-36

Allart, L., Joly, F., Oostvogels, V., Mosnier, C., Gross, N., Ripoll-Bosch, R., Dumont, B. (2024). Farmers' perceptions of permanent grasslands and their intentions to adapt to climate change influence their resilience strategy. *Renewable Agriculture and Food Systems*, 39, ppe33

Metaprogram
BIOSEFAIR

PRODIGE *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Biodiversity
Landscape
Functional heterogeneity
Indicator
Agricultural practices

Thematics involved
Agronomy
Landscape ecology
Political science
Human geography
Construction of indicators
Ergonomics

Divisions involved
ACT
AGROECOSYSTEM

INRAE units involved
UMR LAE
UMR DYNAFOR
UMR SADAPT

External partnership
IDEAS Initiative for Design in Agrifood Systems

Biodiversity indicator: user needs and expectations identified

What do stakeholders in the agricultural sector expect from a biodiversity assessment tool? By consulting them, PRODIGE has identified the features they require. It has also analysed how to improve an existing indicator by taking landscape elements into account. These components were used to develop a predictive indicator of impact on biodiversity.

PRODIGE - Taking into account the needs of potential users and functional representations of landscape elements in the design of a biodiversity indicator for agricultural landscape

Numerous studies show the central role played by agricultural systems in the collapse of biodiversity. Assessing the performance of agricultural systems in terms of maintaining biodiversity is an essential step in supporting their agroecological transition. However, there are few predictive biodiversity indicators, particularly at the landscape level, which is nevertheless the most appropriate level for assessing the effect of agricultural systems on biodiversity (NIVA-Biodiversity is one such indicator).

PRODIGE aims both to (i) analyse the needs of potential users of biodiversity indicators and their position in relation to the NIVA-Biodiversity indicator; and (ii) assess the extent to which taking landscape elements (crops, semi-natural environments, etc.) into account, both quantitatively (e.g. number of crops, percentage of semi-natural environments) and qualitatively (functional characteristics incorporating agricultural practices), improves the consideration of biodiversity in agricultural practices. etc.) at a quantitative level (e.g. number of crops, percentage of semi-natural environments) and qualitative level (functional characteristics incorporating agricultural practices) improves the consideration of ecological mechanisms and therefore the relevance of the indicator, its usability and its suitability for the needs of users of the NIVA-Biodiversity indicator.

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Approaches

- Survey to characterise the profiles of potential users, their approaches to assessing biodiversity in their activities, and their needs and expectations with regard to such indicators. It was conducted at the regional level for the usability analysis framework, in the Vallées et Coteaux de Gascogne region, in the PYGAR Workshop Zone, and at the national level for the usage diagnosis.
- Characterisation of the functional diversity of landscape elements and crops using ecological concepts and agronomic knowledge. The effects on biodiversity were studied using a large pre-existing dataset (FarmLand project).
- Finally, this knowledge was integrated into a predictive indicator of impacts on biodiversity. It is in this context that a method for aggregating variables, CONTRA, was computerised on the INRAE MEANS platform to facilitate its use in the design of predictive indicators.

Results

The use of usability and usage diagnosis frameworks has highlighted divergent expectations and perceptions among users, depending on whether they are potential users or data providers. The definition of biodiversity is one example, between a more heritage-based approach focused on species conservation, championed by environmental protection stakeholders, and a more functional approach based on services, championed by agricultural stakeholders. However, a consensus emerged on the need for consultation between stakeholders on the indicator.

The functional characterisation of crops led to the establishment of a database for 300 crops (with a more complete version for 57 crops). Variables taking functional diversity into account were identified as relevant for inclusion in the indicator.

The feasibility of calculating the indicator was improved in the Tier 1 version. Work is to be continued to produce a consolidated version.

CONSORTIUM
2022-2023

Limited practical application of the concept of ecosystem services in river restoration

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Keywords
Aquatic ecosystems
Wetlands
Restoration ecology
Biodiversity policy
Well-being economics
Nature assessment

Thematics involved
Geography
Political science
Economics
Aquatic and terrestrial ecology
Ecological restoration

Divisions involved
AQUA
ECODIV
ECOSOCIO

Units involved
UMR LISIS
UMR RIVERLY
UMR GESTE
UR EABX
UMR BIOGECO
UMR CESAER
UMR ETTIS

External partnership
OFB - French Biodiversity Agency

REFUSE has used case studies to analyse the disconnect between references to ecosystem services in public policy and their limited ability to guide decisions regarding local biodiversity management in situations involving the restoration of wetlands or watercourses. The finding is that restoration or conservation actions depend heavily on the emergence of specific 'windows of opportunity', which bear no relation to ecosystem service assessments.

REFUSE - Ecological restoration, functionalities, uses and ecological services

Restoring landscapes and habitats through the lens of their utilities. Limits and alternatives. The ecosystem services frame is often used as a reference to justify public actions or policies, or to assess their outcomes. However, its utilitarian approach, like that of nature-based solutions, raises questions and has limits.

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Approaches

REFUSE participants presented and discussed 10 case studies of wetland or watercourse restoration projects, which were cross-analysed using a typology of biases and issues not taken into account in restoration projects framed by an ecosystem services approach. These biases, shortcomings and blind spots were discussed. This work led to the drafting of an article (submitted).

Results

Over the past several decades, ecosystem services have undergone significant conceptual developments and have been incorporated into numerous methodological frameworks to support international strategies and supranational or national policies aimed at preserving or restoring biodiversity. However, the role that this concept can play in the practical implementation of ecosystem restoration projects remains relatively unexplored.

Adopting a multidisciplinary approach to examine the case of French aquatic environments (wetlands and watercourses), REFUSE contributes to a better understanding of the scale mismatch between, on the one hand, the proliferation of references to ecosystem services in national and international public policies and, on the other hand, their limited capacity to guide choices regarding local biodiversity management. The hopes that ecosystem services have embodied in academic fields related to ecology and economics since the 1990s at the international level, as well as the promises they have represented since the 2000s for international or national (French) public policy, have been analysed. The case of France has allowed for an in-depth analysis of how, and why, the lack of scientific data in ecology and land tenure regimes considerably limit the practical applicability of the concept of ecosystem services. Our results show that restoration or conservation actions depend heavily on the emergence of specific 'windows of opportunity', which bear no relation to ecosystem service assessments.

Metaprogram
BIOSEFAIR

SICCCUB *Project result*

EXPLORATORY PROJECT

2021-2023

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Keywords
Observatory
Mountains
Forest regeneration
Global change
Biodiversity

Thematics involved
Functional biodiversity of soils
Forest dynamics
Forest ecology
Landscape history
Forest management
Impacts of past and present uses
Soil organic matter
Pedology

Divisions involved
ACT
AGROECOSYSTEM
ECODIV

INRAE units involved
UR LESSEM
UMR DYNAFOR
UR EFNO
UMR ECO&SOLS

External partnership
LECA Joint Research Unit CNRS - Alpine Ecology Laboratory

In mountain areas, soil biodiversity depends primarily on climate and forest soil chemistry

SICCCUB has established a DNA reference database and found that soil organism diversity is more closely linked to climate and soil chemistry than to forest structure, and that tree seed production varies greatly from one year to the next.

SICCCUB - Monitoring the impact of climate change and land use change on biodiversity and the functioning of mountain ecosystems

The mountain forest as a sentinel of climate change and uses. Mountain areas are particularly sensitive to the combined effects of climate change and land use change. Indeed, the climate in mountain areas is warming faster than in other regions, and in Europe, mountains underwent significant reforestation at the beginning of the century. These changes have already led to significant reorganisation of biodiversity, with consequences for the functions and services provided by mountain ecosystems. Future climate change is likely to amplify these reorganisations.

Approaches

By complementing and linking with the spatio-temporal observatory of biodiversity and the functioning of mountain socio-ecosystems (Orchamp), SICCCUB will enable long-term monitoring of biodiversity dynamics and ecosystem functions.

SICCCUB project investigated the relationships between: past land-use practices and landscape history, tree recruitment dynamics, and biodiversity and ecosystem functions (such as carbon storage and organic matter recycling).

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These functions underpinned the provision of ecosystem services including wood supply, soil quality regulation, reduction of greenhouse gases in the atmosphere, and seed dispersal. The project also provided insights into cultural services related to the aesthetic, cultural, and symbolic representations of nature dynamics in mountain areas.

The project focused on the ORCHAMP observatory, which consists of permanent plots distributed along altitudinal gradients in the Alps and the Pyrenees (see https://orchamp.osug.fr/ for a detailed description). ORCHAMP provided a unique framework to analyze mountain biodiversity and ecosystem functioning.

The project quantitatively described current and past land uses of ORCHAMP plots. Historical sources such as military maps (1818–1866) and Napoleonic cadastral maps (1807–1850) were used to describe past land uses. More recent sources such as historical aerial photographs, land-use and habitat maps, forest management archives, and pastoral surveys were also mobilized.

The ORCHAMP observatory is based on altitude gradients of around 1000 m with permanent plots (30 x 30 m) spaced at around each 200 m of elevation intervals. The observatory also has measurements at landscape and catchment scale, based on remote sensing data and current mapping data.

The SICCCUB project will provide a quantitative description of past and present uses of the plots. "Military maps" (1818-1866) and the "Napoleonic cadastral maps" (1807-1850) will be used to describe past uses around the plots. For more recent uses, old aerial photographs, use and habitat maps, forest management archives and pastoral surveys will be used.

The project monitored tree recruitment and seed production dynamics across altitude. Biodiversity surveys (aboveground and belowground), complementary to ORCHAMP's mandatory eDNA monitoring, were carried out to cross-validate methods and enrich reference databases.

Results

Effect of forest stand structure on soil biodiversity

Forest structure and composition were less important than abiotic variables such as climate and soil chemistry. However, the diversity of certain groups was closely linked to forest structure.

Effects of land use change and climate change on biodiversity

The vectorisation of the landscape structure in the vicinity of the three-step plots (1850 - 1950 - present) enabled the partially decorrelated study of the effects of land use change and climate-related changes. The data enabled analysis of the effect of the current landscape structure and that of 1950 on the biodiversity of springtails and protists by testing landscape metrics on buffers of different radii. Thus, the species richness of epigeal, endogeal and total springtails is better explained by the structure of the old landscape (1950) than the current one (2020).

Comparison of field sampling and mDNA sampling of soil macrofauna

- Consolidation of the mDNA reference database
- Richness estimates made using mDNA approaches are underestimated compared to field approaches.

Change in tree fertility

Regeneration and seed production are marked by very high interannual variability, which makes it difficult to estimate fertility with a short time series collected in the SICCCUB project.

These measurements will continue beyond the project and will therefore offer a unique perspective on changes in tree fertility. They have already been used in large-scale data syntheses, where it is easier to extract reliable information than from a limited sample of plots along a gradient.

Publication

Thuiller, W., Saillard, A., Abdulhak, S., Augé, V., Birck, C., Bonet, R., Choler, P., Delestrade, A., Kunstler, G., Leccia, M-F., Lienard, B., Poulenard, J., Valay, J-G., Bayle, A., Bonfanti, N., Brousset, L., Bizard, L., Calderón-Sanou, I., Dentant, C., Desjonquères, C., Gielly, L., Guéguen, M., Guiter, F., Hedde, M., Hustache, E., Kedhim, N., Lapenu, P., Le Guillarme, N., Marchal, L. , Mahieu, C., Martin, G., Martinez-Almoyna, C., Miele, V., Murienne, J., Paillet, Y., Rome, M., Renaud, J., Orchamp Consortium (2024) ORCHAMP: an observation network for monitoring biodiversity and ecosystem functioning across space and time in mountainous regions. *Comptes Rendus. Biologies*, 347, pp.223-247

Metaprogram
BIOSEFAIR

SPABIO *Project result*

EXPLORATORY PROJECT

2022-2024

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Keywords
Biological invasions
Spatio-temporal heterogeneity
Modeling
Transferability
Applications and governance

Thematics involved
Biological invasions
Spatio-temporal heterogeneity
Modeling
Transferability
Uses and governance

Divisions involved
ECODIV
ECOSOCIO

INRAE units involved
UMR DECOD
UMR CEE-M
UMR PSAE

External partnership
UMR ECOBIO
AMSE – Aix Marseille School of Economics
Regional Natural Park Brière

A new spatialised bioeconomic model for managing invasive species

This tool results from the integration of a spatialised ecological population dynamics model and a cost-effort model for removal. It was tested on water primrose in collaboration with the Brière Regional Nature Park and demonstrated the need to adapt eradication strategies according to the abundance of the invasive species. The need for high-quality data to use the tool was also highlighted.

SPABIO - Dynamic spatialized bioeconomy of biological invasions: proof of concept for the management of Ludwigia sp. in Brière

The management of invasive alien species (IAS) is a complex problem requiring interdisciplinary approaches that combine ecology and economics. Bio-economic decision-making tools are still underdeveloped. Existing models suffer from a lack of ecological realism, from a high level of complexity that makes them hardly usable for applied management problems, and from a relative disconnection from the needs of environmental managers. In other words, although these models have all the ingredients needed for becoming decision-making tools, they remain mainly restricted to the academic sphere and their results have little impact on management.

Approaches

To address these shortcomings, SPABIO relies on transdisciplinary collaboration between ecologists, economists and natural environment managers to

1. develop a new class of bio-economic models that are ecologically realistic and directly applicable to the concrete problems encountered by managers,
2. provide proof of concept for this new theoretical framework using the case of water primrose (Ludwigia sp) in the Brière Regional Nature Park, and
3. prepare the application of the theoretical framework to other IAS problems in various contexts.

SPABIO required a significant amount of work to digitise the spatial records of water primrose abundance and removal in Brière.

We then developed a Bayesian model adapted to the structure of the data collected by managers. The ecological model is a multi-state (4 abundance classes), dynamic (22 years) and spatialised (17,000 square cells of 1 ha) model. the model of the cost-effort relationship for removal is a multiple linear regression, and the bio-economic coupling of the two models is carried out via a cost-effectiveness calculation (cost weighted by the probability of reducing the abundance of water primrose).

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Results

On managing the dynamics of water primrose

The ecological model suggests that the effect of uprooting depends on the abundance of the plant. When water primrose is very abundant in the environment, uprooting promotes a transition to lower abundances. On the other hand, when the environment is not heavily invaded, uprooting accelerates the invasion.

The economic model suggests a quasi-linear cost-effort relationship and therefore no economies of scale. Finally, the bio-economic coupling suggests that weeding is only bio-economically effective in heavily invaded areas.

Our results on water primrose in Brière suggest that the strategy of attempting to eradicate the plant when it is still not very abundant (known as the 'invasion curve' strategy) can be counterproductive. This is an extremely interesting and original finding that challenges the main golden rule of invasion management, namely the imperative to control lightly invaded areas as a priority in order to respond cost-effectively to the dynamics of invasion. Without calling into question the importance of early management actions, this result calls for a case-by-case application of this rule, categorising the invasions to which it applies and those to which it does not apply.

On the prioritisation of water primrose management efforts

Our bioeconomic analysis has produced fundamental results in terms of spatial prioritisation of management efforts, taking into account dispersion dynamics on the one hand and spatialised management costs on the other. In practical terms, and for the management of water primrose in particular, this result should lead to the abandonment of interventions in areas with low levels of invasion in favour of prioritising efforts in areas with high levels of invasion, and in particular focusing removal efforts on large canals with high levels of invasion (i.e. river transport routes).

On the form of data that can be integrated into modelling

The availability and quality of data from managers can limit the implementation of bio-economic models adapted to their needs. In Brière, the water primrose abundance data was already in GIS format, and formatting it for modelling did not pose a major problem. However, data on removal sites (spatial coverage, costs) were not available in sufficient quality. The future development of bio-economic models to support managers requires them to acquire a greater understanding of scientific data.

Publication

Courtois, P., Figuières, C., Martinez, C., Thébaud, G., Thomas, A. (2023) L'économie des invasions biologiques : vers une hiérarchisation des stratégies de gestion. Lannou C.; Rasplus J.-Y.; Soubeyrand S.; Gautier M.; Rossi J.-P. *Crises sanitaires en agriculture. Les espèces invasives sous surveillance*, Chapitre 15, QUAE, pp.237-250, *Savoir-faire*, 978-2-7592-3482-0

Metaprogram
BIOSEFAIR

TRAMETES 2 *Project results*

EXPLORATORY PROJECT

2022-2024

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Keywords
Tree-dwelling microhabitat
Cavity
Biodiversity
Ecoacoustics
Environmental metabarcoding

Thematics involved
Forest biodiversity
Fungal communities
Eco-acoustics
Environmental metabarcoding
Statistics
Taxonomy of wild bees

Divisions involved
ACT
ECODIV
SPE

INRAE units involved
UR LESSEM
UEFM
USC Ecodiv – Rouen
UR PSH

External partnership
Laboratoire EGCE IRD taxonomy of wild bees
Society Fold AI (Germany)
Ecosystemics

Black woodpecker cavities influence fungal biodiversity in forests

The results of TRAMETES2 indicate that the presence of black woodpecker cavities has a significant effect on fungal biodiversity but a negligible effect on birds and bees. The ecoacoustic data collected will be used to develop bird identification tools.

TRAMETES 2 - Contribution of the network of old-growth forest elements to the conservation of habitats and species

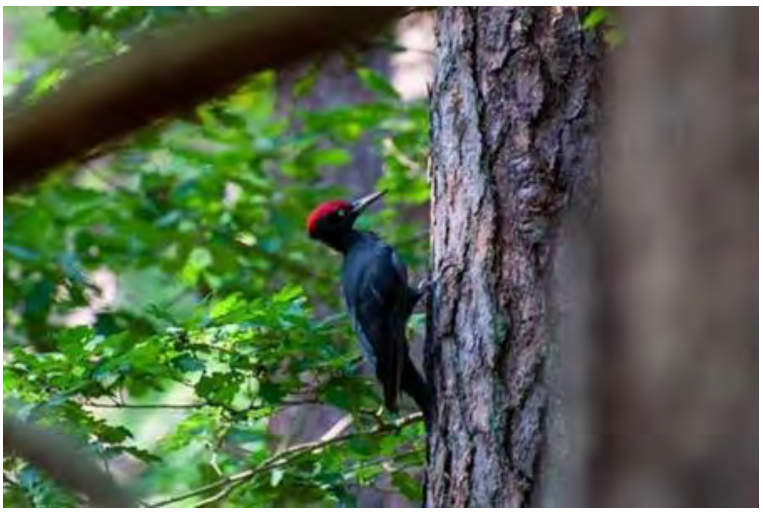
The assessment of the conservation status of forest habitats is mainly based on indirect methods describing the habitat (structural indices, and composition). Concerning species of conservation concern, the contribution of forest structural elements to their status is still poorly understood, and consequently, the link between the conservation of natural habitats and the conservation of species remains relatively unclear–particularly the respective roles of Tree-Related Microhabitats such as black woodpecker cavities and forest maturity.

Approaches

The Biosefair funding for TRAMETES 2 complemented a project funded by the French Office for Biodiversity. Through the study of five forest sites in metropolitan France, we installed 80 paired plots: one with at least one black woodpecker cavity and one without (control). We described the forest structure of these plots, then we equipped them with eco-acoustic sensors for determining bird communities and sampled for fungal communities associated with deadwood and black woodpecker cavities. In parallel (outside Biosefair funding), we worked on wild honeybee colonies, and the main results are presented below.

TRAMETES 2 enabled:

- The collection of data from additional sites to increase the statistical power and robustness of the sampling;
- The extended use of eco-acoustic data to identify bird and bat species (and even whole communities), beyond the few species initially planned in the project;
- The search for vectors of fungi typical of cavities (notably bees), and a deeper description of cavity occupants using environmental DNA methods.



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Results

Impact of the presence of peak cavities on the communities studied

Preliminary results show that the presence of black woodpecker cavities has varying effects depending on the community considered:

- Birds: forest structure, especially the presence of large trees, seems to have a greater effect on communities than the mere presence of cavities. However, some species, particularly secondary cavity nesters, occur more frequently in cavity-rich areas;
- Fungi: fungal communities found in cavities differ from those found in downed deadwood. Some fungal groups are exclusive to cavities, highlighting their crucial role for fungal biodiversity;
- Wild honeybees (non-Biosefair funded work): colonies do not appear to depend on black woodpecker cavities, but rather to smaller cavities (e.g., from great spotted woodpeckers). These colonies seem viable in the medium term (at least 2–3 years).

Contribution of the project on inventories assisted by AI and Machine Learning

Thanks to the substantial volume of acoustic data collected by TRAMETES and other plot data characterizing habitats and species, a new innovative analysis framework for bioacoustic data is emerging. AI thus provides an additional tool to guide management decisions through new insights. This dialogue with algorithms also refines recognition, identifies causal links, and adapts technical systems to local questions.

A first interface is under development.

Publication

Moro, A., Albouy, V., Dickey, M., Kohl, P.L., McCormack, G.P., Remter, F., Requier, F., Rogenstein, S., Rutschmann, B., Thiele, M.J., Visick, O., Bila Dubaić, J. (2024) A protocol for monitoring populations of free-living Western honey bees in temperate regions, *Bee World*, pp. 1-5

Metaprogram
BIOSEFAIR

WATERSEED *Project results*

EXPLORATORY PROJECT

2021-2023

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Keywords
Plant biodiversity
Green and blue corridors
Hydrochory
Seed bank
Ecosystem services

Thematics involved
Agronomy
Botany
Ecohydrology
Ecology
Spatial ecology
Hydraulics
Fluid mechanics
Pedology
Photogrammetry
Transfers in porous media

Divisions involved
AGROECOSYSTEM

INRAE units involved
UMR G-EAU
UMR LISAH
UMR ABSYS

External partnership
Laboratoire CITERES Joint Research Unit – University of Tours - Cities, Territories, Environment and Societies

Water in agroecosystems as a structuring factor for plant biodiversity? A mechanistic model linking water circulation and seed dispersal in vineyards

WATERSEED demonstrated the role of plot heterogeneity on the seed bank (composition and richness). It also demonstrated the role of seed morphology in their dispersal potential during secondary dispersal events that contribute to maintaining biodiversity within agroecosystems. Finally, a mechanistic model comprising three modules (plant growth, the effect of vegetation cover on water circulation, and the transfer of seeds produced by vegetation cover) was developed to explore the potential impacts of climate change on biodiversity.

WATERSEED - The role of water in the spatial structuring of plant biodiversity in wine-growing agrosystems

Studying the dynamics of plant biodiversity, from its emergence to its dispersal by water. Agricultural intensification has degraded ecosystems, and it is now necessary to take greater account of the role of biodiversity in agrosystems and its importance for ecosystem services provision. For the past two decades, cultivators in vineyards have been improving their sustainable management practices, developing a vegetation cover inside inter-rows to limit soil erosion, and an extensive management of plot edges and networks of ditches. These practices support the development of a spontaneous vegetation cover, a source of numerous ecosystem services including for example runoff regulation, water erosion mitigation and organic pollutants retention.

This is a major challenge, particularly in Mediterranean vineyards, where climate change is likely to increase the frequency of intense rainfall.

In order to limit the negative effects of agricultural intensification, it is necessary to rethink the interactions between ditches, inter-rows of perennial crops, headlands and agricultural plots. These elements host a spontaneous vegetation that provides numerous ecosystem services in terms of regulation and supply, and facilitates water circulation in the landscape. WATERSEED will analyse how water structures the distribution patterns of plant communities, the dispersal of seeds by water and the spatial structure of species according to soil moisture gradients.

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Based on the hypothesis that water is a key driver in structuring plant communities in Mediterranean regions, the WATERSEED project aimed to:

- better understand the determinants of potential plant biodiversity structuring in hydrographic networks,
- analyze the factors of seed dispersal by hydrochory, and
- integrate the acquired knowledge into a model simulating dispersal and growth of spontaneous vegetation cover in order to test scenarios of interstitial space redesign for maximizing ecosystem functions of plant cover.

Approaches

Drawing on experimental plots and domains (Domaine de la Jasse and the Roujan Observatory) of LISAH, we highlighted increased plant diversity and a greater importance of hydrochorous and zoochorous dispersal in ditch networks compared to vineyard plots. From a field experiment, we demonstrated the variability of seed dispersal factors, depending on intrinsic traits (shape, buoyancy) and extrinsic conditions (micro-topography, vegetation cover density). Finally, the model built from these observations and experiments justified the importance of cover management practices to improve the resilience of vineyard systems facing hydroclimatic extremes.

This project re-examined the role of water in agroecosystems as a driver of plant biodiversity structuring. It advocates for a better understanding of the functional properties of vegetation in relation to water flows, in order to design solutions that maximize both water resources and biodiversity.

Results

Seed bank analysis

It highlighted the influence of intra-plot heterogeneity (variability in grass cover practices between rows and alternation between plots, headlands and ditches) on the composition and species richness of the seed bank, with an increase in these indicators in neighbouring uncultivated areas (headlands and ditches). These results suggest the importance of non-productive areas within the landscape in the composition and species richness of the soil seed bank.

Hydrochory experimentation

Seed morphology plays a role in their dispersal potential during secondary dispersal events, with more spherical seeds being more susceptible to being displaced by runoff. Seed morphologies with appendages (hooks, hairs, etc.) were more sensitive to soil surface properties that facilitated their trapping (roughness, vegetation cover).

Secondary dispersal therefore plays an important role in maintaining plant biodiversity within agroecosystems, and even increasing it without direct human intervention.

A striking result is the virtual absence of seed movement within the grassy inter-row spaces.

Mechanistic modelling

By combining several models (multi-species plant growth under water stress, simulation of friction between vegetation cover and runoff water, and seed transfer), it has been possible to begin studying the influence of climatic variables (temperature, rainfall, ET0) on the friction generated by vegetation cover on water circulation.

The use of IPCC scenarios to simulate climate change in the model input seems to show an increase in friction generated by vegetation cover in the coming years, probably as a result of faster and more significant vegetation cover development during periods of heavy rainfall.

The prototype created will enable more practical questions to be answered, for example: how can the model be used as a virtual laboratory to test new spatial and temporal arrangements of landscape elements in order to maximise water resources and plant biodiversity?

However, this modelling work has also highlighted gaps in our knowledge. In order to make progress, it will be necessary to prioritise other seed dispersal factors and the importance of plant community determinants.

Valorisation for seedling recognition of collected data

An original dataset compiling photos of seedling development forms the basis of a research collaboration with the Pl@ntNet team to offer a service dedicated to the early recognition of wild species.

A thesis related to the project was completed by Martin Faucher (defended in December 2024) – The contribution of uncultivated areas to the biodiversity of Mediterranean agroecosystems through the study of the dispersal, growth, and natural vegetation

Publications

Faucher, M., Grellier, S., Chaudron, C., Janeau, J.-L., Rudi, G., Vinatier, F. (2024) Mediterranean vineyard soil seed bank characterization along a slope/disturbance gradient: Opportunities for land sharing. *Agriculture, Ecosystems & Environment*, 361, pp.108821

Faucher, M., Grellier, S., Chaudron, C., Janeau, J.-L., Rudi, G., Vinatier, F. (2025) Secondary Seed Dispersal by Hydrochory During Surface Runoff Inside a Mediterranean Vineyard. *European Journal of Soil Science*, 76 (6), pp.e70257

Defended thesis

Metaprogram
BIOSEFAIR

CAMARGUE *Thesis results*

THESIS
2022-2025

Modeling the functioning of the delta provides insights into integrated management approaches that reconcile agriculture with ecosystem conservation

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Thematics Involved
Modeling
Hydrology
Agronomy
Ecology

The model of the Camargue delta's functioning (MAELIA-Delta), developed in this thesis and tested under various scenarios, demonstrates the central role of water management in balancing agricultural activities, soil salinization, and the preservation of natural habitats in the Camargue. It provides a body of knowledge that stakeholders can use to design a more integrated management approach for the delta, aimed at reconciling agriculture and ecosystem conservation.

CAMARGUE - Integrated modelling of networks of activities, ecosystem services and biodiversity in the Camargue Island: which resilience in a context of global change and agro-ecological transition?

The Camargue (Rhône delta) is a complex social-ecosystem with important issues regarding biodiversity conservation and economic and cultural activities. In a context of global change, anthropogenic (water management in agricultural and natural areas, agricultural practices) and climatic (rainfall, evapotranspiration) drivers affect the hydro-saline balance. This hydro-saline functioning is a central element in the dynamics of the Camargue's habitats and species, and the associated networks of activities and services.

Summary

The Camargue, the Rhône Delta, constitutes a particularly complex social-ecosystem (SES), characterized by a strong interdependence between natural environments and human activities. This region, a biodiversity hotspot and home to major economic, agricultural, and cultural interests, is now facing the combined effects of climate change and shifts in water management and agricultural practices. Changes in rainfall and evaporation patterns, soil salinization, sea-level rise, and land use profoundly affect the hydro-saline balance, which is the cornerstone of the delta's ecological functioning.
In this context, we have developed a conceptual model of the Ile de Camargue (located in the center of the Rhône Delta), within which hydro-saline dynamics, water management, economic activities (agriculture, hunting, fishing, tourism), and natural habitats interact. This model is based on four sub-models providing complementary representations of: i) water governance, ii) agriculture, iii) bird communities, and iv) fish communities. This conceptual framework highlights the relationships (causal chains, feedback loops, interactions, indirect effects, and trade-offs) between the various components of this deltaic SES.
Based on the knowledge we have gained about this delta, we have developed an integrated model called MAELIA-Delta. This model is an extension of the MAELIA platform, adapted for the simulation of hydro-saline dynamics and agricultural practices.
Then we developed several scenarios of climate change and of agricultural practices transition (crop diversification, development of agroecology, changes in rice-growing areas, etc.) to evaluate and demonstrate the model's ability to simulate the processes at play on the Ile de Camargue.

In conclusion, this thesis highlights the central role of water management in balancing agricultural activities, soil salinization, and the preservation of natural habitats in the Camargue, and provides knowledge that stakeholders can use to design a more integrated management approach for the delta, that aims at reconciling agriculture and ecosystem conservation. In the medium term, the developed model can be applied to other deltas to assess the effects of climate change or agricultural transitions, and could be enhanced to better represent the interactions between hydrological networks, natural habitats, and biodiversity.

Publications

Rodier R., Boutron O., Béchet A., Therond O. (2025) Interdependencies among hydro-saline dynamics, economic activities, ecological processes, and biodiversity in a deltaic social-ecological system: insights from the Rhône delta (southern France). *Ecology and Society*, 30 (3).

THESIS

2020-2023

A prototype tool to assist in the design of species mixtures that provide ecosystem services

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Funding: Biosefair metaprogramme / Arvalis institut du végétal

Thematics involved
Agroecology
Agronomy
Functional ecology
Science of design

In current practice, crop mixtures combine cereals and legumes to control weeds and recycle nitrogen. The various methodological approaches employed (experimentation, modelling, knowledge-sharing workshops, database analysis) proved to be highly complementary in the design of the EcosysteMIX prototype, a tool to assist in the design of species mixtures based on the functional approach.

ECOSYSTEMIX - Mixing species to produce ecosystem services: co-design of an integration and knowledge sharing tool mobilizing the concepts of functional ecology

Mixing species is an agroecological practice central to increasing the ecological functioning of agroecosystems (resilience to hazards, stability of performance, efficient use of resources, regulation of pests and diseases) in a context of global change (reduction of inputs, climate change). However, this practice comes with a complexity in the choice and management of crops and requires farmers to have knowledge and tools to help them implement it.

Summary

In a transition to agroecological cropping systems, the diversification of agroecosystems through species mixtures has been identified as a central practice. Carefully-designed mixtures could provide ecosystem services to support sustainable, resilient agriculture and less dependence on synthetic inputs. However, it is not easy to choose the right species for a mixture, in order to deliver the ecosystem services sought and adapted locally. The trait-function-service approach of functional ecology has been identified as an interesting way to establish trait assembly rules, in order to guide the choice of species in a mixture according to the targeted service. Our aim is therefore to propose a generic method to design species mixtures based on a functional ecology approach, taking into account local conditions and the ecosystem services sought. In this PhD work, we (i) compiled and analyzed existing data, with the aim to assess the diversity of mixtures and the services provided, (ii) conducted a field experiment with the aim to study the behavior of species in sole crop vs. in mixture (iii) conducted knowledge sharing workshops in order to build assembly rules for the design of mixtures and (iv) modeled and developed a prototype tool to assist in the design of mixtures. Our results showed that (i) 60% of the mixtures made were between cereals and legumes, and that the most sought-after services were weed regulation and nitrogen recycling, (ii) the trait values of a sole crop and a mixed crop were different and depended not only on the trait considered, but also on the species present in the mixture, (iii) the realization of an ecosystem service depended on several traits, and that the same trait could be important for the realization of several ecosystem services. In addition, we showed that (iv) the expertise of different stakeholders was complementary and made it possible to fill knowledge gaps and decontextualize some knowledge to make it generic, and (v) the functional approach is a strong basis for the design of mixtures. We built a prototype tool to support the design of species mixtures based on this approach. Finally, the different methodological approaches used (experimentation, modelling, knowledge-sharing workshops, database analysis) proved to be highly complementary in the design of the EcosysteMIX prototype.

Publications

Ouattara M.S., Paut R., Valantin-Morison M., Verret V., Médiène S. (2023) Hierarchical modeling highlights how ecosystem service provisioning by service crops intercropped with oilseed rape depends on their functional trait values Agriculture, Ecosystems & Environment, n° 357

Ouattara M.S., Paut R., Prost L., Valantin-Morison M., Médiène S. (2025) A functional ecology approach to define a conceptual and participatory method for designing species mixtures: a case study on nitrogen cycling and weed control Agronomy for Sustainable Development, 45 (5)

Metaprogram
BIOSEFAIR

ISOÉTIDES *Thesis results*

THESIS

2022-2025

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Thematics Involved
Population and community genetics
Community ecology

The biodiversity of Aquitaine's coastal lakes is shaped by the limited dispersal capacity of species and environmental filtering mechanisms

The isoetid communities of the oligotrophic coastal lakes of Aquitaine, ecosystems unique in Europe, are under serious threat. The microsatellite markers developed by ISOTEIDES to characterize genetic diversity and analyze the relative contribution of spatial and environmental processes to the structuring of taxonomic and genetic diversity lead to recommendations for the conservation management of these lakes at both the local and regional levels.

ISOETIDES - Genetic and taxonomic diversity of isoetids communities of Aquitaine's coastal shallow lakes

Lakes and ponds of the Aquitaine Atlantic coast are unique natural ecosystems, not only at the national but also at the European scale. These systems host a high taxonomic diversity, especially for aquatic plants. Indeed, isoetid communities represent a set of species with high conservation value, also including one endemic species. These communities are however highly threatened, especially by anthropogenic activities, and most of the coastal Aquitaine's lakes have already experienced their extinction. Knowledge on these species is still however scarce, particularly concerning their genetic diversity. While conservation and restoration actions are emerging with the redaction of a National Plan for preserving these communities, understanding their genetic diversity, their relationships with taxonomic and functional diversity appear as a major issue.

Summary

The isoetid communities of oligotrophic coastal lakes in Aquitaine constitute ecosystems unique at the European scale, harbouring sensitive habitats listed under the Habitats Directive (3110). These aquatic macrophyte communities, adapted to oligotrophic conditions, face increasing anthropogenic pressures: eutrophication, climate change, and invasive species. In this context, understanding the processes structuring their biodiversity represents a major challenge for their long-term conservation.

This thesis adopts an integrative approach combining community ecology and landscape genetics to disentangle the relative contribution of spatial and environmental processes in structuring taxonomic and genetic diversity. We developed microsatellite markers to characterise the genetic diversity of eight macrophyte species (*Baldellia ranunculoides, Eleocharis multicaulis, Juncus bulbosus, Littorella uniflora, Lobelia dortmanna, Myriophyllum alterniflorum, Phragmites australis, Schoenoplectus pungens*) across 27 stations distributed among four lakes of the Aquitaine coast (Carcans-Hourtin, Lacanau, Cazaux-Sanguinet, Parentis-Biscarrosse).

Our results reveal exceptionally high levels of genetic differentiation (mean FST 0.26-0.27), three to ten times higher than values typical of aquatic plants, indicating extremely limited gene flow between populations. Isolation by distance constitutes the dominant pattern, although its intensity varies strongly among taxa (from $r = 0.10$ for *E. multicaulis* to $r = 0.80$ for *J. bulbosus*), reflecting contrasting dispersal capacities. Among the species studied, two benefit from national protection status and are subject to a National Action Plan: *L. dortmanna* presents a critical situation with near-zero heterozygosity ($He < 0.05$), while *L. uniflora*, despite a moderate raw FST, reveals one of the highest standardised differentiation values in the network ($F'ST = 0.72$).

Analysis of species-genetic diversity correlations (SGDC) reveals marked scale-dependence: the near-complete absence of correlation at the local scale (α-SGDC) contrasts with the emergence of robust correlations at the regional scale (β-SGDC) for all eight species. In B. ranunculoides and *S. pungens*, the only species displaying significant SGDCs at both scales, the correlation is entirely mediated by environmental factors (lake surface area, hydraulic connectivity, natural land cover), demonstrating that species richness and genetic diversity respond in parallel to the same gradients without direct correlation. The absence of correlation between α-SGDC and β-SGDC coefficients suggests that local demographic processes and regional dispersal constraints structure biodiversity in a largely decoupled manner.

This thesis demonstrates that dispersal limitation and environmental filtering act jointly to structure biodiversity in Aquitaine coastal lakes. Conservation of habitats of community interest 3110 requires a balanced approach combining local habitat quality management (maintaining oligotrophy and limiting anthropogenic disturbance) and regional functional connectivity management, with particular attention to *L. dortmanna* (a genetically depauperate umbrella species) and *L. uniflora* (highly differentiated populations requiring distinct management).

Publications

Debailleul E-M., Jamoneau A., Lepais O. (2026) Genetic diversity of aquatic macrophytes in Aquitaine lakes. *Conservation Genetics*, 27 (1),

THESIS
2021-2024

An innovative analytical approach based on the distribution patterns of plant species traits

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Funding: Biosefair metaprogramme / Clermont-Auvergne-Métropole

Thematics involved
Ecology
Agronomy

The innovative analytical approach (SKR) developed in PRAIRIES MC CC, combined with a large dataset on permanent grasslands in the Massif Central, has shown that the dynamics of trait distributions depend on management practices. In unfertilised grasslands, trait distributions are remarkably even and stable. Ceasing fertilisation allows for the long-term recruitment of a rich and diverse grassland flora. The SKR approach can help to design management methods suited to the conservation and restoration of biodiversity, as well as to the maintenance of ecosystem multifunctionality.

PRAIRIES MC CC - Functional response of grasslands in the Massif-Central to climate change: identifying the role of biodiversity in the short, medium and long term

Summary

Understanding and predicting the dynamics of biodiversity under global change is a major scientific challenge. However, biodiversity responses to global change are inherently complex.
Drivers of change not only affect species diversity and abundance but also alter biotic interactions between species, which may impact community assembly and dynamics. In this context, studying the diversity of functional traits within communities could lead to significant advances, as traits reflect how species respond to and influence their environment. To make the trait-based approach operational for the study of complex ecological systems, we developed an innovative analytical framework based on the study of the shapes of trait distributions. The shapes of trait distributions can be characterised by an inequality between the skewness and the kurtosis, the Skewness-Kurtosis Relationship (SKR). Using this inequality, we developed two key indicators.
The TADeve, which characterises the evenness of trait distributions, and the TADstab, which characterises the stability of trait distributions. Using permanent grasslands as a study model, we highlighted the relevance of studying the evenness (TADeve) and stability (TADstab) of trait distributions in order to disentangle the influence of deterministic processes (e.g. habitat filtering, niche differentiation), while accounting for the inherent stochasticity of ecological systems (Chapter 1).
Using a long-term dataset of managed permanent grasslands (17-years), we demonstrated that the temporal variability of trait distributions was not random, but depended on management practices (Chapter 2). Intensively managed grasslands (high levels of fertilisation) are associated with unstable and uneven trait distributions. These results are consistent with predictions of the "habitat filtering" theory and the occurrence of intense competition between plant species that limit local diversity. Conversely, extensively managed grasslands (no fertilisation) were linked to remarkably even and stable trait distributions over time. Furthermore, we also showed that the cessation of fertilisation in extensively-managed grasslands led to a rapid convergence towards even and stable trait distributions, which promoted the long-term recruitment and persistence of a rich and diverse grassland flora. These findings are consistent with a theoretical scenario of niche differentiation, which predicts a stable coexistence among functionally contrasting species. Finally, we found that the high evenness and stability of trait distributions, in extensively managed grasslands, are explained by a functional complementarity between dominant and subordinate species, facilitating the long-term stabilisation of the functional assemblage and of the entire plant community (Chapter 3).
Using observational data from various ecological context, we showed that semi-natural and natural plant communities shared a similar functional organisation. The observation of common functional patterns over space and time suggests the existence of general rules governing the assembly, diversity, and dynamics of plant communities.

In conclusion, the SKR approach appears to be a suitable tool to study complex dynamic systems, such as ecological systems in the context of global change. In the Anthropocene era, identifying general assembly rules based on functional traits could enable the design of management methods adapted to the conservation and restoration of biodiversity, as well as the maintenance of ecosystem multifunctionality.

Publication

Rondeau N., Le Bagousse-Pinguet Y., Louault F., Martin R., Carrère P., Klumpp K., Liancourt P., Gross N. (2024) Data submission on June 17: "Maximizing functional evenness on multiple trait dimensions promotes the long-term persistence of grassland species richness".

Metaprogram
BIOSEFAIR

SEINARIOS *Thesis results*

THESIS
2021-2023

The effects of connectivity, management and climate scenarios on river fish communities

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Funding: Biosefair metaprogramme / AESN (Seine-Normandie Water Management Agency)

Thematics involved
Aquatic ecology
Hydrology

SEINARIOS sheds light on the role of connectivity in the composition of river fish communities, as well as on the influence of management and climate change on future river ecosystems. It provides practical guidance for future management and new methodologies for assessing connectivity within river networks and integrating it into modelling approaches for the distribution of river fish, whilst evaluating the significance of climate change and land-use management on the conservation of fish species.

SEINARIOS - Prospects for biodiversity in the Seine drainage basin in the face of global change and connectivity constraints

Summary

River ecosystems are among the most species-diverse in the world. Global change, coupled with anthropization of watersheds and fragmentation of riverscapes, jeopardize river fish communities and put their future conservation in peril. There is an urgent need for knowledge to inform the design of the operations necessary to the conservation of freshwater ecosystems and fish species. However, the influence of watershed management, river fragmentation and land use on fish distribution and conservation is still poorly understood. This thesis aimed to address this knowledge gap by investigating the role of watershed management and fragmentation on fish species distribution in a warming 21st century, in order to provide information in support of river management and produce tools to better approach this issue. We first studied longitudinal connectivity and its influence on river fish communities, then we built watershed management scenarios which we integrated into species distribution models to study the influence of climate change and watershed management on potential future fish communities, before studying the spread of uncertainty between these two components.

The Seine-Normandie basin, a highly anthropized watershed in Northern France, was selected for this study. A dataset comprising over 2,000 study sites was compiled for the analysis of longitudinal connectivity. Novel connectivity indices were developed, based on functional traits of fish and river fragmentation, some indices accounting for local context (e.g. river size and river centrality within the basin). We were able to assess the relative importance of connectivity in fish distribution via species distribution modelling, indices which included local context performing especially well. We found that dams play a pivotal role in shaping fish distribution.

In order to model future fish distribution, four climate projections were selected across two-time horizons, 2050 and 2100. In addition, we constructed four management scenarios to describe different future political orientations with respect to riverscape management. We were able to produce several prospects of species distribution through ensemble modeling. Most species were found to exhibit a decline in range over time due to climate change, management scenarios producing more complex outcomes. Scenarios linked with limited environmental restoration led to high rates of extirpation while scenarios with more ambitious prospects often resulted in enhanced survival rate. These responses exhibited wide variation across species, hindering the identification of a single scenario fitting the whole community. Finally, we highlighted the relative importance of uncertainty linked to climate change and territorial management across eight species. We found that in most cases climate change carried more uncertainty than watershed management. However, the portion of uncertainty carried by territorial management was still important, ranging between 6 % and 30 % on average depending on species. Some species (the bleak, roach) tolerant for warm water or environmental stressors associated with climate change were more impacted by territorial management in specific sites.

Through this PhD we provided insights into the role of connectivity on the composition of river fish communities as well as the influence of management and climate change on future river ecosystems. We were also able to provide new practical clues for future management and new methodologies for assessing connectivity in river networks and integrating it into modeling approaches. We produced plausible futures for river fish distribution, allowing us to assess the importance of climate change and territorial management on fish species conservation. We believe many of these approaches can be applied in similar contexts and contribute to the creation of knowledge necessary to implement the urgent measures required to safeguard river ecosystems in future decades.

Publications

Felin S., Belliard J., Grenouillet G., Moatar F., Le Pichon C., Thieu V., Thirel G., Jeliazkov A. (2025) The role of river connectivity in the distribution of fish in an anthropized watershed *Science of the Total Environment*, n°959.

Metaprogram
BIOSEFAIR

SYNBIOTOX

THESIS

2022-2025

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Thematics involved
Ecology
Ecotoxicology
Constructed wetlands
Pesticides
Amphibians
Aquatic invertebrates
Biomonitoring

Understanding the potential impacts of agricultural contaminant flows on aquatic fauna in constructed wetlands (CWs)

SYNBIOTOX, through ecological and ecotoxicological monitoring of a pilot constructed wetland (CW) located in Seine-et-Marne, demonstrates that the risk posed by agricultural contaminant flows within the CW is significant for amphibians, and that negative behavioural and ecological effects are exerted on aquatic fauna. This thesis provides a better understanding of the potential impacts of agricultural contaminant flows on aquatic fauna in constructed wetlands.

SYNBIOTOX - Synchronisms and antagonisms in the relations between agricultural environment, biodiversity, and ecological functions in an agricultural constructed wetland

Some of the agricultural contaminants (pesticides, nitrogen) spread on cultivated soils reach the hydrosphere through agricultural drainage (1) with proven consequences on aquatic ecosystems and their functions. Constructed wetlands are designed to break down nitrates and certain pesticides through natural purification features. Nevertheless, they constitute potential reservoirs of contaminants likely to impact the wild species they shelter by acting as ecological traps.

Summary

Agrochemicals, including pesticides and nitrates, can be transferred to the hydrosphere, with adverse effects on organisms and aquatic ecosystems. Constructed wetlands (CWs) can be implemented in the agricultural landscape to reduce the transfer of agrochemicals to the hydrosphere through their natural purification properties. However, although their primary aim is to reduce pollution of the aquatic environment, paradoxically, CWs can act as interceptors and concentrators of pesticides and nitrates, with the negative repercussions that these contaminants can have on aquatic organisms, making CWs potential ecological traps for aquatic fauna.

By studying a pilot site located in Seine-et-Marne (France) and subject to water quality monitoring since 2012, the present thesis aims to assess the potential for an agricultural CW to act as an ecological trap for amphibians and aquatic invertebrates. Through a series of multi-level, in situ ecological and ecotoxicological monitoring studies, the results obtained tend to show that the risk induced by agrochemical fluxes in the CW is notable for amphibians, and that negative sub-cellular, behavioral, and ecological effects are exerted on aquatic fauna. This work provides a better understanding of the potential impacts of agricultural contaminant fluxes on aquatic fauna in CWs.

Publication

Michel Al. J.W., Tonial J., Bettencourt-Amarante S., Chaumont C., Girondin M., Tournebize J., Jeliazkov A., Lebrun J. D. (2026) First in situ application of a non-invasive sampling approach to assess pesticide effects on amphibian enzymatic activities, *Environmental Chemistry and Ecotoxicology*, 8.

Current researches

Metaprogram
BIOSEFAIR

SALUD

FLAGSHIP PROJECT

2025-2028

Understanding the links between forest and human health, vulnerability to global changes, and biological diversity

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Keywords
One Health
Biodiversity
Forest
Fire hazard
Lyme disease

Thematics involved
Forest ecology
Fire ecology
Health ecology
Genetics
Population biology
Remote sensing
Plant pathology
Social anthropology
Ecosystem services
Food webs
Modelling

Divisions involved
ACT
ECODIV
SA

Units involved
URFM
UR LESSEM
UMR RECOVER
UMR BIOEPAR
UR EFNO
URZF
UMR Silva
UMR TETIS
UREP
UMR BIOGECO

Partners
Laboratoire Chrono-Environnement

Forests host exceptional biodiversity and provide essential ecosystem services, ranging from carbon sequestration to disease regulation. Yet, deforestation, overexploitation, and anthropogenic pressures are weakening their resilience and fostering the emergence of health risks. In this context, the "One Health" approach–linking human, animal, and environmental health–offers a relevant framework to understand the interactions between forest health and human health. The SALUD project aims to explore these connections by studying the impacts of biodiversity and forest management history on two major issues: tick-borne diseases and fire risk. Thus, the project seeks to fill this gap by investigating how human activities, particularly forest management, affect forest ecosystem health and their potential repercussions on human health, such as the emergence of zoonotic diseases or wildfire risks.

© Pilar Fernandez

Objectives

The SALUD project seeks to better understand how the health of forest ecosystems directly or indirectly influences human health. To this end, it is structured around four main objectives:

- Assess the influence of forest management history on biodiversity, stand structure, and forest resilience. Old-growth forests, untouched for several decades, will serve as a reference state to characterize a "healthy" ecosystem;
- Analyze the vulnerability of forests to major hazards: wildfire risk and phytosanitary threats (pathogenic fungi and insects);
- Quantify tick population density and pathogen prevalence (particularly *Borrelia* spp.) along a forest management gradient. This approach will allow testing the dilution and amplification hypotheses of zoonotic risks in relation to biodiversity;
- Integrate these different dimensions to understand how forest health–for example, through trophic networks and ecosystem services–affects human health. This will provide essential knowledge for designing operational indicators and guiding sustainable management strategies that reconcile conservation, risk prevention, and human well-being.

Approaches

To achieve these objectives, SALUD adopts a multidisciplinary and multi-scale approach, combining ecology, genetics, epidemiology, and modelling.

The approach first relies on the selection of "pilot sites" in mountain beech–fir forests, representative of different management histories (exploited forests, forests abandoned for several decades, old-growth forests). On these sites, multitaxonomic inventories (plants, fungi, insects, birds, mammals, bats) will be conducted, along with structural (composition, regeneration, deadwood, canopy openness) and genetic (adaptive diversity of trees) measurements.

At the same time, tick density and pathogen prevalence will be assessed through standardized sampling and molecular analyses. These data will be related to host community composition, identified through trapping, acoustic monitoring, and floristic surveys.

Concerning fire risk, measurements of combustibility (deadwood, microclimate, litter moisture content) and modelling will help assess forest stand vulnerability.

All data will be integrated into trophic network analyses and multi-service models to link forest health, biodiversity, and health risks. This integrative approach, also drawing on national databases and remote sensing, will generate reliable indicators to evaluate and anticipate the impacts of forest management on both human and ecosystem health.

Metaprogram
BIOSEFAIR

ARTECO

PATHFINDER PROJECT

2025-2027

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Keywords
Heterogeneous landscapes
Edges/ecotones
Organism flows
Meta-ecosystems
Massive DNA barcoding

Thematics involved
Mathematics/statistics
Community ecology
Molecular biology

Divisions involved
ACT
AQUA
ECODIV
SPE

Units involved
UREP
UMR DYNAFOR
UR HYCAR
URZF
UMR BAGAP
UMR IGEPP
UE Saint-Laurent-de-la-Prée

Inferring arthropod spatial flows in ecotones between (semi-) natural and crop habitats

Numerous empirical studies have documented the link between landscape structure and biodiversity, providing concrete guidelines for the ecological intensification of agricultural landscapes. However, they are based on ecological processes that are still poorly understood, and which shape the response of organisms to the multiplication of anthropogenic ecotones. Among these processes, the movement of organisms (foraging, dispersal, spill-over) and their habitat preferences play a central role. Quantifying these processes would enable us to better predict the effects of landscape and ecological infrastructures (hedges, grass strips).

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Objectives

We propose to work towards a better understanding of the ecological processes influencing the dynamics of organisms within heterogeneous landscapes, 1) by bringing together an interdisciplinary consortium (mathematics, ecology, molecular biology) of partners interested in ecotones and 2) by carrying out a pilot project to serve as a proof of concept. This project will aim to develop original methods for inferring arthropod flows at the interface between habitats, based on high-resolution species distribution data, both spatially (metric transects) and taxonomically (massive DNA barcoding), focusing on predatory taxa (beetles and spiders) for their biological control potential. We will concentrate our efforts on three types of interfaces: wheat crops on the one hand, forests, meadows or riparian zones on the other. These three interfaces allow us to study the role of semi-natural habitats (forests/grasslands/riparian forests) in the provision of ecosystem services for agriculture (pest regulation). Meetings of the consortium upstream and downstream of this project will enable us to prepare the setting up of an ANR-type project by the end of this project, capitalizing on the results of the exploratory project.

Approaches

We will sample terrestrial invertebrate communities along transects perpendicular to the interface, using suction-sampling methods (for a broad spectrum of arthropods - focusing on predatory invertebrates with a potential biological control role). The organisms sampled will be determined to species level by massive DNA barcoding, in order to determine abundance profiles along the transects for each population making up the communities. These abundance profiles (clines) will feed into the project's development of new inference methods, inspired by population genetics, to estimate invertebrate flows between plots. The project's originality is therefore twofold. From a biological point of view, the aim is to go beyond pattern analysis (distance and magnitude of edge effect) and delve deeper into the spatial processes involved, by explicitly estimating and integrating the flows of organisms between habitats. From a technical point of view, the aim is to implement recent and innovative methodologies known as "meGabarcoding", which involve the massive barcoding of tens of thousands of individuals, providing access not only to community diversity (like meTabarcoding), but also to the abundance of individuals of each species, and even to a certain level of intra-specific polymorphism. By coupling this megabarcoding approach with the acquisition of photographs of sampled individuals, we will contribute to the ongoing development of automatic image-based recognition systems (and AI) for terrestrial invertebrates, with a view to moving towards non-lethal monitoring methods. These methodological developments will help to modernize biodiversity monitoring methods and enable us to make a quantum leap in our understanding of ecotone ecology.

Metaprogram
BIOSEFAIR

FARMSOUND

PATHFINDER PROJECT

2025-2027

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Keywords
Biodiversity
Bird communities
Ecoacoustics
Organic farming
Soundscapes

Thematics involved
Agro-ecology
Bioacoustics
Biogeography
Landscape ecology
Community ecology
Historical ecology
Ethno-ecology
Human geography
Geomatics
Deep learning
Modelling
Teledetection

Divisions involved
ACT
AGROECOSYSTEM
ECODIV
SPE

Units involved
UMR DYNAFOR
UMR BAGAP
UR PSH
UREP
UMR SAVE
UMR LISAH

Partners
SETE - CNRS
OFB
University of Caen Normandie
UMR Chrono-environnement - CNRS / University Marie et Louis Pasteur
University of Helsinki (Finlande)

A multiregional network of acoustic biodiversity monitoring in French farmland soundscapes

The FARMSOUND project aims at (1) federating a scientific network for monitoring rural acoustic landscapes in France and their acoustic biodiversity; (2) jointly analyzing the factors determining their acoustic diversity and the composition of acoustic bird communities; (3) proposing socio-ecological indicators of the cultural value of soundscapes and their acoustic diversity. FARMSOUND will test the hypothesis of positive responses of acoustic biodiversity to the level of landscape naturalness and diversity of agricultural management intensity, and in particular to the current and historical amount and configuration of permanent grasslands and the proportion of organically farmed plots at the landscape scale.

© Luc Barbaro

Objectives

FARMSOUND aims at providing an integrative, non-invasive and innovative method for monitoring the biodiversity of French rural landscapes composed of mosaics of crops, meadows and forests, taking into account both their wide inter-regional diversity and their strong intra-regional heterogeneity. In response, we are developing new socio-ecological indicators based on the acoustic diversity of soundscapes recorded by passive automatic recorders. Acoustic indices calculated from sonograms can be used to characterize the overall acoustic diversity and complexity of a soundscape. They also make it possible to quantify the relative proportions of phonies (i.e., biophony, geophony or techno-anthropophony) and their co-occurrence in a rigorous, standardized, repeatable and non-invasive way. Systematic identification of acoustic bird communities using deep learning algorithms will also be carried out during the 2nd year of the project. FARMSOUND is based on a network of sites recorded by passive acoustics at a dozen workshop sites in 8 French regions, using standard recorders. The acoustic data acquired at these sites (roughly N = 500 soundscapes expected to be recorded at the end of the project) will be used to test the effect of the composition and current and past configuration of rural landscapes on their current acoustic diversity and communities, as well as the effect of the intensity of agricultural practices (including the proportion of organic farming) and the level of surrounding landscape naturalness.

Approaches

The questions and approaches of FARMSOUND are structured into a main task of modeling the response of acoustic indices to the structure and management intensity of current agricultural landscapes and three additional inter-disciplinary tasks:

(1) What is the effect of the historical amount of permanent grassland in the landscape on current acoustic diversities and communities? Has compositional and configurational heterogeneity changed since the immediate post-war period? Is there a link between landscape changes and trends in the evolution of key songbird species in agricultural landscapes over recent decades?

(2) How can we optimize the use of algorithms for automated recognition of species vocalizations and various sound sources, whether biophonic, geophonic or techno-anthropophonic? Can we characterize bird "acoustic communities" in a standardized way, and how can we define this new concept of community compared to the one used for decades in community ecology?

(3) Is acoustic diversity a good indicator of the sound quality of agricultural landscapes? Can we link a perception of acoustic well-being with the composition and richness of bird communities in a soundscape? Can we estimate the cultural value of bird songs at the community level, and is there a link between the acoustic traits of bird songs and their contribution to the cultural diversity of songs?

Metaprogram
BIOSEFAIR

SOUTERRE

PATHFINDER PROJECT

2025-2027

Diversity and spatio-temporal dynamics of groundwater fauna to assess both exchanges between groundwater and rivers and the biological quality of the aquifers

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Keywords
Groundwater invertebrates
Spatio-temporal dynamics
Dispersal
Bioindicators
River-groundwater exchanges

Thematics involved
Community ecology
Molecular ecology
Hydrobiology

Divisions involved
AQUA
ECODIV

Units involved
USC Ecodiv-Rouen
UR EABX
USC LEHNA
UMR BIOGECO

Partners
UMR M2C - CNRS / University of Rouen Normandie
SEPANSO Aquitaine

Groundwater systems are critical ecosystems comprising both some of the rarest habitats on the planet and aquatic invertebrates specifically adapted to these environments, named stygobitic fauna. This fauna interacts more or less with surface ecosystems depending hydrogeological conditions. While they are certainly impacted by the effects of human activities and the global change like surface ecosystems, taxonomic and ecological knowledge of the environments and their fauna is extremely dispersed in France and around the world. They are not part of any management or conservation plan.

© Louise Lejosne

Objectives

SOUTERRE proposes:

1. To identify the assemblages of the stygobitic fauna in Normandy groundwater and to determine biotic and abiotic factors that shape these assemblages,
2. To use this fauna as bioindicators of the biological quality and vulnerability of groundwater systems by testing on data collected in both Normandy and New Aquitaine regions,
3. To understand the spatio-temporal dynamics of stygobitic species between subterranean and surface ecosystems,
4. To understand the current dispersal of individuals (i.e. gene flow) between populations in Normandy and past dispersal events (i.e. since the Pleistocene) at national and European scales,
5. To initiate experiments using environmental DNA in future sampling protocols for groundwater studies.

Approaches

A sampling of several sites with different characteristics is currently carried out monthly in 2025 to inventory and characterize both groundwater fauna communities and biotic and abiotic factors that shape species assemblages. Also, this monitoring will allow to test whether these assemblages are constant over seasons or whether they vary according to different weather conditions (e.g. meteorological forcing).

The sampling is carried out by filtering water with a pump (i.e. 300 L of water), Surber nets and plankton nets in order to capture all taxonomic groups regardless of their size: from copepods (i.e. size of the order of mm) to amphipods (i.e. size of the order of cm).

Moreover, these data will be used to propose bioindicators for groundwater systems.

Molecular analyses will be also carried out for both a species of the genus *Proasellus* and a species of the genus *Niphargus* to study and compare gene flows and possible genetic structure of populations in Normandy between two species that have different dispersal abilities. At a larger scale and in collaboration with other research units in Europe (e.g. Slovenia), phylogeographic approaches will be used to study post-glacial colonization or re-colonization events of both species.

Metaprogram
BIOSEFAIR

VERTYGE

PATHFINDER PROJECT

2025-2027

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Keywords
Epiphytes
Biodiversity
Dendromicrohabitats
Altitudinal gradient
Climate change

Thematics involved
Community ecology
Systematics in bryology
Environmental metabarcoding of fungal and faunal communities
Biomonitoring methods through the use of dendromicrohabitats as a bioindicator of biodiversity assessment
Scientific mediation

Divisions involved
ACT
ECODIV

Units involved
UR EFNO
USC Ecodiv-Rouen
UR LESSEM

Partners
LECA - CNRS

Biodiversity linked to epiphytic dendromicrohabitats along altitudinal gradients

Dendromicrohabitats (DMHs) are morphological singularities on trees that have multiple functional roles in the life cycle of many species: shelter, feeding, reproduction... However, few studies have examined the links between DMHs and the communities they host. Project VERTYGE focuses on these functions within mountain epiphytic DMHs (ivy, bryophyte, lichen) distributed along an altitudinal gradient and along the vertical position in the tree.

© Adeline François

Objectives

VERTYGE aims to increase knowledge of the role of epiphytes in forest biodiversity, along altitudinal (altitude) and vertical (tree height) gradients in the French Alps.

Two main objectives are targeted:

- To identify animal (micro- to macrofauna) and fungal taxa inhabiting epiphytic DMHs by environmental metabarcoding,
- To understand how functional and taxonomic variation in DMHs (morphology and composition) in relation to altitude and height along the main vertical axis filter assemblages of similar animal and fungal communities.

Beyond improving fundamental knowledge, VERTYGE will consolidate forest management tools in a context of climate change and biodiversity erosion, and will promote scientific communication and public mediation around forest biodiversity, dendromicrohabitats and VERTYGE results.

Approaches

To investigate the links between biodiversity and epiphytic DMHs, we propose to sample the plots of the ORCHAMP observation network already described and valorized. Sampling will be carried on approximately 30 trees.

Along the vertical axis of the tree, epiphytic DMHs will be described at several heights using conventional methods based on morphological criteria, and then sampled. In situ habitats will be accessed by tree-climbing. Second, bryophytes and ivy species will be identified on morphological criteria in the laboratory, and animal and fungal taxa collected from epiphytes will be identified by environmental metabarcoding.

The links between substrate (DMH), community, altitude, tree height and carrier species will then be analyzed jointly by the various project members.

To disseminate the results and other scientific advances about forest biodiversity, a seminar will be organized at the end of the project, in conjunction with a seminar aimed at relations between scientists and managers.

Knowledge, methods, results and issues relating to forest biodiversity will be disseminated to users through a halfday layman's workshop.

Metaprogram
BIOSEFAIR

AGROFORDIV

CONSORTIUM
2026-2027

Establishing the groundwork for an interdisciplinary exploration of diversified agroforestry systems

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Keywords
Biodiversity
Agroforestry
Agroecology
Ecosystem services
Cropping system health

Thematics involved
Agronomy
Ecology
Sociology
Geography
Anthropology
Management Sciences
Food Sciences

Divisions involved
ACT
AGROECOSYSTEM
TRANSFORM

Units involved
UMR ABSys
UMR SAS
UMR Agronomie
UR Ecodéveloppement
UMR BAGAP
UMR SADAPT
USC LER
UMR PAM

Partners
University Rennes 2
GRAB
Institut d'études politiques de Rennes
Institut Agro Dijon
VVOUM Association - Toward Open, Urban, Mediterranean Orchards
FiBL France - Organic Agriculture Research Institute
CIVAM SAEL - Agroecological systems in Limousin
CIRAD

Highly diversified agroforestry systems–orchard-market gardens, forest gardens, or successional agroforestry systems (also known as syntropic agroforestry systems) are emerging in France and Europe due to their significant ecological, agronomic, and social potential. Although promising in addressing current challenges (biodiversity loss, climate change, agroecological transition, among others), their adoption is still hindered by various technical, economic, and institutional barriers. The consortium built around this project aims to better understand the functioning and impacts of highly diversified agroforestry systems, which are still poorly studied, while laying the foundations for participatory and transdisciplinary research capable of addressing the agronomic, ecological, and societal challenges of current agriculture.

© Ferme Bocaux d' amour – F. Calvet

Objectives

The goal of AgroForDiv is to structure an interdisciplinary research network on diversified agroforestry systems. To achieve this, it relies on the co-construction of a common research agenda to collectively advance the reflection around the following axes: approach:

- Characterizing highly diversified agroforestry systems by focusing on their design (spatial and temporal arrangement of species), management practices (implementation and modalities), and the decision-making elements underlying them (the reasons behind the choices made).
- Evaluating the relationships between biodiversity and ecosystem services, considering the structure of the systems (strata, plant diversity) and their management modalities.
- Analyzing the contribution of these systems to the overall health of soils, ecosystems, and humans, through an integrated "One Health".

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Example of spatial arrangement and species selection of a highly diversified agroforestry system in a temperate climate.

Approaches

Different meetings, reflection time and regular webinaries will identify existing and missing knowledge around highly diverse agroforestry systems. They will also make it possible to co-construct the work agenda in order to advance collectively in the production of priority research issues to be sent and a positioning item. The co-construction of a characterization and evaluation protocol of diversity and ecosystem services is also provided.

Metaprogram
BIOSEFAIR

COP26

CONSORTIUM
2026-2028

Assessment of the impact of copper on the health of terrestrial and aquatic ecosystems

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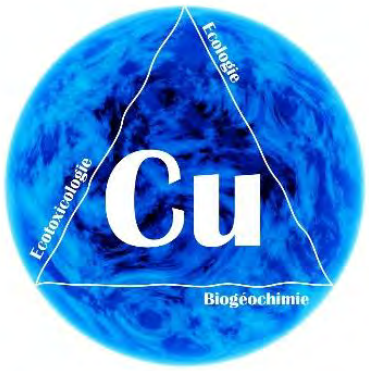
Keywords
Copper
Low dose
Ecotoxicity
Multi-targets
Multi-environmental compartments

Thematics involved
Biogeochemistry
Functional ecology
Community ecology
Ecotoxicology
Agronomy

Divisions involved
AGROECOSYSTEM
AQUA
ECODIV
SPE

Units involved
UMR ISPA
UR EABX
UMR ECOSYS
UMR SAVE

COP26 aims to build an interdisciplinary consortium around a comprehensive approach to assessing the environmental impact of the use of copper fungicides in agriculture. By inviting agronomists, biogeochemists, ecotoxicologists and ecologists to initiate a joint discussion on copper, its uses in crop protection, its dynamics in soils and waters, its effects on soil and aquatic organisms, and on the ecological functioning of soils and waters, this project aims to support INRAE on issues related to global health, in particular by bridging biodiversity, ecosystem services, plant health and animal health.



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Objectives

Copper (Cu) contained in copper fungicides used to protect crops (especially vines) against mildew is a fungicide that agriculture can hardly do without (at least in the medium term). It is therefore necessary, in addition to the search for alternatives to Cu, to accurately assess the impact of copper on environmental health and the functioning of wine-growing ecosystems at the realistic doses at which it accumulates. To date, there is a lack of data on Cu speciation in natural waters and on the toxicity of realistic doses of Cu for aquatic organisms or soil macroorganisms, as well as on the impacts of Cu on the trophic interaction networks involving these communities and the ecological functions they support.

The main objective of COP26 is therefore to i) build an interdisciplinary consortium (agronomists, biogeochemists, ecotoxicologists and ecologists) around a global approach to assess the environmental impact of the use of copper fungicides in agriculture and ii) initiate a common discussion on copper, its uses in crop protection, its dynamics in soils and waters, its effects on soil and aquatic organisms, and finally on the ecological functioning of soils and waters.

Approaches

By discussing visions of partners in assessing the effects of copper, COP26 will enable the sharing of approaches (methodologies, concepts) and of diverse expertise related to the "low dose" issue, differences between environmental compartments (soils and soil drainage waters), and the understanding of bioavailability, bioaccumulation, and ecotoxicity at different scales of impact. The organization of a writing retreat will lead to the preparation of an opinion article in which we will provide a state-of-the-art overview of Cu effects on communities and the functioning of agroecosystems, at the concentrations (and forms) at which it accumulates. The conceptual and methodological bottlenecks to better understand Cu effects on the overall health of the agroecosystems where it is applied will also be described. Through the consortium's interdisciplinary expertise, COP26 will provide a reflection on the environmental impact of copper useful for the agricultural world and for regulators, on the diagnostic tools for assessing copper pressure in soils and drainage waters of wine-growing soils, as well as on the models used to predict the ecotoxicological impact of copper fungicides by considering the relationships between bioavailability, bioaccumulation and ecotoxicity of Cu for a wide range of targets and traits.

Metaprogram
BIOSEFAIR

FUSEE

CONSORTIUM
2026-2028

Urban Forests and Ecosystem Services: Evaluating to Manage

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Keywords
Ecosystem services
Urban forest
Participatory science and research
Green infrastructure

Thematics involved
Ecology
Urban forestry
Bioclimatology
Sociology
Geography
Economics
Information Sciences

Divisions involved
ACT
AGROECOSYSTEM
ECODIV
ECOSOCIO

Units involved
UMR BIOGECO
UR ETTIS
UMR ISPA
UMR ECOSYS
UMR LISIS
UMR TETIS

Partners
Université Lyon 3 – Faculté des Humanités, Lettres et Sociétés
Centre Emile Durkheim, URFIST Bordeaux
CRAUM – Chaire de recherche sur l'arbre urbain et son milieu – Université Laval (Québec)

Trees are living beings that form part of the urban socio-ecosystem. They provide essential ecosystem services: they buffer extreme temperatures, mitigate pollution, support biodiversity and contribute directly and indirectly to improving well-being. However, their presence can be perceived as a nuisance–competition for space, allergy risks, damage to property and people–and their monitoring and maintenance generate costs for municipalities and individuals who own most of the trees in cities. The benefits of the services and the costs of the disservices associated with urban trees are difficult to quantify and compare in the absence of an appropriate analytical framework.

This programme is jointly supported by the BIOSEFAIR and BETTER metaprogrammes.

Objectives

The FAO defines urban forests as 'a network or system including all wooded areas, groups of trees and individual trees located in urban and peri-urban areas, including forests, street trees, trees in parks and gardens, and trees in abandoned areas.

The balance between the ecosystem services and disservices associated with it is determined by the identity, specific, architectural and functional diversity, abundance and distribution of trees in urban areas. However, the characteristics of the urban forest are themselves the result of biological, sociological, economic and regulatory constraints. The urban forest reflects both the attitudes of individuals towards trees and the evolution of urban policies.

The FUSEE project – Urban Forest and Ecosystem Services: Evaluate to Manage – has two objectives:

- Build a common conceptual framework for assessing the ecosystem services provided by the urban forest as a whole, fully integrating its biological, ecological, social, cultural, economic and political dimensions;
- Develop tools to assess the services and benefits that trees in cities actually, potentially or supposedly provide.

Approaches

The project is being rolled out in five successive phases aimed at structuring an interdisciplinary scientific community around the assessment of ecosystem services provided by the urban forest.

The initiation phase (January 2026) establishes a common framework for analysis and develops a shared glossary.

The acculturation phase (April 2026 – March 2027) will organise a series of bimonthly webinars bringing together scientists and socio-economic actors to explore different ecosystem services and discuss conceptual and methodological barriers.

The co-construction phase (June 2027) brings together researchers, practitioners and citizens to prioritise their concerns regarding ecosystem services and develop a questionnaire for professionals and residents, prior to the next phase.

The co-design phase (October 2027) takes the form of a writing workshop aimed at defining priority issues, research methods and partnerships, as well as the variables needed to construct spatialisable indicators of ecosystem services.

Metaprogram
BIOSEFAIR

RESOTEC

CONSORTIUM
2026-2027

Use of social networks and remote sensing to estimate forest cultural ecosystem services

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Keywords
Ecosystem services
Forest
Remote sensing
Social network
Ecology

Thematics involved
Ecology
Informatic
Remote sensing

Divisions involved
ACT
ECODIV
MATHNUM

Units involved
UMR RECOVER
UMR AMAP
UMR TETIS

Partners
CEFE CNRS - Centre d'écologie fonctionnelle et évolutive
CESAB FRB - Centre de synthèse et d'analyse sur la biodiversité

Optimising the ecosystem services provided by forests is a growing challenge for forest management, which requires clear quantification of the link between stand characteristics and service provision. Supply and regulation services (wood supply, carbon sequestration), which are easier to assess, are often favoured. On the other hand, cultural services (aesthetic value, recreational activities) are given less consideration because they are difficult to assess. Geolocalised data from social networks offers new ways of quantifying these services. At the same time, the development of remote sensing now makes it possible to characterise the structure and composition of forests on a national scale.

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Objectives

RESOTEC aimed at testing the potential of remote sensing and social network data to characterise the link between forest stand structure and composition and cultural ecosystem services.

The first objective is to establish a proof of concept on the potential of these data to improve our understanding of the forest attributes that structure the value of cultural ecosystem services by conducting an initial study focusing on the aesthetic and landscape value service. In the literature, this service has so far been assessed mainly on the basis of sociological questionnaires: here we propose a quantitative assessment based on the density of photos published on the Flickr social network.

The second objective is to explore the potential for diversifying data, methodological approaches (e.g. crowdsourcing) and the services considered (e.g. recreational activities such as wild gathering, sports or naturalistic use) in order to characterise the link between forest attributes and cultural ecosystem services.

Approaches

The project is structured around two complementary approaches:

1. To meet the first objective, we are going to study, via an M2 internship, the effect of forest structure and composition metrics and landscape attributes on the aesthetic value of forest stands, calculated from the IGN's HD LIDAR campaign and land-use databases (e.g. BD Forêt V2). For this purpose, geolocalised data from the Flickr application over the last 10 years in several regional nature parks with predominantly forested areas in the Mediterranean region (Sainte-Baume, Alpilles, Baronnies provençales) have already been compiled. This internship will provide an initial insight into the potential of data from social networks for linking forest attributes and cultural ecosystem services.
2. To meet the second objective, we are going to bring together a consortium of researchers working on the evaluation of cultural services in order to explore, through a 2-3 day workshop, the prospects for building a more ambitious project (ANR type). In particular, the workshop will look at the possibilities of diversifying both the cultural services evaluated and the methodological approaches considered.

Metaprogram
BIOSEFAIR

CO-PRAM

THESIS

2022-2025

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Starting Date: 1/11/2025
Research Unit: UMR BIOEPAR

INRAE Site: Pays de la Loire

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PhD Student: Manon Guillaumin
University and Doctoral School: Oniris VetAgroBio Nantes, ED VAAME

Funding: Biosefair metaprogramme / Région Pays de la Loire

Thematics Involved
Ecology
Biostatistic
Zoonotic diseases
Epidemiology

Assessment of the influence of connectivity between wooded areas in the landscape on tick-borne disease risk: modelisation approach

Backgrounds and challenges

The emergence of tick-borne animal and zoonotic diseases is influenced by complex interactions between ticks, transmitted agents, vertebrate reservoir hosts and their habitats. Changes in the composition of the landscape can strongly alter the relationships between species and the abundance of populations, thereby affecting the 'acarological risk', defined as the density of ticks infected by a pathogen.

Objectives

The aim of this work is to examine in depth the methodological issues involved in modelling the influence of the degree of fragmentation of agricultural landscapes in wooded areas on the acarological risk, using the example of bacteria of the genus Borrelia, the agents of Lyme disease. Bayesian statistical analyses of existing sets of observed data and real landscapes will be used to identify the variables influencing the risk in wooded habitats in a bocage landscape. These variables will be integrated into a dynamic model based on the coupling between a landscape model and a model of bacterial transmission within tick populations. Developed within a conceptual framework of metapopulations, this model will enable scenarios to be explored both theoretically and by comparison with the data, particularly with regard to the respective influence of the characteristics of the woods (size, composition) and their spatial arrangement.

Approaches

Data were collected as part of the Biodilutique project (MP Biosefair, 2021-2023), which aimed to assess the influence of host factors and landscape characteristics on the acarological risk caused by various pathogens, in particular bacteria of the genus Borrelia.

Two tick-collection campaigns were carried out in wooded areas of varying size, on the site of the Plaine et Val de Sèvres Long-Term Ecosystem Research (LTER) area (France). These ticks were analysed to estimate their carriage of the pathogen. The data were geo-located over the whole area.

These data can be supplemented by analysis of camera-trap data, which will make it possible to estimate variations in the presence of large hosts (notably roe deer) in different wooded areas.

Photo réalisée par IA

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BIOSEFAIR

DYNAGRASS

THESIS
2023-2026

Temporal dynamics of biodiversity and ecosystem services in French permanent grasslands in the context of global changes

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Thematics Involved
Community ecology
Functional ecology
Landscape ecology
Remote sensing

Backgrounds and challenges

Permanent grasslands play an essential role in maintaining grass-fed livestock and providing key ecosystem services for the agro-ecological transition (pollination, pest control, soil fertility) and society (carbon storage, water purification, aesthetic value). In France, permanent grasslands are one of the most diversified ecosystems but also one of the most threatened at the national scale. Indeed, their surface has considerably decreased over the last decades, which hinders the functioning of agricultural landscapes as well as the conservation of a unique heritage biodiversity. Moreover, global changes are likely to influence the characteristics of the remaining grasslands. However, we lack knowledge on the temporal dynamics of biodiversity and ecosystem services of permanent grasslands at the French national scale, as well as on the underlying causes and consequences of these dynamics.

Objectives

Using a unique database compiled by the French National Botanical Conservatories, the thesis will characterize the temporal dynamics of taxonomic, phylogenetic and functional diversity of permanent grassland plants at different spatial scales (from plot to national territory) over the last decades. By combining these data with cartographic and statistical data, it will then assess the causes of these dynamics, particularly in terms of land use and climate changes. Finally, by mobilizing remote sensing data, it will assess their consequences from a functional point of view, particularly in terms of the resilience of grasslands to climatic hazards.

This thesis thus aims to address the major scientific challenge of understanding the temporal dynamics of biodiversity in response to multiple factors of global change and its consequences on the functioning of ecosystems. It also aims to provide actionable knowledge to improve the conservation of permanent grasslands and promote the agroecological transition of the livestock sector and its adaptation to climate change.

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Permanent grasslands in the Pyrenees National Park

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JUST-PLAN

THESIS
2025-2028

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Thematics Involved
Spatial economy
Ecology

Environmental justice and spatial planning decisions

Backgrounds and challenges

Urban regions face environmental risks that are exacerbated by climate change (CC). By controlling and planning the conversion, restoration, or conservation of natural spaces, spatial planning directly affects the well-being of populations and their resilience to these risks. Indeed, natural spaces contribute to health and well-being and represent an important asset for adaptation and resilience due to the ecological functions they perform and the ecosystem services (ES) they provide (regulation of temperatures, floods, and pollution; recreation and reduction of anxiety; awareness-raising and education about biodiversity; etc.). Yet, planning decisions are rarely studied through the lens of who loses or gains from changes in natural spaces and their ecosystem services.

Objectives

Climate change (CC) adaptation policies based on nature rarely integrate social and economic dimensions. The literature has shown that this can lead, in the case of renaturation policies, to prioritizing urban areas that are poorly endowed with natural spaces but where resident populations have higher incomes and education levels, better access to employment, higher life expectancy, and greater access to health services (Liotta et al., 2020). More broadly, socio-spatial segregation leads to an unequal distribution of vulnerabilities, as well as unequal adaptive capacities in the face of a changing environment. There is therefore a need to broaden the perspective adopted in spatial planning policies aimed at climate change adaptation through renaturation or the fight against land artificialization, in order to better address issues of environmental justice. To this end, we develop theoretical and empirical contributions on diagnosing environmental justice and identifying the locations of corrective actions by confronting and enriching existing approaches, while considering a set of ecosystem services associated with natural spaces.

Approaches

First, the approach includes a comprehensive literature review aimed at identifying existing indicators of environmental inequality and environmental justice, as well as methods for targeting priority areas within renaturation or anti-land-artificialization policies, particularly those characterized by a cumulative concentration of social and environmental disadvantages. This analysis seeks to compare their conceptual and methodological differences and to assess their implications for public policy. Particular attention is paid to the effects of spatial unit choices (municipalities, neighborhoods, grid cells) and the analytical boundaries considered (urban centers, peri-urban areas) on the measurement of inequalities. Various data sources are mobilized, including land-use data, socio-economic data, and data revealing individual preferences or behaviors. We examine the evolution of environmental inequalities across several dimensions, such as access to natural spaces, exposure to urban heat, and vulnerability to flooding. An analysis of the economic mechanisms underlying these dynamics also constitutes a central component of the research. Targeting methods are then employed to identify priority areas for public intervention, taking into account the cumulative nature of inequalities, through measures of the marginal contribution of spatial units or simulations of renaturation or conservation policies. Finally, in order to incorporate the potentially undesirable dynamic effects of environmental policies, such as gentrification, we use residential choice models to construct counterfactual scenarios. Overall, this approach aims to inform future strategies for spatial planning and climate change adaptation.

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Mexico City : la présence de nature, situation très contrastée entre deux quartiers adjacents

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MACROTOX

THESIS

2025-2028

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Thematics Involved
Ecotoxicology
Ecology
Macro-ecology
Modelisation
Statistics

Impact of toxic chemical pressure on the current evolution of macroinvertebrate communities in French watercourses

Backgrounds and challenges

This PhD is set within the major challenges related to the erosion of aquatic biodiversity. After several decades of improvement, recent studies indicate a slowdown, or even a reversal, of this trend for the richness and abundance of aquatic macroinvertebrates. This situation raises questions about the existence of pressures for which current river protection measures remain insufficient, particularly toxic chemical contamination. Indeed, multi-contamination has been identified as a major threat to aquatic biodiversity, yet its specific effects remain insufficiently characterized and quantified within ecosystems. The recent development of active biomonitoring techniques, now deployed nationwide in France, offers new prospects for specifically qualifying this pressure within the environmental variability, a first step toward addressing the operational challenges of river protection and restoration.

Objectives

The overall objective of this PhD is to characterize the specific effects of chemical contamination on the diversity of macroinvertebrates in French national rivers by comparing taxonomic monitoring data from surveillance networks with in situ ecotoxicology indicators derived from active biomonitoring. These new indicators quantify exposure to different substances as well as the toxicity of the environmental mixture. This main goal is divided into several specific objectives:

1. Identify national-scale taxonomic patterns associated with chemical contamination according to the type of pressure (agricultural, urban, industrial, natural).
2. Examine the influence of contextual factors (geographical, climatic, etc.) on these response patterns to chemical pressure and identify possible interactions in order to explain the observed territorial differences.
3. Reassess the impact of chemical pressure, in light of the spatial results from points 1 and 2, on the temporal trends of invertebrate communities at observatory sites involved in the long-term monitoring of the effects of the Rhône River ecological restoration.
4. Explore the community processes (erosion, replacement, homogenization) underlying the regional structuration of communities along gradients of chemical pressure.
5. Provide a functional interpretation of the observed taxonomic changes and identify biological traits selected or counter-selected in response to chemical pressure.
6. Assess whether these functional changes lead to shifts in community vulnerability to other pressures affecting aquatic ecosystems.

Approaches

This work seizes the recent opportunity to combine taxonomic monitoring data collected over the past 20 years within national surveillance networks with in situ ecotoxicological indicators (caged gammarids), repeatedly sampled at several hundred sites over the last five years. These two types of data, complemented by various environmental variables, will be analyzed using different statistical modeling approaches at multiple scales (national, hydro-ecoregions, watersheds). In a first step, the goal is to figure out changes in macroinvertebrate communities (richness, abundance, composition) attributable to different types of chemical pressures (agricultural, industrial, urban, etc.), while accounting for environmental context. This knowledge will then be used to better understand the diversity of dynamics observed locally within the Rhône hydrosystem through the macroinvertebrate monitoring data collected during restoration activities carried out as part of the RhônEco program. In a second step, beta-diversity metrics will also be examined to disentangle the processes of regional structuring (species turnover, homogenization) associated with chemical pressure. Finally, an approach based on species bio-ecological traits will translate taxonomic changes in terms of functional diversity in order to better understand the influence and direction of selective pressures acting on these traits and, ultimately, on the functional structure and composition of communities (e.g., assessment of the degree of functional redundancy). The hypothesis that sensitive species are replaced by functionally equivalent tolerant species will be tested, and stress sensitivity values (thermal, chemical, etc.) will be used to assess the potential vulnerability of communities to environmental change.

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MICROPLASTIQUES

THESIS
2022-2025

Ecotoxicological effects and ecological consequences of microplastics on soil functioning

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Funding: Biosefair metaprogramme / ANR CE34 Contaminant, Environnement, Santé projet E-Dip "Environmental Dynamics and Impacts of contaminant cocktails originating from Plastics in soil ecosystems" 2022-2026

Thematics Involved
Ecotoxicology
Microbial ecology
Plant ecophysiology
Functional ecology
Soil biogeochemistry

Backgrounds and challenges

The increasing use of various kinds of plastics leads to the accumulation and long-term storage of microplastics (MP) in soils. There is a growing scientific literature linking the presence of MP and the consequences for soil organisms that perform essential ecological functions. However, for the most part, these are ecotoxicological approaches through effects on certain organisms studied separately (microorganisms, micro-, macrofauna and plants), without addressing ecotoxicity issues. Moreover, in agricultural soils, the presence of MP may be due to inputs via amendments with organic matrices and their impact on the biological functioning of soils is then little documented.

Objectives

The objective of this thesis is to quantify the ecotoxicological effects and to understand the ecological consequences of MP on soil functioning, focusing on the relationships between processes in the soil, implemented by organisms belowground and aboveground. In particular, we will test the hypothesis that interactions between organisms in the soil exacerbate exposure to MP, while interactions in the presence of a plant mitigate MP exposure in each biological compartment.

Approaches

We will test the direct effects of MP on different model organisms and aim to assess the influence of trophic interactions on MP ecotoxicity via feedbacks from the different organisms studied. The general approach is based on experiments in controlled systems with an increasing complexity of exposure situations, and a modelling of the observed effects with regard to food webs. The expected results will provide new knowledge on the functional ecotoxicity of MP, with the aim of developing a conceptual model.

From the earthworm's point of view

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MODIMIR

THESIS

2024-2027

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Thematics Involved
Plant and microbial ecology
Biogeochemistry
Modeling

Modeling the Effects of Microbial Diversity on the Regulation of Carbon and Nutrient Cycles in Agroecosystems

Backgrounds and challenges

The thesis aims to understand the impact of biodiversity loss on ecosystem services and to support the ecological transition of agriculture. To achieve this, it relies on a novel approach that models ecosystem multifunctionality, focusing on the synchrony between soil and plants. The objective is to identify the conditions and controlling factors (such as climate, soil, and species diversity) that govern ecosystem functioning. The research also includes both field and laboratory experiments to test these models.

Objectives

The goal is to understand how microbial and plant diversity, along with soil and climate conditions, influence carbon (C) and nitrogen (N) fluxes in diversified agroecosystems.

The specific objectives are as follows:

- Identify regulatory mechanisms: This involves detecting and describing the processes through which microbial and plant diversity control C and N cycles. In concrete terms, the research focuses on how different species interact to affect the availability and movement of these nutrients
- Develop conceptual models: Based on the mechanisms identified, the next step is to create theoretical models. These models will represent the complex interactions between biodiversity, soil, and climate, and how they influence nutrient fluxes.
- Validate models with experimental data: To ensure that the models are realistic and accurate, the thesis will use data from previous experiments as well as new measurements collected specifically for this research. This calibration and evaluation phase is crucial to confirm the relevance of the models.
- Assess different scenarios: Finally, the validated models will be used to simulate various scenarios. This will make it possible to evaluate the impact of different combinations of microbial and plant diversity, and soil-climatic conditions, on ecosystem multifunctionality. In other words, it will help predict how greater biodiversity can improve soil fertility or resilience to climate change.

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OCCAVI

THESIS

2024-2027

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Thematics Involved
Landscape ecology
Community ecology
Conservation biology

Can low-intensive agricultural landscapes limit the decline in bird populations?

Backgrounds and challenges

A European study has shown that populations of farmland birds have declined by nearly 60 % over the last 40 years, and that intensive agriculture is the main pressure associated with this decline (Rigal *et al.* 2023). It also shows that the impact of intensive agriculture is compounded by the growing impact of climate change on these populations. However, this large-scale study is based on an approximation of agricultural intensity, measured by the value of pesticide and fertilizer purchases per hectare. This approach is not sufficient for analyzing the role of the multiple facets of agricultural intensification on long-term trends in bird populations. The relative weight of each of these components, as well as their spatial and temporal interactions, still need to be elucidated in order to understand the mechanisms behind the observed decline.

Objectives

Through the simultaneous analysis of bird population dynamics and changes in landscape structure and practices over the last 40 years, this thesis project aims to address the gaps in our understanding of the role of different aspects of agricultural intensification on long-term bird population trends.

The project involves the mobilization of data from the Suivi Temporel des Oiseaux Communs (national program) and regional monitoring carried out on three long-term study sites in Occitanie: Coteaux de Gascogne, Pic-Saint-Loup, and Grands Causses.
The aim will be to:

- Assess bird population trends at the national level in relation to different aspects of agricultural intensification (crop rotation diversity, extensive farming practices, and density of agroecological infrastructure);
- Identify the characteristics of these low-intensification agricultural landscapes that favor the maintenance of bird populations in Occitanie in a context of climate change;
- Analyzing temporal variations in the bird response to interactions between different local farming variables (crop rotations, inputs, mowing dates, etc.).

The focus on these three study sites in Occitanie, characterized by relatively extensive agricultural landscapes but with spatial variability in the different components of agricultural intensification, should make it possible to identify the contexts that limit biodiversity decline in agricultural environments.

Agricultural landscape of Occitanie (Pic-Saint-Loup, Coteaux de Gascogne, Causse Méjean)

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REMIFO

THESIS

2023-2026

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Thematics Involved
Anthropology
Ecology

What place do the actors of forest territories give to plants in their representations and collective practices?

Backgrounds and challenges

French forests suffer the combined effects of climatic, health and human disturbances, while at the same time being identified as one of the solutions to the ecological transition. As a result, controversy over the future of forests and associated ecosystem services intensifies. These debates could reflect, on the ground, more profound changes in the interactions between humans and these environments and be embodied in new modes of governance. Drawing on the theories of care, the ontological turn and ethnobotany, our research involves investigating the collective transformations underway in the Livradois-Forez Regional Nature Park.

Objectives

Through a survey of collective transformations underway in the Livradois-Forez Regional Nature Park, our aim is to track changes in people's relationships with forests and, more broadly, with plants, in order to report on the transformations experienced by local actors, which could lead to the emergence of new modes of governance in forest areas. More specifically, the study will focus on:

- Changes experienced by local players (including forest managers), i.e. the way in which individuals and groups experience the ecological and forestry crisis in their area. This involves questioning the players about the changes they are observing, the knowledge they are producing, and the practices they are adjusting and developing;
- Changing relationships with forests: in a context where the management choices made in French forests are now being questioned by various members of civil society, our aim is to extend the debate on interactions between species and to include interactions between humans and non-human;
- The link between different types of knowledge: we want to identify and connect scientific and local knowledge, in order to gain a better understanding of (1) how, and through what knowledge, stakeholders perceive changes in the forest, and (2) the extent to which they draw on and articulate this knowledge to develop individual and collective practices;
- The potential emergence of new modes of governance in forest territories: How can the great uncertainties surrounding climate change prompt groups of stakeholders to commit and take action in order to protect ecosystems that are increasingly seen as 'new commons'? How the emergence of new stakeholders and new ways of thinking about forest ecosystems may have implications in terms of governance, by highlighting sometimes contradictory or conflicting interactions between various groups of stakeholders?

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Old forest in Forez with large dead wood standing on and on the ground

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SABEMAF

THESIS

2023-2026

Structuring edaphic biological activity in relation to soil multifunctionality in agroforestry systems in Mediterranean and semi-arid tropical environments

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Thematics Involved
Soil ecology
Ecophysiology
Quantitative ecology
Agroecology

Backgrounds and challenges

The project aims to understand the way in which the biological activity of agroforestry systems is structured, in time and space, in relation to the soil multifunctionality in Mediterranean and semi-arid tropical environments. The project will be divided into three lines of research. The first will focus on community structures and soil interaction networks according to different spatial and temporal heterogeneity gradients. The aim is to identify patterns of community assembly and interaction networks at different scales (i) spatial and (ii) temporal. (i)

Objectives

At the spatial level, the assembly of communities and soil interaction networks in two agroforestry sites (Mediterranean and tropical) under the plant communities that make up these sites (crops, trees, herbaceous strips) will be studied. (ii) The temporal dynamics of the identified assemblages will be compared according to daily and seasonal components. The second axis of the project will focus on the synchronicity between the phenology of the different soil organisms and agro-ecosystem management. The aim is to identify, at key phases of the crop cycle and agro-ecosystem management (interventions on the crop and between crops), the activity levels of the different soil organisms according to their functional group (chemical engineers, ecosystem engineers, biological regulators). The third phase of the project focused on the link between the levels of biological organization and the multifunctionality of agroforestry soils. The aim in this part is to identify structural parameters that correlate with indicators of soil functioning (infiltration, respiration, production, etc.).

The study will be carried out on two agroforestry sites: one agroforestry site in a Mediterranean environment (located in Mauguio near Montpellier in France) and one tropical agroforestry site in a dry zone (located in Niakhar in Senegal). The monitoring of edaphic biological activity will be carried out by in-situ imaging, using buried scanners positioned in different areas and at different depths of the agroforestry sites.

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ZHYBRID-E

THESIS

2024-2027

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Funding: Biosefair metaprogramme / Région Sud / University of Aix-Marseille

Thematics involved
Aquatic ecology
Genomics
Population genetics
Modeling
Bioinformatics
Biodiversity management

Detection of hybrid zones in aquatic environments and response to climate change by e-barcoding

Backgrounds and challenges

Anthropogenic pressure on aquatic environments in the South region is intensifying, amplified by marked climate warming. It manifests as habitat fragmentation, reduced river flow, and warming of water bodies, leading to impacts on fish growth, reproduction, tolerance to hypoxia, and resistance to parasites and contaminants. When these constraints become too severe, multiple hybridizations emerge, linked to the overlap of ecological niches. In this context, the assessment of hybridization rates appears essential, but its implementation on a large scale remains technically and financially challenging. The advent of metabarcoding and environmental barcoding (non-invasive, rapid, inexpensive) allows for a considerable reduction of sampling efforts and species-level identifications.

Objectives

The PhD project aims to develop a tool for detecting where pure and hybrid individuals coexist within fish populations, based on the use of environmental DNA. The objectives are to:

- Develop around thirty independent nuclear markers representative of the genome of the species studied and compare them with a mitochondrial marker;
- Model the absence of hybridization by testing the congruence of the different nuclear markers (mitochondrial and nuclear), knowing that incongruence reflects a hybridization process;
- Validate the effectiveness of the tool in mesocosms and *in natura*.

Approaches

The first step will consist of selecting in silico around thirty orthologous gene sequences of about 100 bp from a database containing more than 25,000 genes. We will target the most variable genes in the species of interest, mainly Parachondrostoma toxostoma (Toxostome), Telestes souffia (Blageon), and Chondrostoma nasus (Hotu). Amplification protocols will be optimized and tested on mesocosms containing pure individuals, F1 and F2 hybrids in order to calibrate hybrid detection, before applying them to eDNA from study sites known to host hybrid individuals.

The development of the protocol and modeling will be reinforced by data from our mesocosms (pure and hybrid individuals), before being perfected and applied in the field.

Fieldwork (fishing campaign and eDNA) will focus on several stations:

- the Rhône basin hosting populations of Toxostoma, Blageon, and Hotus, in parapatry or sympatry, with or without signs of hybridization;
- the Argens basin (in collaboration with the "Syndicat Mixte de l'Argens"), where populations of Barbus barbus and Barbus meridionalis coexist, with the aim of methodological transfer for routine use of the developed tool.

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[1] Sequences of the same gene in different species, inherited from a common ancestor - [2] bp = base pair: the basic unit of DNA - [3] Species (or populations) living in the same geographical area and coming into contact naturally - [4] Species (or populations) living in neighbouring areas, with a small area of contact

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