INRAE

# SICCCUB

## Monitoring the Impacts of Climate Change and Land-Use Change on Biodiversity and the Functioning of Mountain Ecosystems

Métaprogramme BIOSEFAIR

## Project report : 2021 - 2024

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**Abstract**

Mountain areas are particularly sensitive to the combined effects of climate change and land-use change. Indeed, mountain climates are warming faster than in other regions, and in Europe, mountains have undergone significant reforestation at the beginning of this century. These changes have already led to major reorganization of biodiversity, with consequences for the functions and services provided by mountain ecosystems. Future climate change is expected to amplify these reorganizations.

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.

The 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). 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 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.

The presence of large and very large trees, the quantity and diversity of deadwood, and the occurrence of dendro-microhabitats were analyzed in relation to biodiversity measures across different groups (plants, fungi, bacteria, and insects).

Regarding organic matter recycling, soil macrofauna (earthworms, woodlice, millipedes, dung beetles) and mesofauna (springtails and oribatid mites) were sampled and analyzed to test the relationships between past and present land use and the functional composition of soil communities.

**Résultats**

SICCCUB involved a group of INRAE researchers with diverse ecological expertise (forest ecology, grassland ecology, soil macrofauna ecology, historical ecology, landscape ecology, conservation ecology) in a long-term observatory of mountain ecosystems covering the Alps and the Pyrenees. The project contributed to the spatial extension of the network (particularly in the Pyrenees), but above all to a thematic extension of the measurements and data collected along the gradients. It therefore fitted into the long-term monitoring carried out by the Orchamp project, which should continue beyond the strict duration of SICCCUB.

The first major result was the analysis of the effect of forest stand structure on soil biodiversity. Soil organisms, as key actors of decomposition, play a central role in forest ecosystem functioning, but the influence of forest structure on this biodiversity was still poorly understood. The large dataset acquired since 2016 on forest structure, combined with the major eDNA analysis effort of 37 soil trophic groups (carried out by LECA – CNRS), enabled us to address this question at the scale of the entire Alps (results published in *Soil Biology and Biochemistry*). Results showed that 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. This was, of course, the case for groups directly interacting with trees (e.g. ectomycorrhizae), but also for higher trophic levels. Moreover, the diversity of forest conditions promoted the diversity of soil organisms studied. Figure 1 illustrated the main questions of the paper.

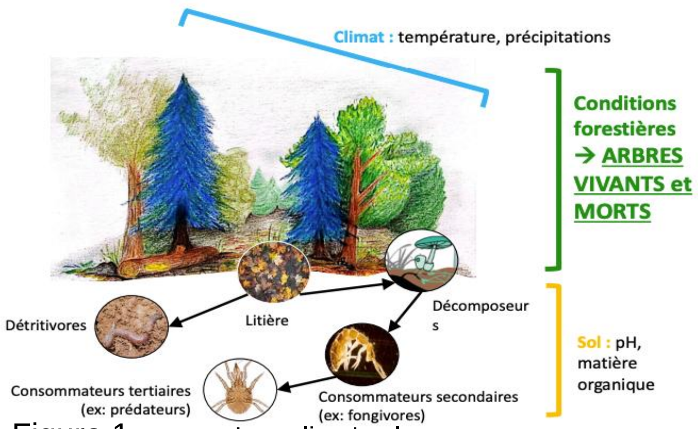


Figure 1. source Laureline Leclerc

The second major result was the analysis of landscape structure in the vicinity of the plots at three time steps (1850 – 1950 – present), for both forest plots and open habitats (Figure 2).

This required considerable work of digitization and harmonization of land-use types (vectorization of 1950 aerial photographs and 1850 military maps). Land uses that were difficult to identify on these old maps were validated with the cadastral maps. The resulting cartographic database described the landscape surrounding the Orchamp plots since 1850. This allowed us to analyze the combined effects of land-use change and climate variation on multitaxa biodiversity.

However, land-use changes were strongly correlated with climate (varying with altitude, but also latitude), which made it difficult to disentangle these two effects in the analyses. The long-term monitoring perspective of the Orchamp network nevertheless offered the possibility of capturing ongoing climatic changes, which could partly limit this correlation.

The data enabled the analysis of the effect of current and 1950 landscape structure on the biodiversity of springtails (Collembola) and protists, by testing landscape metrics across buffers of different radii (Figure 3).

The main results of this analysis were the negative relationship between heterogeneity index and Collembola richness, as well as the validation of the hypothesis that the amount of heathland and grassland habitats influenced Collembola communities. Temporal dimension was also important for Collembola: the specific richness of epigeic, endogeic, and total Collembola was better explained by the structure of past landscapes (1950) than by the current landscape (2020).

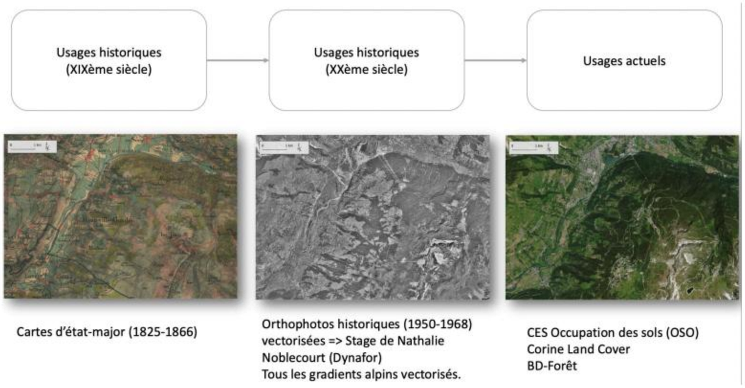


Figure 2 source Nathalie Noblecourt

The third major result was the sampling of soil macrofauna along 13 Orchamp gradients, with a total of 750 samples and 9,000 invertebrates. These observations were then assigned to trophic guilds (GRATIN). These data served to strengthen the reference database for eDNA analyses.

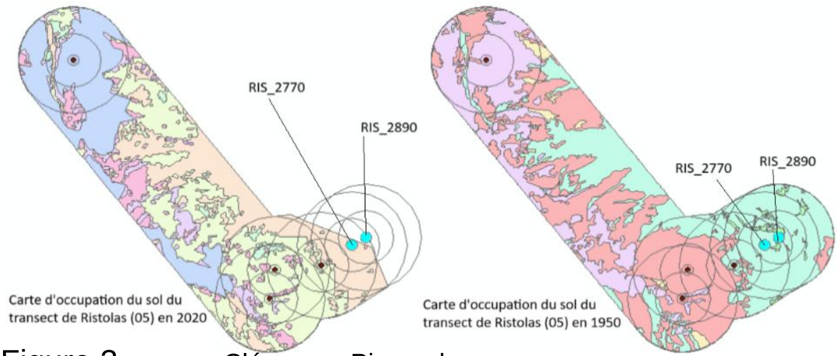


Figure 3. source Clémence Pierrard

A first analysis was conducted to evaluate the concordance between richness estimates from eDNA and from field approaches. This analysis showed an underestimation with field methods (Figure 4).

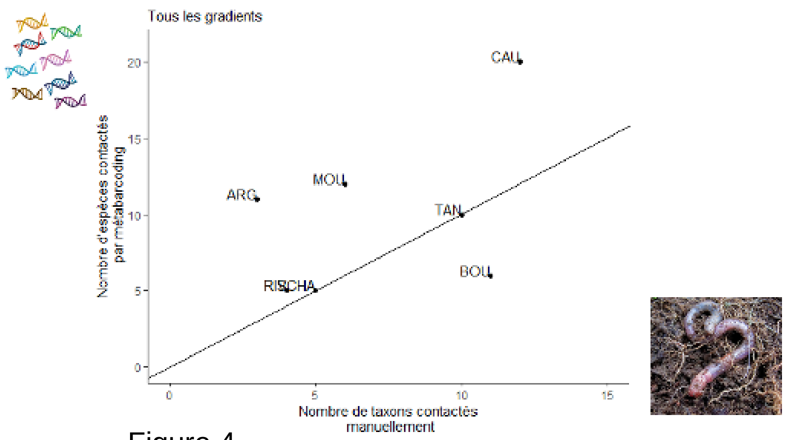


Figure 4.

A fourth major task was the monitoring of tree seed production and regeneration along a subset of gradients near Grenoble. This work, carried out in collaboration with Jim Clark (Duke University), used both seed traps (Figure 5) and fecundity estimates from a sample of plot trees (cone and seed counts using binoculars). Tree fecundity showed very strong interannual variability, which made it difficult to estimate fecundity with the short time series collected during SICCCUB.

Figure 5.

These measurements will be continued beyond the project and therefore will offer a unique perspective on changes in tree fecundity. Nevertheless, these data had already been mobilized in large-scale syntheses, where robust information could be extracted more easily than from the restricted sample of plots along a gradient (see the list of publications where these data were used).

**Scientific perspectives**.

The most important perspective of this project will be to ensure long-term monitoring of the Orchamp plots, in order to track medium- and long-term changes in mountain ecosystems (20 to 50 years). This will require sustained investment in the observatory and close collaboration with local stakeholders (National Parks, Regional Nature Parks, ONF, Regions, etc.).

A key question raised by our preliminary analyses of land-use change effects on mountain biodiversity will be: what is the best method to analyze the interactions between land-use changes and climate change at large scales, given that in mountain landscapes these changes are not independent?

In addition, monitoring tree regeneration (seeds and seedlings) across the Orchamp network will make it possible to test many factors that are rarely explored in relation to regeneration, such as the effect of past land use and the diversity of soil organisms.

Finally, a methodological perspective will be the contribution of the vectorizations produced along the Orchamp gradients to train automatic vectorization algorithms.

Publication related to SICCCUB project

Leclerc, L., Calderón-Sanou, I., Martinez-Almoyna, C., Paillet, Y., Thuiller, W., Vincenot, L., & Kunstler, G. (2023). Beyond the role of climate and soil conditions: Living and dead trees matter for soil biodiversity in mountain forests. *Soil Biology and Biochemistry*, *187*, 109194. https://doi.org/10.1016/j.soilbio.2023.109194

Laureline Leclerc. (2022). Importance relative de la structure et de la composition de la forêt pour la diversité des groupes trophiques du sol le long des gradients altitudinaux dans les alpes Françaises. Aix Marseille Université. Rapport de Master 2. Encadrement Y. Paillet & G. Kunstler (LESSEM).

Nathalie Noblecourt (2022) Caracterisation des dynamiques paysageres en zone de montagne. Rapport de Master 2. Université de Toulouse. Encadrement A. Brin (DYNAFOR) et L. Berges (LESSEM).

Aurélien Navarro (2023). Étude de la macrofaune du sol en réponse à l'altitude dans les Alpes et les Pyrénées. Université de Montpellier. Encadrement M. Hedde (Eco&Sols)

Clémence Pierrard. (2023). Étude des effets de la structure et la composition des paysages actuels et passés sur la richesse spécifique des collemboles et des protistes du sol dans les Alpes françaises. Rapport de Master 2. Université Paris-Est Créteil. Encadrement A. Brin & C. Sirami (DYNAFOR) et L. Berges & G. Kunstler (LESSEM).

## Publications using the seed data collected on the Orchamp plots

Foest, J. J., et al. (including Kunstler G.) (2024). Widespread breakdown in masting in European beech due to rising summer temperatures. *Global Change Biology*, *30*(5), e17307. https://doi.org/10.1111/gcb.17307

Journé, V., et al. (including Kunstler G.) (2022). Globally, tree fecundity exceeds productivity gradients. *Ecology Letters*, ele.14012. https://doi.org/10.1111/ele.14012

Qiu, T., et al. (including Kunstler G.) (2022). Limits to reproduction and seed size-number trade-offs that shape forest dominance and future recovery. *Nature Communications*, *13*(1), 2381. https://doi.org/10.1038/s41467-022-30037-9

Qiu, T., et al. (including Kunstler G.) (2023). Masting is uncommon in trees that depend on mutualist dispersers in the context of global climate and fertility gradients. *Nature Plants*, *9*(7), 1044–1056. https://doi.org/10.1038/s41477-023-01446-5