

 ECART

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

## Métaprogramme BIOSEFAIR

### Project report: 2024 - 2026

January 2026

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 (i) describe the stratification of microclimates and communities in trees (little-known aspects in tree crowns), (ii) 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. (iii) carry out the methodological developments necessary for acquiring canopy data.

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  $\mu$ Pi 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)

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.

## Detailed results

In January 2026, data acquisition is still ongoing for questions E3 (device installed in March 2025, micrometeorological data acquisition to continue until June 2026) and M2 (device installed in October 2025, data recording until June 2026). Data for question E2, limited to bryophyte readings at the base of the trunk, will be analysed at a later date.

Deployment of the DC prototype (question M1): difficulties have helped us progress

The DC prototype developed at the start of the project (question M1) was deployed on the samples for questions E1 and E3, with numerous difficulties. In this prototype, the sensors (temperature, light radiation and relative air humidity) are grouped together in boxes (nodes), mounted in series according to the daisy-chaining principle and thus connected by cable to a recording station, whose batteries are powered by a solar panel fixed above the tree on a Canopix mast developed by the EFNO unit.

Pre-installation difficulties: The size of the trees to be equipped meant that the distances between nodes were greater than those for which the I2C communication protocol was

designed: signal amplification had to be programmed using microcontrollers. To secure data acquisition, commercially available sensors were purchased to duplicate the nodes (with adaptations to enable data download from these sensors, which were not designed for this purpose). To prevent damage from vandalism or wild boars, only the commercially available sensor was installed at the base of the trunk.

Post-installation difficulties: Various hardware issues arose: disruption in data recording for the acquisition station, which collected recordings from 24 sensors; poor mobile network coverage in the forest, complicating data transmission and remote monitoring, internal data loggers recording data erratically after the stations shut down (in the event of a power cut, for example), and trunk base sensors only recording over a partial period (due to battery failure or lack of space on the recording card).

As a result, the 2024 micrometeorological data is incomplete (recording errors, line shifts), and the period for which complete data is available for the 12 trees is reduced to one month (from 8 July to 8 August), even though the sensors were in place from mid-June to the end of October.

Positive points:

The DC prototype developed meets the following criteria:

- two-way remote transmission (remote management)
- modularity and scalability (numerous possible measurement points, different types of sensors that can be assembled together, possibility of assembling third-party sensors via the I2C interface, nodes that can be reused in other configurations for future projects). The system of nodes strung together in series allows adaptation to large trees: each new node extends the string without needing to be connected directly to the recording station (thus reducing the total length of cables).
- Replicability (access to assembly plan, accessible open source software)
- Sustainability (autonomous system, does not depend on subscriptions or proprietary licences)
- Independence (data uploaded to INRAE's own server).

### **Questions E1 and E2: Downward revision of sampling ambitions**

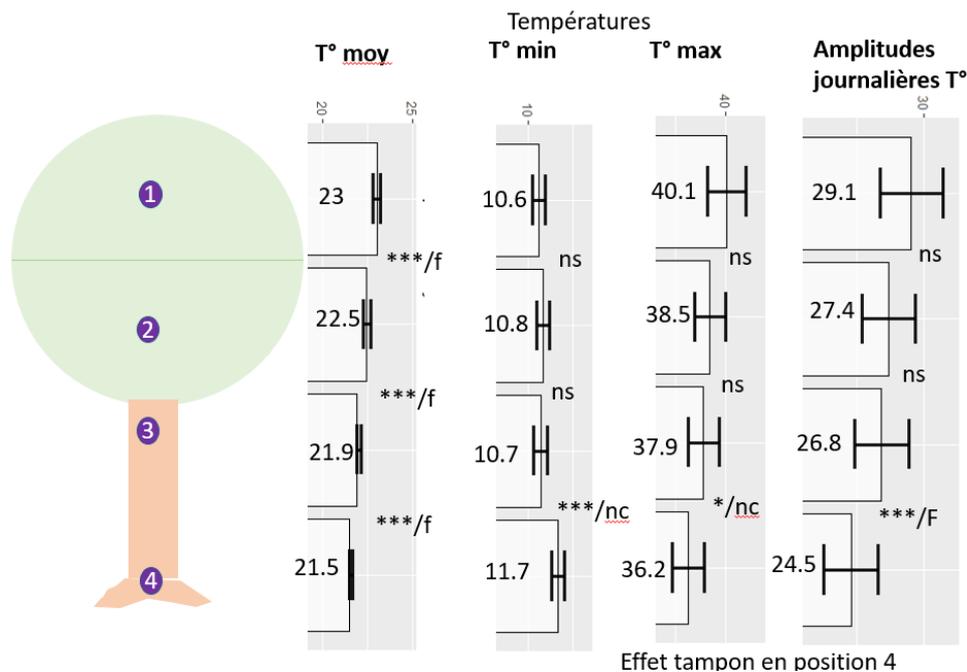
The delay in installation led us to revise our ambitions downwards:

- E1: 6 pairs of healthy/dying trees instead of 8, horizontal garland of nodes in the crown for 4 trees (3 dying and 1 healthy). Overall, the micrometeorological data are usable for the vertical garland (4 positions along the trunk), for 6 repetitions, and are complete for the period from 8 July to 8 August 2024.
- E2: the lack of pedunculate oaks that could be paired with sessile oaks in the same state of health and the lack of time to set up the sensor garlands led us to abandon this question. The five pairs of pedunculate and sessile oaks identified during the survey were subject to a bryophyte inventory on the first two metres at the base of the trunk. This data usefully complements an existing similar dataset, which will thus reach the number of repetitions required for analysis.

## Initial results on the health gradient (question E1)

Bryophyte data are available for the eight locations (four on the trunk and four on the branches of the crown), and micrometeorological variables for the four locations on the trunk for the period from 8 July to 8 August 2024. Fungus samples have been collected, but the eDNA data are not yet available.

It is primarily the position in the tree that explains the micrometeorological variables and reveals a clear buffering effect in position 4.



Health status exacerbates micrometeorological differences between locations (greater differences in declining health for certain variables, in healthy health for others), but there are very few direct effects of health status on the variables measured at each location.

For bryophytes (around thirty species), tree decline leads to a decrease in abundance of more than 10% at the top of the trunk and in the southern outer crown. In addition, differences in abundance depending on position in the tree, which are insignificant in healthy trees, are significant in declining trees. Beyond this interaction between position and health status, it is the daily temperature range interacting with health status that best explains bryophyte richness, with a negative effect that is all the stronger when the tree is healthy. Finally, ACC reveals clearly differentiated species associations between the top of the trunk, the base of the trunk, and the rest of the crown. We were surprised to frequently find a species rarely found in the undergrowth in the crown: *Frullania fragilifolia*.

## Comparison of the two solutions (prototype C and $\mu$ Pi solution)

In progress. The  $\mu$ Pi solution (developed by the ISPA and BIOGECO units, in the form of a wireless network of ESP32 microcontrollers communicating via Wi-Fi) was adapted and presented at the seminar on 3 December 2025. It is installed on a tree from the 2025 sample to compare the two solutions over an extended measurement period (October 2025-May 2026).

## Comparison of passive spore sensors (M3)

The experiment (5 replicates) consisted of projecting scleroderm spores into an airtight chamber equipped with fans and containing 5 types of passive traps (bare sessile oak bark, epiphytic moss cushion, blade coated with Vaseline, adhesive tape, sponge roll passed over epiphytic moss cushion). The traps were then placed in demineralised water and shaken to detach the spores, before extracting DNA from the liquid. We found no significant difference in DNA quantities or spore densities (counted under a microscope) between traps. However, PCR amplification of fungal ITS2 depends significantly on the type of trap and varies according to the quantity of spores introduced (1 ml or 5 ml): natural traps (epiphytes and bare bark) are as effective as adhesive and Vaseline traps, which are more effective than roller traps.

In progress. The  $\mu$ Pi solution (developed by the ISPA and BIOGECO units, in the form of a wireless network of ESP32 microcontrollers communicating via Wi-Fi) was adapted and presented at the seminar on 3 December 2025. It is installed on a tree from the 2025 sample to compare the two solutions over an extended measurement period (October 2025-May 2026).

### **Comparison of passive spore sensors (M3)**

The experiment (5 replicates) consisted of projecting scleroderm spores into an airtight chamber equipped with fans and containing 5 types of passive traps (bare sessile oak bark, epiphytic moss cushion, blade coated with Vaseline, adhesive tape, sponge roll passed over epiphytic moss cushion). The traps were then placed in demineralised water and shaken to detach the spores, before extracting DNA from the liquid. We found no significant difference in DNA quantities or spore densities (counted under a microscope) between traps. However, PCR amplification of fungal ITS2 depends significantly on the type of trap and varies according to the quantity of spores introduced (1 ml or 5 ml): natural traps (epiphytes and bare bark) are as effective as adhesive and Vaseline traps, which are more effective than roller traps.

### **Device installed for question E3**

After discussions with managers to clarify the criteria for selecting islands (stands of mature oak trees, compact in shape, entirely surrounded by young stands < 7 m in height) and to avoid any semantic confusion with islands in the statutory sense used in management (landscaped islands, ageing islands, senescence islands, in particular), we selected 10 islands in the Orléans, Saint-Palais and Vierzon forests, ranging in size from 0.45 to 7 ha. We equipped two trees per island (at the edge and in the centre) with the DC prototype for micrometeorological measurements. The data (micrometeorology, bryophytes and fungi) will be acquired in 2026.

Discussions at the end-of-project seminar identified important points to consider when interpreting the results and additional data to be acquired for this purpose (history of island management, dendrometric characterisation of the island and young stands, site characterisation, wind speed).

### **Contributions and conclusions from the seminar to present and discuss the initial findings**

This seminar brought together more than 30 participants, including 22 in person: project partners, forest managers (4 CNPF, 2 DSF, 7 ONF), other researchers from INRAE (URFM, ISPA, PIAF, LESSEM) or other institutes (EDYSAN laboratory – University of Picardie). It enriched the project group's vision and initial results with the insights of experts from several disciplines: silviculture, forest management, entomology, bryology, forest health, forest ecology, tree ecophysiology, dendrometry, phytoecology, micrometeorology, Their

contributions helped to identify the project's valuable achievements, even though there are still many issues to be studied in order to answer all the questions raised by managers, areas for improvement (experimental design, formulation of hypotheses or data processing methods), gaps (e.g. variables not taken into account in sampling), resources to be mobilised (teams working on similar topics, methods).

### **Scientific perspectives.**

On **methodological aspects**, the teams that developed the two solutions (DC and  $\mu$ Pi) will continue to collaborate to improve their solutions. In the case of islands surrounded by regenerating stands, wind speed would be a useful measurement, as it is likely to differ between the centre and the edges and to influence air temperatures and relative humidity.

**Regarding the completeness of micrometeorological data:** algorithms can be used to fill in data sets over periods of around ten days. For bryophytes, the period of complete data available in 2024 (8 July - 8 August) makes sense in terms of bryophyte ecology and biology: this is a priori the period during which micrometeorological variables reach limiting values for these organisms. However, data covering longer periods would be preferable.

**With regard to ecological data analysis methods**, the end-of-project seminar identified several areas for improvement:

- for the effect of health status, replace the two-level factorial variable (healthy vs. declining, arbitrarily defined on either side of the Deperis D score) with a multi-level factorial variable (Deperis classes), or with continuous quantitative variables (% leaf deficit or value of Deperis score components)
- analyse the diversity of bryophyte species traits
- add environmental data for the sampled trees as a covariate (e.g. diameter, density of nearby undergrowth, canopy cover, presence of dendromicrohabitats). For undergrowth density, HD LIDAR data from the IGN could be used (calculate the density of points per stratum within a 10 m radius around the tree).