

PROJECT

SUMMARY

Tender category: Call for proposals.

Coordinator: Mr François Pimont (INRAE URFM).

Duration: 18 months (September 1, 2023 - February 28, 2025).

Project partners: INRAE, ONF, DSF.

AFORCE grant amount: €40,618.04.

THEMES



PROJECT CONTEXT AND OBJECTIVES

Climate change will increase the risk of forest and natural area fires in zones that are already exposed, and will cause this risk to emerge in new territories, including in mountainous areas where the terrain complicates risk analysis. Forest stands that have historically been little or not exposed to fire will thus be more frequently confronted with fires, while their vulnerability to this hazard is poorly known by operational services.

The objectives of the project are:

- to provide managers and operational staff with projections of the expansion of forest fire risk areas;
- to synthesize scientific and expert knowledge on the vulnerability of tree species;
- to better understand the danger of fire in mountainous areas, particularly variations related to altitudinal gradients;
- to study prospects for improving knowledge and its dissemination.

KEY DELIVERABLES AND TARGET AUDIENCES

Category	Deliverable	Description	Target audiences
Internship Report (National School of Meteorology)- 	RIZZIATO T., 2024. Improvement of climate indices used for the prevention of forest fires in mountainous areas. >>>>	Hazard index spatially refined in the mountains.	Managers and experts, researchers.
Study Report 	REVERTEGAT C. & al., 2025. Synthesis on the vulnerability of forest stands to fire. >>>>	Summary on the vulnerability of species.	R&D agents, forestry advisors/development, managers and experts, teachers and trainers, government services, researchers, nurserymen, owners.

PROJECT PARTNERS

INSTRUCTIONS FOR USE

Forest Weather Index (FWI)

The assessment of risk in mountainous areas relies heavily on the mapping of the Forest Weather Index (FWI), most often calculated using meteorological data at an 8 km "SAFRAN" resolution, which is too coarse to represent danger in mountainous zones, particularly in areas with steep altitudinal gradients (Fig. 1). In the VULNEFEU project, reanalysis techniques based on the SAFRAN dataset are being explored at LESSEM to improve the spatial resolution of the maps and the estimation of the resulting danger level for the affected stands. Climate projections of fire occurrence.

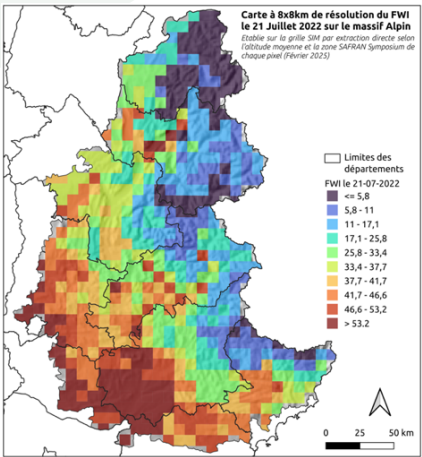


Figure 1: Example of an illustration of a hazard metric (FWI/IFM) calculated with a basic SAFRAN resolution of 8 km.

Climate projections of fire occurrence

Climate projections of fire occurrence > 20 ha were carried out at INRAE URFM to anticipate the effects of climate change on the exposure of territories on behalf of the Ministry in charge of Agriculture in 2023. Based on the probabilistic Firelihood model, adjusted with past fires, they allow anticipation of the potential evolution of fire activity in the future. However, these analyses were conducted according to different warming scenarios, which makes the data complex to use for managers. In the Vulnéfeu project, we produced a single scenario corresponding to the Reference Warming Trajectory for Climate Change Adaptation (TRACC), which should support the adaptation of France's economic activity through vulnerability studies (Fig. 2).

	2030	2050	2100
Monde (pré-industriel)	+ 1,5 °C	+ 2,0 °C	+ 3,0 °C
Fr-Hex (pré-industriel)	+ 2,0 °C	+ 2,7 °C	+ 4,0 °C
Fr-Hex (ref. 1976-2005)	+ 1,4 °C	+ 2,1 °C	+ 3,4 °C

Tableau 2. Lignes 1 : niveaux de réchauffement planétaire par rapport à la période pré-industrielle 1850-1900. Lignes 2 et 3 : niveaux de réchauffement correspondants sur la France hexagonale par rapport à la période pré-industrielle et 1976-2005.

Figure 2: Description of TRACC. (Source: Météo-France)

Vulnerability of stands

Moreover, knowledge regarding the vulnerability of stands to forest fires is generally scattered across numerous scientific or technical studies, sometimes focusing on local studies that are not generalizable. In addition, there is also expert knowledge within the various professions related to fire. There is currently no synthesis of this knowledge that is usable by managers. In the project, an engineering PhD, Camille Revertegat, was recruited to synthesize the available knowledge for 28 common and future species (Fig. 3), both from the literature (approximately 350 documents consulted) and from experts (through a survey that involved 28 experts).

Chêne sessile (Quercus petraea)
Chêne vert (Quercus ilex)
Chêne liège (Quercus suber)
Chêne pédonculé (Quercus robur)
Chêne pubescent (Quercus pubescens)
Chêne chevelu (Quercus cerris)
Chêne des Canaries (Quercus canariensis)
Chêne des Pyrénées (Quercus pyrenaica).
Châtaignier (Castanea sativa)
Hêtre (Fagus sylvatica)
Charme (Carpinus betulus)
Érable (Acer opalus)
Copaine d'Amérique (Liquidambar styraciflua)
Pin d'Alep (Pinus halepensis)
Pin de Turquie (Pinus brutia)
Pin pignon (Pinus pinea)
Pin noir (Pinus nigra)
Pin maritime (Pinus pinaster)
Pin sylvestre (Pinus sylvestris) .
Sapin de Douglas (Pseudotsuga menziesii)
Sapin blanc (Abies alba)
Cèdre (Cedrus atlantica)
Épicéa (Picea abies)
Sapin de Céphalonie (Abies cephalonica)
Mélèze (Larix decidua)
Séquoia (Sequoia sempervirens)
Calocèdre (Calocedrus decurrens)
Cyprès (Cupressus sempervirens)

Figure 3: Species selected for the fire vulnerability study

RESULTS

Forest Weather Index (FWI)

Regarding IFM in mountainous areas, the work carried out has led to a very interesting initial product described in Tom Rizziato's internship report (Rizziato T., 2024). Since then, this work has been continued and refined thanks to funding from the DGPR of the Ministry of Ecological Transition, which has allowed a number of remaining obstacles in the method developed during the internship to be overcome (notably discontinuities at the edges of the SYMPOSIUM zones). The map opposite (Fig. 4) also benefits from the methodological contributions obtained after Tom Rizziato's internship in Vulnéfeu, funded by the Ministry of Ecological Transition (DGPR 2024-2025).

Climate projections of fire occurrence

The maps derived from climate projections according to the RCP of the Firelihood model allow for mapping the expected evolution of the effects of climate change on the number of forest fires > 20 ha in metropolitan France (Fig. 5).

Figure 5: Projections of the number of fires larger than 20 ha according to the TRACC, made using the Firelihood model developed at URFM. Following Pimont et al. (2023), the projections were reanalyzed to produce map outputs corresponding to the TRACC (see Fig. 2).

Vulnerability of Forest Stands

The results of the synthesis work on vulnerability are the subject of a 152-page report (REVERTEGAT C. & al., 2025) including a description of the context and general information (18 pages), forest stands in relation to fires (22 pages), and knowledge concerning silviculture and preventive management (10 pages). The report is richly illustrated with original and educational figures (Fig. 6).

The report also includes 28 species datasheets (Fig. 7), summarizing the available knowledge. Vulnerability is represented by the vulnerability score, which expresses the sensitivity of each species according to the different aspects of vulnerability (Flammability, Resistance, and Resilience). A reliability index was provided for each rating, based on the number of references found and the level of consensus within the literature, among the experts consulted, and between the two. Descriptive texts highlight the various information provided by the literature and the experts. A second part of the species datasheet presents the structural and architectural characteristics of the species and stands, which may influence their vulnerability to fire.

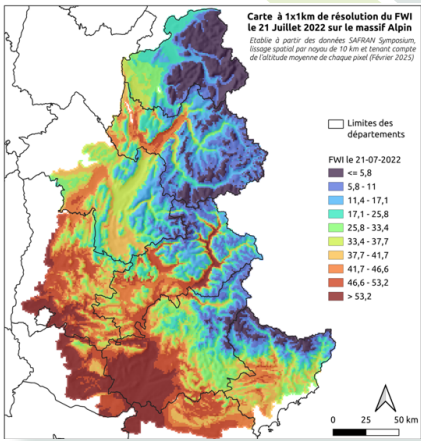


Figure 4: New IFM map derived from the approach developed at LESSEM (1 km resolution).

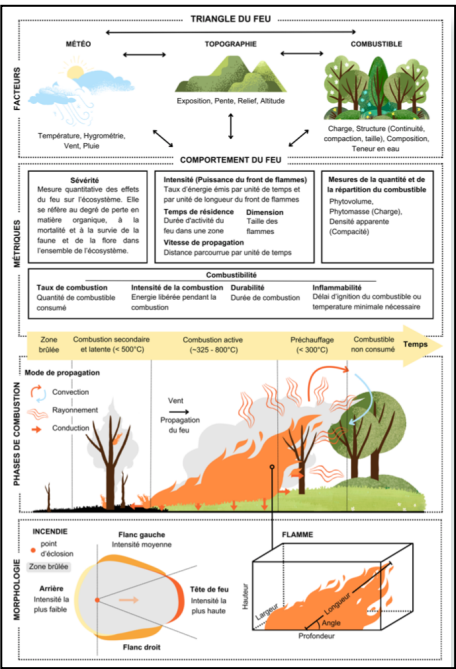
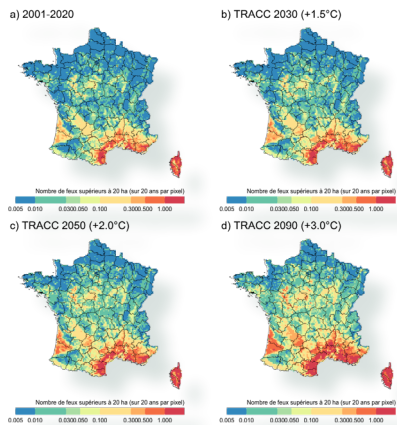
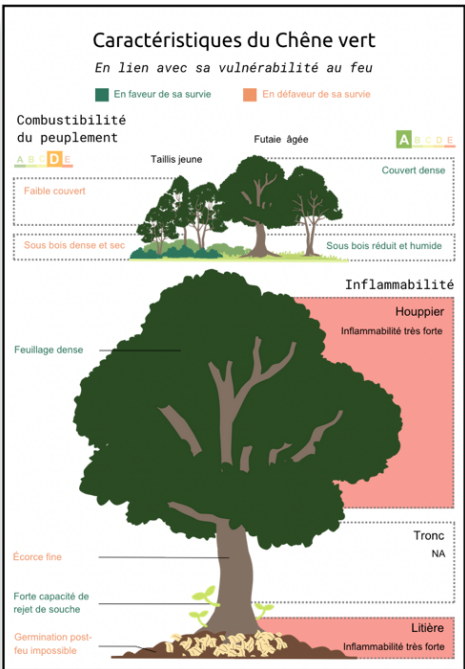


Figure 6: Example of an illustration included in the report.



Figure 7: Example of a fuel sheet.



■ KEY LESSONS

A forward-looking section concludes the six-page report. It will be noted that the fire vulnerability of different tree species results from three distinct and complementary criteria (flammability, resistance, resilience). The project made it possible to synthesize knowledge for 28 main species. Despite the extensive research conducted during the project, knowledge remains incomplete for certain temperate species. Another limitation of the approach is related to the fact that stand vulnerability does not depend solely on the species that compose them, but also significantly on stand ages and structures, which can vary greatly for the same specific composition depending on climate and management history. These factors will be explored in a thesis funded by ADEME, beginning at URFM and LESSEM in 2025, conducted by Camille Revertegat under the supervision of Jean-Luc Dupuy to take a broader look at the different factors of stand vulnerability, we will need to make use of all available data (fire perimeters, land use, HD LiDAR, satellite severity measurements, etc.) to better understand how the different vulnerability factors interact, in connection with management.

In the shorter term, species sheets should be shared on the ClimEssences website (downloadable sheet), and the content of ClimEssences will be enriched with the information available in the sheets.

■ CONTACT

The project leader is Mr [François PIMONT](#). Chief Engineer of Bridges, Waters and Forests, head of the Fire Physics and Ecology team at INRAE in Avignon, within the Mediterranean Forest Ecology Unit (URFM).

For more information about the project, you can also contact Mr [Eric RIGOLOT](#) (Research Engineer), Mr. [Jean-Luc DUPUY](#) (Research Director), Mr. [Julien RUFFAULT](#) (Postdoctoral Fellow) et Ms [Camille REVERTEGAT](#) (Forestry Engineer) within INRAE URFM, and Mr. [Sylvain DUPIRE](#) (Research Engineer) within INRAE LESSEM.

The project was carried out with the participation of several units within INRAE (INRAE URFM, INRAE LESSEM, INRAE RECOVER, and INRAE UR 1456 ETTIS), the DFCI Agency, and the RDI department of ONF, as well as with the DSF.

■ FOR MORE INFORMATION

More information is available on the [VULNEFEU project page](#) of the RMT AFORCE.



References

- ¹ Pimont F, Dupuy JL, Ruffault J, Rigolot E, Opitz T, Legrand J, Barbero R. Projections of the effects of climate change on forest fire activity in the 21st century: Final report. INRAE. 2023. <https://hal.inrae.fr/hal-041499362>
- ² Revertegat C, Rigolot E, Dupuy J-L, Dupire S, Toutchkov M, Ruffault J, Deuffic P, Boutte B, Pimont F, 2025. Synthesis on the vulnerability of forest stands. 152p. [>>>>](#)
- ³ Rizziato T, 2024. Improvement of climate indices used for forest fire prevention in mountain areas. End-of-study internship report. 38p. [>>>>](#)

PROJECT FUNDERS