
# Montclima Seminar

## Climate and natural risk in mountain areas

### Strategies for Managing and Preventing Drought Impacts on Forests in the SUDOE Mountains

30 September 2021

Interreg Sudoe

EUROPEAN UNION

MONTCLIMA

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# Index

# General Introduction

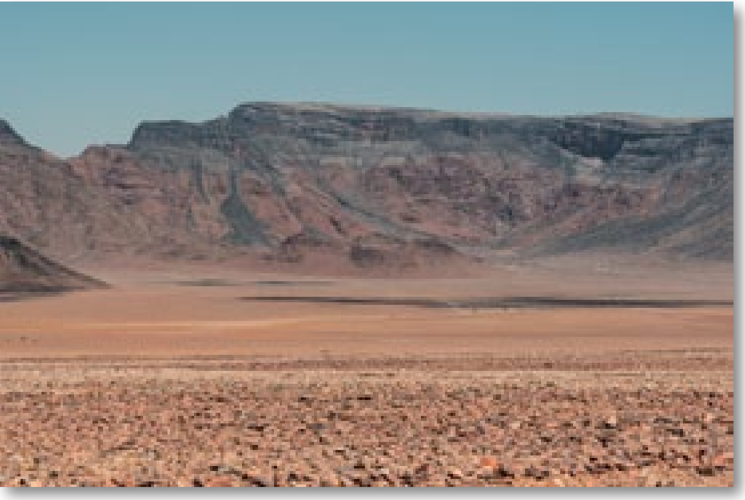
Map of the SUDOE Space

The purpose of this report is to present the main conclusions and lines of action defined during the **3rd Transnational Seminar of the SUDOE MONTCLIMA Project on strategies for managing and preventing drought impacts on forests in the SUDOE mountains**. The hybrid seminar, organised by CREAF, was held on 30 September 2021 in Barcelona, Spain.

The main objective of the seminar, in line with the MONTCLIMA Project's vocation, is to contribute to improving **strategies for managing and preventing drought impacts on forests in the SUDOE mountains** with the aim of:

- Sharing knowledge and experiences on good management practices and prevention strategies for drought impacts on forests.
- Contributing to more effective and efficient forest management policies.
- Strengthening the resilience of the SUDOE mountain territories to drought and the impacts of climate change.

The MONTCLIMA SUDOE Project contributes to the development of a **framework of reference that serves as a transnational strategy for preventing natural hazards** that have a particularly severe effect on mountain areas in the southwest of Europe.



These mountain areas are some of those most affected by natural events and it is expected that in the future these hazards will increase significantly as a result of climate change. Global warming has caused the average flow in rivers of the Mediterranean basin to fall by between 10 % and 20 % in recent years and **if society does not act, droughts will be increasingly more frequent, which will undoubtedly lead to an increase in the risk of forest fires**. These, in turn, will cause a loss of surface vegetation and this, together with extreme rainfall, worsens the phenomenon of erosion.

Mountain areas are particularly vulnerable to soil loss due to their morphology, climate and vegetation, and it is estimated that between 20 and 50 tonnes of soil are lost per hectare each year. This means a decrease in their ability to cushion the effect of heavy rains and, therefore, an increase in floods and overflows. **Increasingly severe droughts, rising temperatures and changes in rainfall patterns are just some of the possible repercussions**, but in addition to environmental damage, these hazards are also causing considerable economic and social losses that affect the way of life of the inhabitants in the various regions in question.

The devastating effects of these hazards, which stem from both natural events and their interaction with the infrastructures and services of each territory, **know no borders or administrative boundaries and must therefore be analysed in a coordinated manner** by the countries and regions affected and dealt with through a transnational framework of collaboration that benefits all those involved. This is the only way to protect and preserve the mountain areas shared by our territories.

**www.montclima.eu**

# Objectives

This transnational seminar on strategies for managing and preventing drought impacts on forests in the SUDOE mountains focused on:

**Analysing the risks of drought in the SUDOE area, sharing management and prevention strategies being implemented in the SUDOE mountain forests and studying how to manage these forests and landscapes to reduce the impacts of drought at a local level.**

**Discussing management and prevention strategies that strengthen the resilience of mountain regions to drought and the impacts of climate change.**

**Comparing drought impact assessment and monitoring methodologies, as well as modelling tools and forest management strategies used to increase the resilience of SUDOE mountain forests to drought.**

**Making public and disseminating the conclusions of the seminar among sector professionals and the general public.**

**Similar to the Cooperation Programme Southwest Europe (Interreg V-B SUDOE), which adopts the Europe 2020 Strategy as the basis for smart, sustainable and inclusive growth, the purpose of this seminar was to contribute to a greater cohesion in the application of common best practices for the prevention of natural hazards, with an emphasis on the impacts caused by drought, to improve their prevention and management in SUDOE forests.**

# Welcome to the MONTCLIMA Project

**Eva García-Balaguer** (Coordinator of the Pyrenees Climate Change Observatory of the Working Community of the Pyrenees, CTP-OPCC, current lead partner of the MONTCLIMA Project) introduced the seminar bringing to the table the need to **develop cooperation between the different stakeholders involved** in the SUDOE territories, from researchers and companies to citizens, so that the tools for preventing climate and natural hazards are effective.

This is the third of five seminars programmed as part of the MONTCLIMA Project. The first, held in Soria in Spain, was on the four natural hazards — droughts, floods, forest fires and erosion — studied as part of the project and their connection with climate change in the SUDOE mountain regions. The second was held in Leiria in Portugal and focused on strategies for managing and preventing forest fires in the SUDOE area. This third seminar, held at the Institute of Catalan Studies in Barcelona, focused on strategies for managing and preventing the impacts of drought on forests in the SUDOE mountains. Two seminars remain. One will be held in Bilbao in Spain on the risk of erosion and the last will be held in Andorra on floods.

Eva García-Balaguer also reminded participants of the goal of the MONTCLIMA Project, which is to improve knowledge about climate change and natural hazards so that prevention tools and methods can be provided to achieve greater resilience in the face of present scenarios and those which are to come. For these tools to be truly useful, she emphasised the **need for a multi-risk perspective** to deal with the problems and challenges studied.

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# Institutional Opening Session

**Rosa Amorós i Capdevila** (Secretary General of CTP-OPCC, Catalan Government) underlined the need to **capitalise on the strategies implemented** in the different experiences developed as part of the MONTCLIMA Project. Like Eva García-Balaguer, she emphasised the importance of a **multi-risk perspective** for dealing with the impacts on the mountains resulting from climate change, given that extreme events imply economic losses and damage to goods and people.

Projects like MONTCLIMA allow new perspectives to be generated, knowledge transferred and new alliances to be created that promote the development of strategies for improving resilience. These pursuits must be supported because the challenges are great and the response to them needs to be as fast as possible.

For this reason, the **Pyrenees Climate Change Strategy** has been developed, a cross-border strategy for furthering climate action in the Pyrenean bioregion.

**Joan Pino Vilalta**, as director of CREAF, the seminar's host organisation, reminded participants of the urgent and unavoidable need to further the research and experiences, given the **recent episodes of forest decline** in the SUDOE mountains. The frequency and intensity of the risks that forests are facing, together with the interaction of human activities, must be urgently and rigorously addressed to create **effective climate adaptation responses and improve decision making** in light of the problems in the natural environment.

# I. The context

## Risk of droughts in the SUDOE space Historical data and future pojections

**Sergio M. Vicente-Serrano**
(Pyrenean Institute of Ecology, IPE-CSIC, and member of the IPCC)

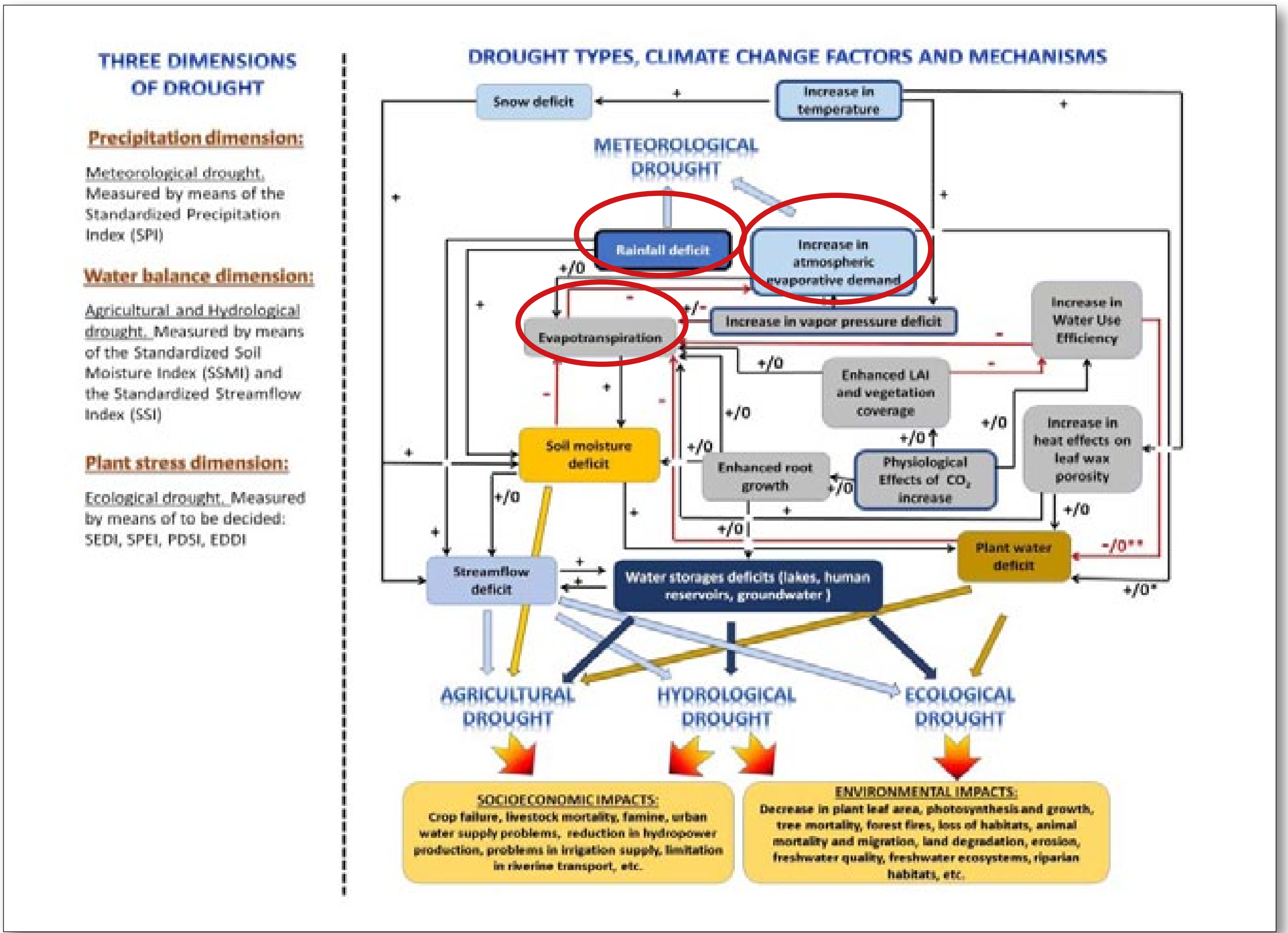
Droughts have significantly and repeatedly affected human society, as shown by records that date back to the 15th and 16th centuries. **They are recurrent and very difficult to predict, showing no clear frequency** and occurring with a very **high spatial and temporal variability**. In Spain, this spatial variability is due to the existing climatic diversity.

**Economic impacts of droughts are socially and financially high** as shown by the following data for Spain since 1991:

- 12 million inhabitants endured water restrictions in 1995.
- Between 1991 and 1995, the drought accounted for 3500 million euros in economic losses.
- Between 1992 and 1995, agricultural production suffered annual losses of between 1200 and 1800 million euros compared to previous and subsequent years.

- The short and intense drought that affected Spain in 2005 led to a notable fall in hydropower production (18 000 GWh).
- In 2012, the largest burnt area (199 000 hectares) was recorded since 1994, as a result of the severe drought that affected the country.

Droughts are a **highly complex event**, as shown by the following diagram.




There are many interactions when there is a drought. Weather conditions intervene and begin to interact with the entire system and influence soil moisture, evaporation, etc., which, in turn, has significant feedback effects on the atmosphere. All this leads to different **types of droughts that are related to a series of impacts on these systems**:

- Meteorological Droughts: lack of precipitation for a specific period, measured using the Standardized Precipitation Index (SPI).
- Hydrological and Agricultural Droughts: incidents in reservoir levels and mountain headwaters. These are measured by the Standardized Soil Moisture Index (SSMI) and the Standardized Streamflow Index (SSI).
- Ecological Droughts: impacts on natural vegetation and forests, measured by different indicators (SEDI, SPEI, PDSI, EDDI).

The conditions of one type of drought aren't necessarily related to those of another. It is a complex issue that gives rise to debate within the scientific community. **Drought is probably the most complex extreme hydroclimatic natural event in existence** (much more than floods or tropical cyclones, for example).

According to the precipitation deficit index, some studies argue that droughts in Europe can be explained by anthropogenic causes. However, other studies differ from this view because societies have been affected by a lack of rainfall with great variability at a spatial and temporal level, which is the general trend in the Mediterranean. This is verified through the analysis of rainfall data from long historical series thanks to the recovery and reconstruction of records from the middle of the 19th century, coinciding with the beginning of the instrumental era and the setting up of the first weather stations in Spain, France, Italy and Portugal. In this way, it has been shown that since 1870, the **evolution of rainfall is seasonal with high temporal variability**. Therefore, rainfall analysis will also depend on the period of study being considered.

## How are these precipitations grouped in time?

**Droughts are very difficult to measure** so they are characterised by a series of **composite drought indices** using different variables (meteorological, soil moisture, evaporation, etc.) that allow different periods to be observed, for which conditions are considered dry:

- **Magnitude**: accumulated deficit below a specific threshold
- **Duration**: number of consecutive months or years below a specific threshold.
- **Intensity**: average deficit for the period that is below the threshold.

By studying these parameters from a rainfall viewpoint for the Mediterranean region, the conclusions are not clear. As expressed in the **latest IPCC report, no clear or statistically significant trends have been detected in rainfall or the frequency of droughts**, in contrast to the conclusions of previous studies. This **does not mean that droughts in our region are not on the rise** because the Mediterranean is one of the regions in the world most affected by global warming.

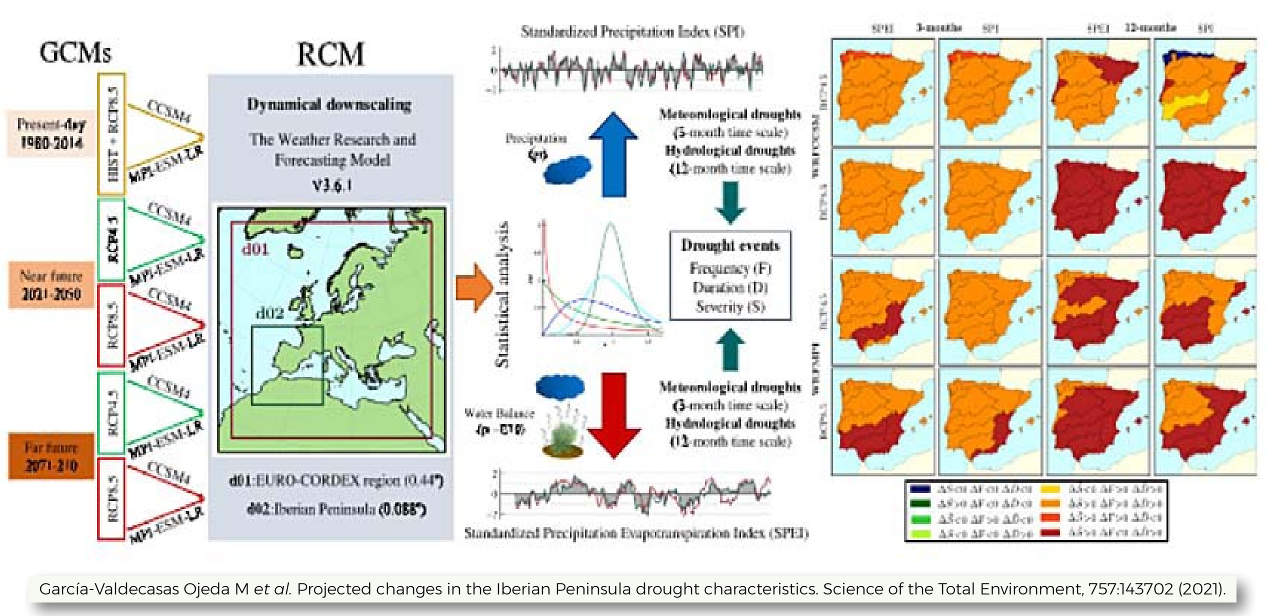
The higher the temperature, the greater the effect on the aerodynamic component of water demand by the atmosphere: **evapotranspiration**. As the average temperature rises, so does the atmosphere's ability to hold water vapour. In addition, there are other types of mechanisms, such as relative humidity, which is falling in the mid-latitudes due to differences in warming between continental and oceanic zones. All this is leading to a rise in the pressure deficit, which explains why increasingly more water from the soil is being lost.

When there is water available, this atmospheric demand is not very relevant but under dry conditions, the situation can become very critical because, for example, vegetation will be subjected to a lot more stress.

## What has happened on the Iberian Peninsula in relation to atmospheric water demand and the indicators that affect it?

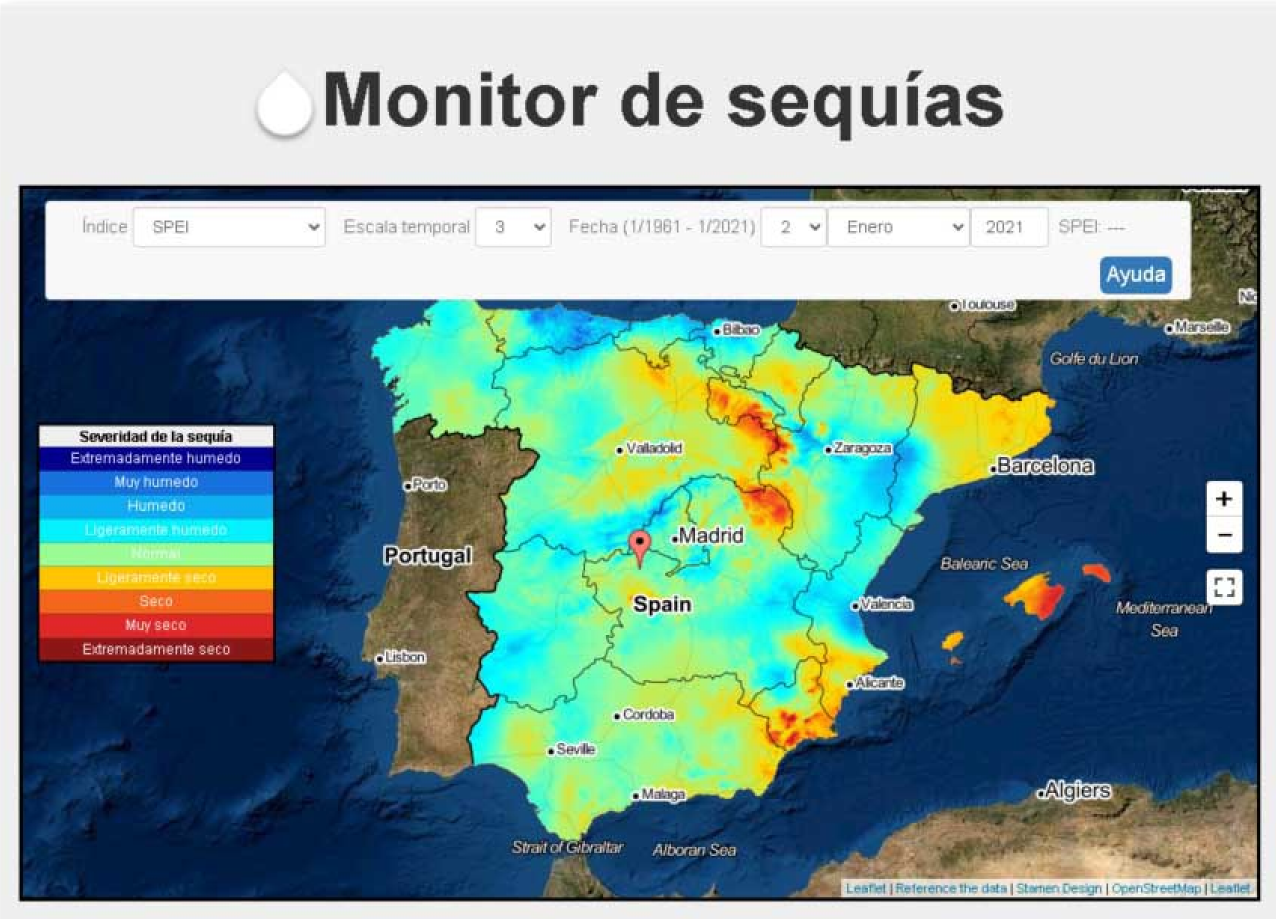
Radiation has been more or less seasonal over recent decades, as has wind speed. However, **relative humidity has fallen across almost all the territory**, which has led to an **increase in atmospheric water demand throughout practically the entire region**.

In Spain, sensitivity to drought conditions and water demand by the atmosphere do not occur in winter. The development of first growing vegetation or winter grain crops is not being affected by rising temperatures because atmospheric water demand in winter is very low. The **greatest sensitivity occurs basically in the summer months** when water demand is very high and summer temperatures have notably risen. This means that during dry years, in summer, **the vegetation is under more stress**, there is more dry matter and conditions are met that lead to **an increase in the probability of events occurring, such as fires, less plant growth, decline and mortality of forest stands**, etc.




García-Valdecasas Ojeda M *et al.* Projected changes in the Iberian Peninsula drought characteristics. Science of the Total Environment, 757:143702 (2021).

According to a recent projection study on droughts throughout the 21st century, carried out using the aforementioned indicators, in Spain, for both the **RCP4.5 and RCP8.5 emissions scenarios by the IPCC**, there will likely be an **increase in the frequency, duration and severity of droughts** as a result of climate change and linked to the **increase in atmospheric water demand**.




CSIC has developed the **monitor de sequías** (Drought Monitor), a tool that measures these and other parameters, which are updated weekly, to study and **monitor the droughts on the Iberian Peninsula**. The tool is available for anyone to consult.

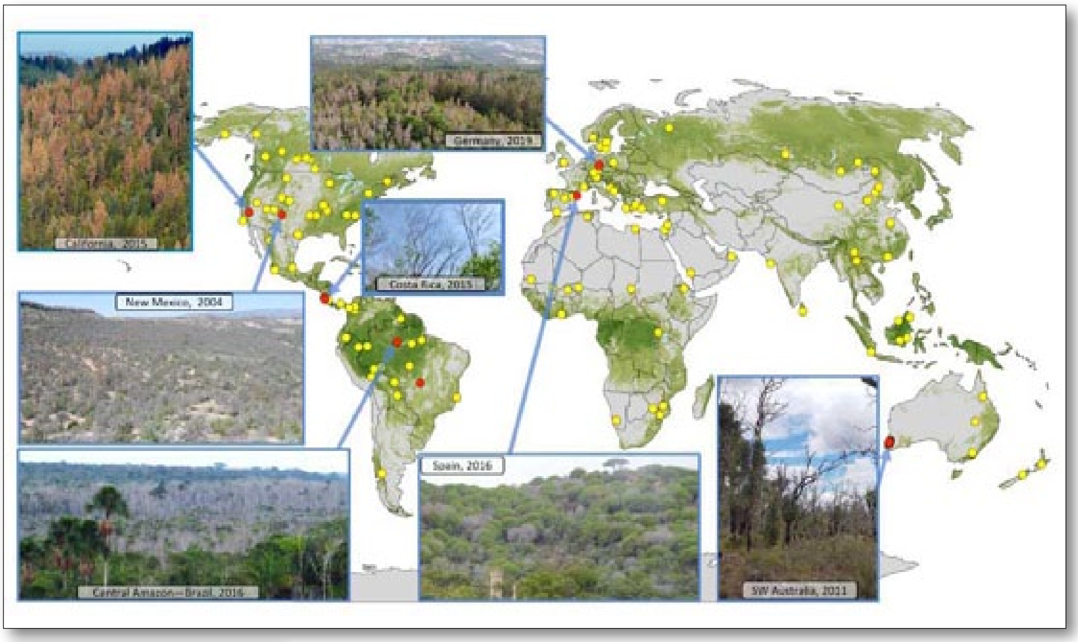
# II. Strategies for managing and preventing drought impacts on forests in the SUDOE mountains

## How drought impacts forests in the SUDOE space

Jordi Martínez-Vilalta (CREAF)

The **availability of water** determines the **distribution and functioning of forests**.

**Forest decline** associated with drought and high temperatures is a **global phenomenon** that **particularly affects mountain areas**.




Hartmann *et al.* (*ARPS*, in revieu).

All **models predict that forest decline events linked to drought will increase over the coming decades as a result of climate change**. Climate change is shifting the climate zones where ecosystems have historically existed due to rising temperatures and varying rainfall, which is leading to an increase in the mortality rates of trees and forests. Models also predict **changes in the distribution, density and composition of forests**.

The key question is, **how can we know how close we are to catastrophic changes in our forests and predict which ones will be most affected?**

## 1

## A FEW LESSONS LEARNT

- The importance of the **repercussions of changes in forest management and mountain use**. The main historical changes detected in forests result, above all, from changes in land use and other human factors. These changes in forest use affect their development and distribution.

## 2

- The importance of community attributes, such as **functional diversity**. Functional diversity increases the resilience of forests to disasters. By comparing inventory data, it appears that drought-resistant species, which generally grow less, are more dominant, and at the same time there is a greater diversity of drought-tolerant species in forest communities. These two effects compensate each other and are making forests grow more, at least for the moment.

## 3

- Although we are beginning to understand the **mechanisms** that cause drought mortality, the **enormous number of variables and processes involved make it exceedingly difficult to make predictions**.

## 4

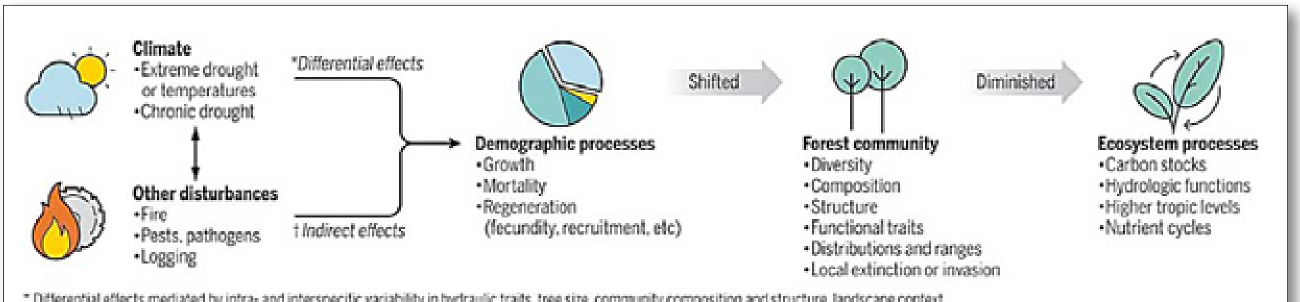
- We must be prepared for **"surprises"** (for example between 2012 and 2020 forest decline has affected 3.3 % of forests in Catalonia).

## 5

- The importance of considering **regeneration** processes after a mortality episode.

## 6

- We must consider the interaction of the drought with other disturbances, such as fires and plagues.



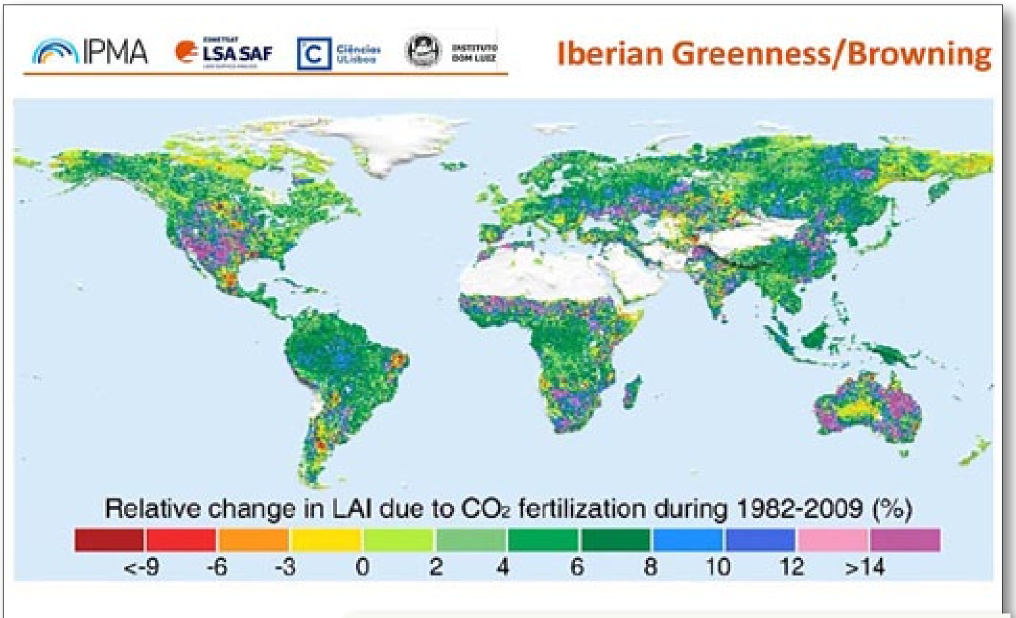
Brodribb *et al.* (*Science* 2020)

**Monitoring** is one of the most powerful tools we have for obtaining **data** and **reducing uncertainties** in trends, attribution, mechanisms, spatialisation and consequences of mortality episodes.

# How to monitor drought impacts on forests

## Experiences from Portugal. Evaluation of the impacts of drought and heat on forest productivity

**Célia Gouveia** (Universidade de Lisboa)




https://www.thegwpf.com/nasa.higher-co2-levens-responsible-for-greening-earth/

In **recent years**, at a **global level**, certain places have seen an **increase in vegetation vitality**, thanks to the fertilising effect of $CO_2$, while others have seen a fall or impoverishment leading to a certain level of vegetation degradation.

A study has been carried out to assess whether or not there has been an increase in vegetation productivity on the Iberian Peninsula in recent decades. To this end, **remote sensing** data has been used that provides an overall spatial coverage that is also continuous. The **NDVI** (Normalized Difference Vegetation Index) was applied to a 30-year database (1982-2012). The initial hypothesis is that there is a relationship between an increase in vegetation and its vitality and an increase in rainfall. However, the results of the study show that, in recent years, there has been a **clear increase in vegetation** on the Iberian Peninsula despite there being **no clear causal relationship with the evolution of rainfall**. This situation is particularly evident when a spatial analysis is done.

Subsequently, the precipitation effect was removed from the NDVI and this simulated NDVI was then compared with the observed NDVI. By analysing the differences, a pattern emerged that made it possible to differentiate an **overall situation of improvement in the vegetation on the entire Peninsula**, with some specific points of decline.

The changes in vegetation productivity on the Iberian Peninsula was also studied according to the type of vegetation and in relation to land-use changes. To this end *Corine Land Cover* maps from 1990, 2000 and 2006 were compared, marking the areas where land-use changes occurred. The results show that while in **natural vegetation zones productivity improved, in crop areas it became worse**.

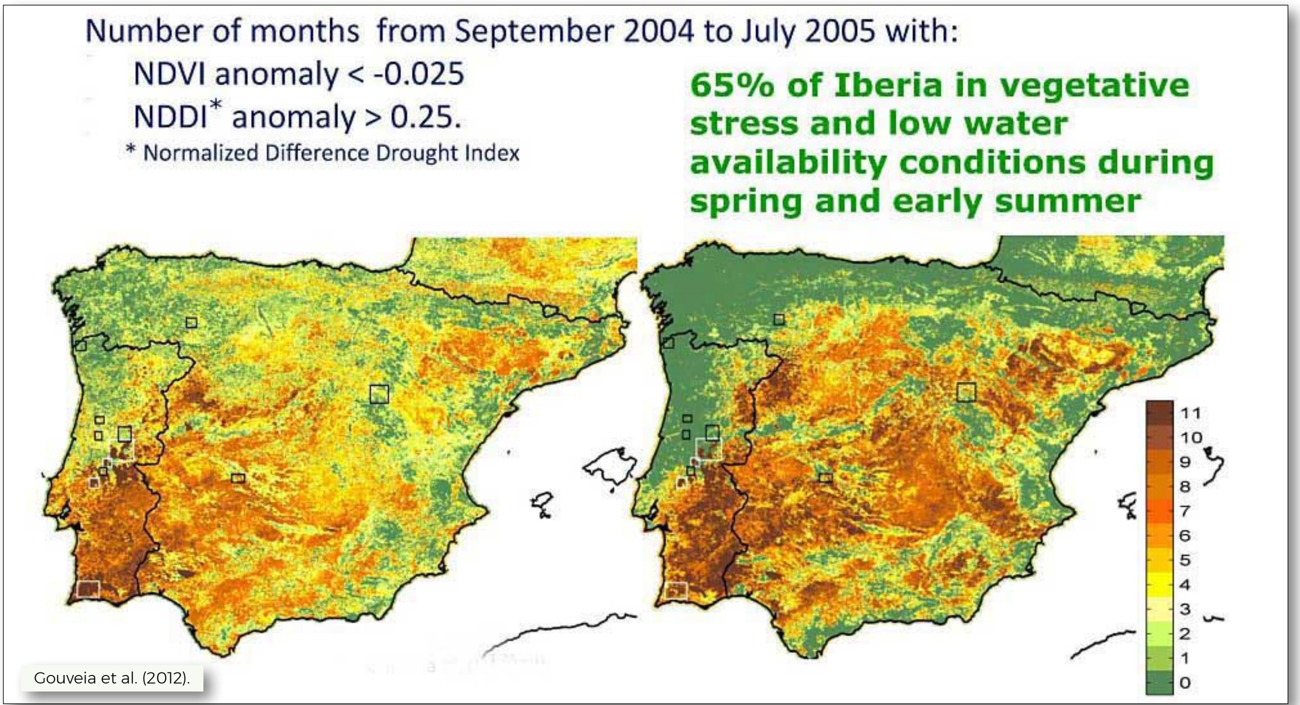
## Evaluation of the impacts of drought and heat on forest productivity

Célia Gouveia

Regarding the evolution of droughts in Portugal, satellite data from 1999 to 2006 was used, again, with NDVI. This analysis reflects the i**mpact of the 2005 drought**, when anomalies in the index began very early (from November 2004 to November 2005) and **acute plant stress occurred, above all in southern Portugal**.

The same analysis was carried out for the rest of the Iberian Peninsula but based on data from up to 2011. In this case, the Normalized Difference Drought Index (NDDI) was used in addition to the NDVI. The results show that where there was **more water stress, there was more drought**, which is also where the NDVI was lower. The **most sensitive areas to drought were forests, although the effect is different according to the type of vegetation. Broadleaved Mediterranean forests are better adapted to hot dry summers**. In turn, **coniferous forests are more resistant to short-term droughts than broadleaved forests**.

Soil moisture indicators and the GPP satellite index (Gross Primary Production index) reveal that **recovery from the impact of the 2005 drought did not occur until 2007** with the subsequent **impact on carbon sequestration by vegetation**.




Gouveia et al. (2012).

The **impact of droughts on forests is different according to the tree cover** (fraction of canopy cover). In the case of forests with **low cover**, there is clearly a **slow recovery impact that affects productivity** (GPP index). In the case of forests with high cover, the effect is not as pronounced. Regardless of the tree cover, the results show that these drought **episodes** lead to a **very significant loss in $CO_2$ absorption**.

# Experiences from Catalonia, Spain. The DEBOSCAT Programme: the Catalan monitoring network of drought impacts

**Mireia Banqué** (CREAF)

The DEBOSCAT programme is a **network that monitors the impact of droughts in Catalonia**, making it possible to see the evolution of the decline of Catalan forests through fieldwork and the entry of data by rangers.

Forest decline is measured by the **mortality, defoliation and discolouration** of the trees.

This makes it possible to detect where forest decline episodes are going to occur, study the vulnerability of species (which species are affected) and find out the recovery and recurrence of the forest decline.

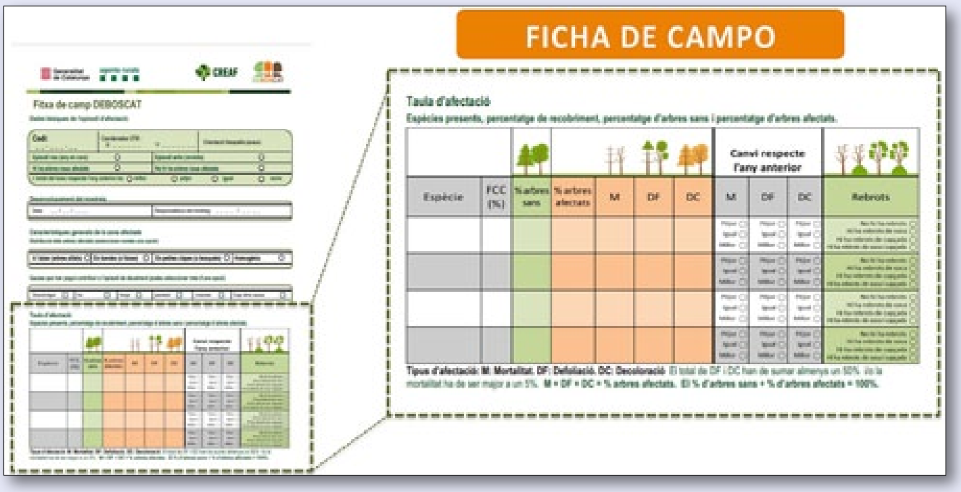
## The objectives of the DEBOSCAT programme are the following:

- Establish minimum thresholds to determine when a degradation episode is occurring, by **monitoring forest decline on an annual basis**, detecting possible changes and **identifying the most vulnerable areas and species**.
- Make available **precise, up-to-date and georeferenced information** that is useful for **planning, management and research**.
- Provide the administration with a **decision-making tool** for forest planning and management, as well as **knowledge about the vulnerability** of forests.

## The methodology used for monitoring is the following:

- Detection of episodes of **mortality, defoliation and discolouration** that have occurred during the year and re-examination of previously detected episodes.
- Gathering of information about the understory.
- Minimum surface area affected of **3 hectares**. Only the episodes that affect a surface area of 3 ha or more are included.
- Annual field campaign in **September**.
- **Comprehensive** study of the entire region.

Monitoring is carried out using field forms that are completed by the Government of Catalonia's rangers and using the monitoring network's online app for observing the state of forests in Catalonia.



# The DEBOSCAT Programme: the Catalan monitoring network of drought impacts

Mireia Banqué

## Why is DEBOSCAT of interest?

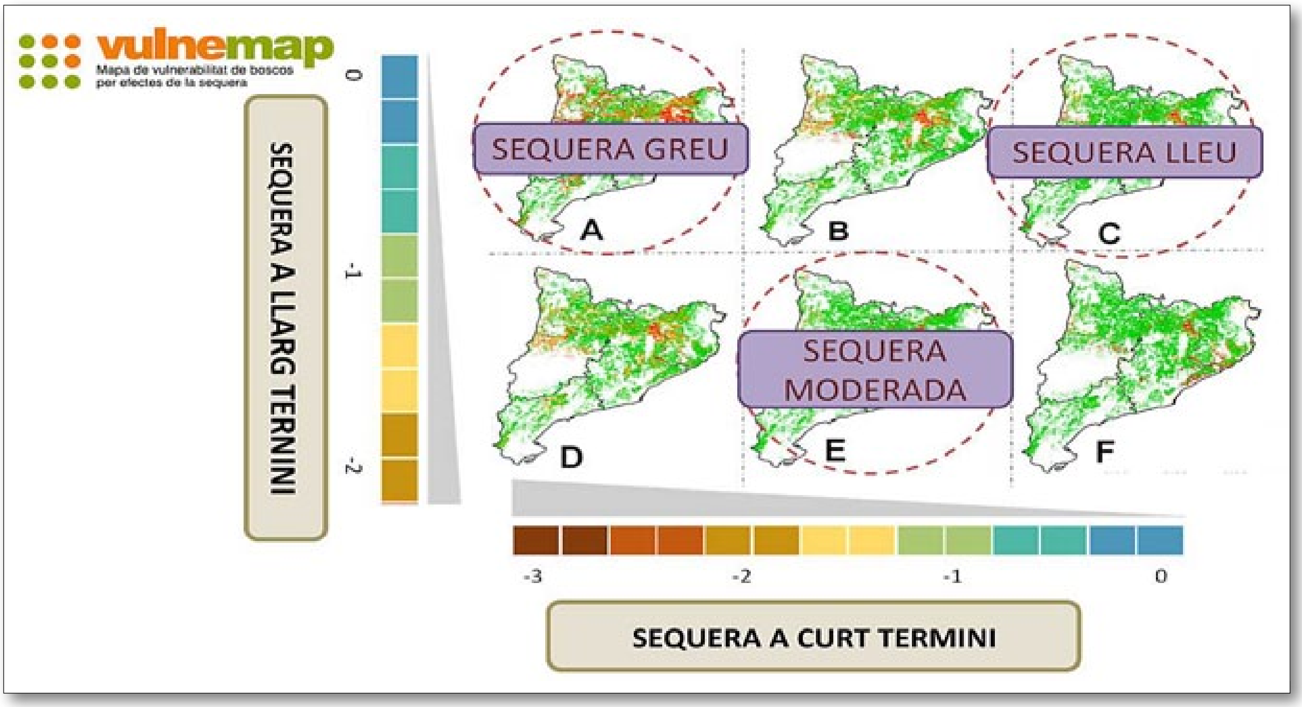
By studying decline episodes, information provided by rangers is gathered and used by CREAF in scientific studies to create **predictive models for efficient forest management**.

This efficient management considers the limited resources available for maintaining forests in the best possible condition and seeks to adapt the forests to the lack of water, increase a resistance and resilience to disturbances and conserve the goods and services that forests provide.

So far, DEBOSCAT has been gathering data for a decade (2012-2021). In the analysis of the data for this period, it has been found, for example, that 32.2 % of the surface area affected in 2016, had already been affected in 2012. This leads to the following question, what would happen if every four years some areas were affected again?

DEBOSCAT is also a very useful tool with multiple uses:

- The **development of vulnerability maps** for Catalan forests (Vulnemap) in relation to the impacts of climate change. These maps are developed using statistical models that study responses and also predictive variables, such as climate, forest, topographic and lithological variables.
- The study of **forest decline in relation to soil moisture** at 1 metre of depth (by satellite).
- The study of which forests in a specific zone will suffer most from the effects of climate change applied to the Montseny Natural Park, as part of the European project LIFE CLINOMICS.
- The study by the Provincial Council of Barcelona of the effects of droughts on forests in the province of Barcelona.



## Experiences from France. French forest health monitoring network: Actions of the French Forest Health Department

**Morgane Goudet** (Forest Health Department, Ministry of Agriculture and Food, DSF)

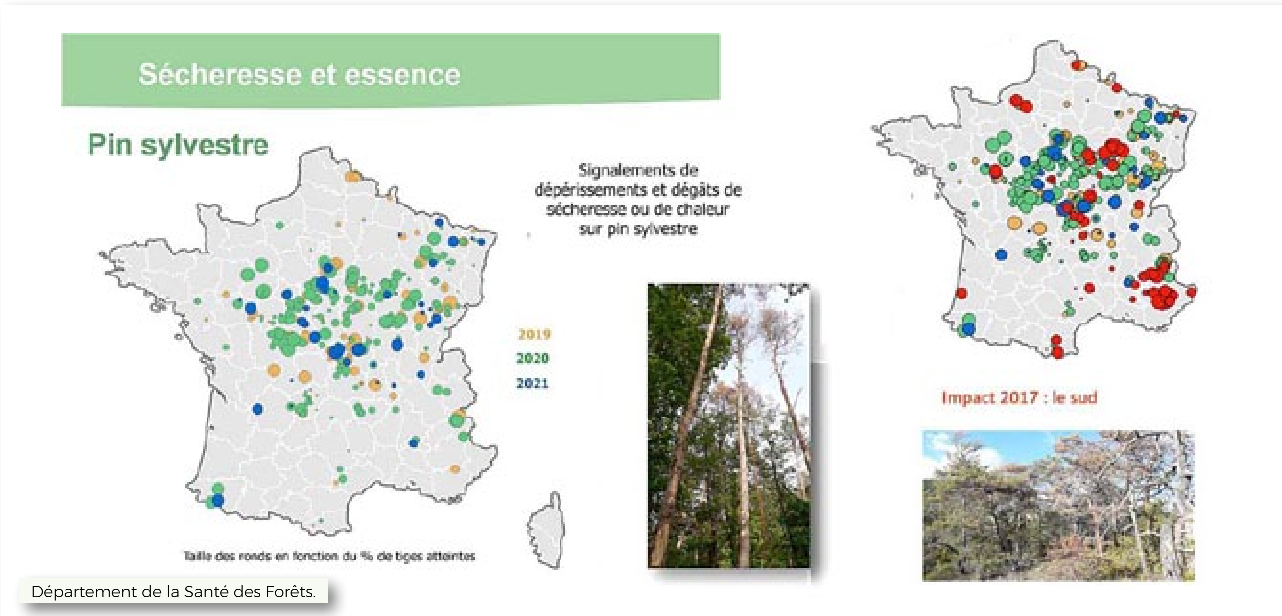
The French Forest Health Department (DSF) is divided into six main areas and has 260 rangers, four national experts and a network of research centres, laboratories and regional networks. Its main areas of work are:

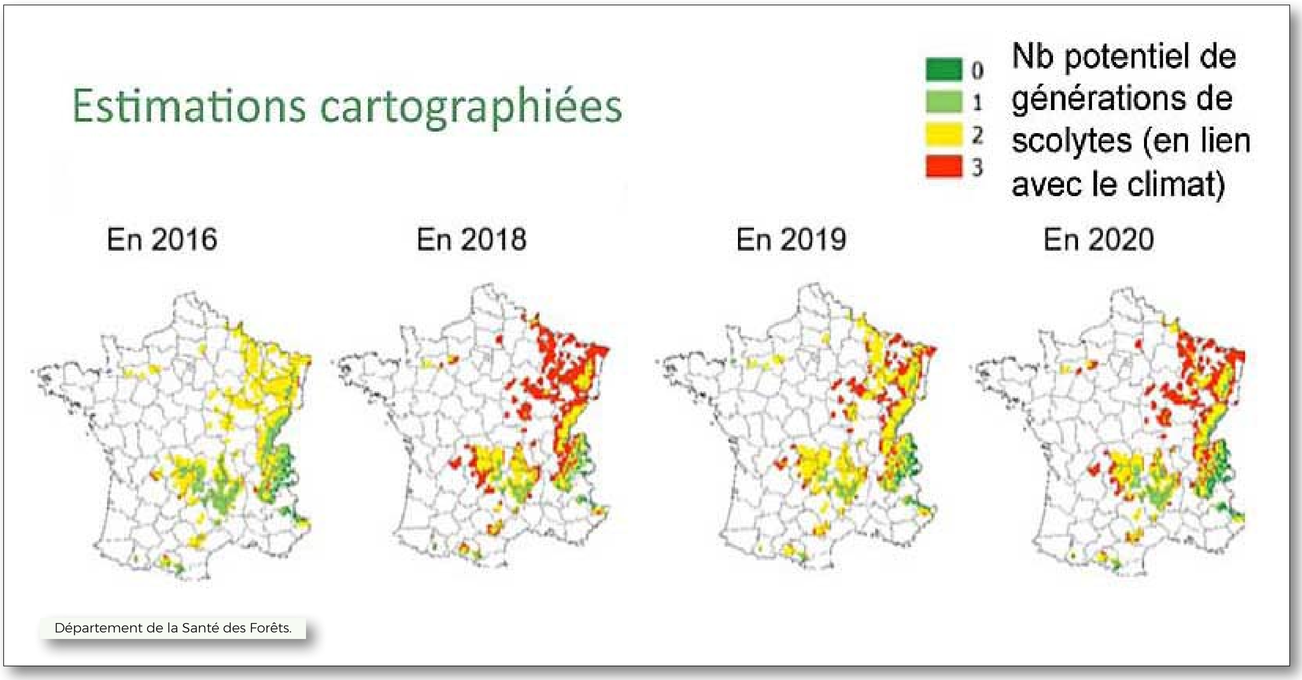
- **Monitoring** the forests.
- **Diagnosing forest health problems**.
- Helping and advising forest managers.

These objectives are carried out by:

1. **Monitoring** the main **forest health** problems through:
   - Studying the cyclical nature of episodes that affect forests.
   - Detecting emergencies.
   - Quantifying episodes.
2. **Monitoring endemic and invasive organisms**.
3. **Health monitoring** of biotic and abiotic problems that affect forests, such as heatwaves and droughts. To this end, 4000 annual observations are made, for which 800 samples are gathered, allowing 300 different episodes to be detected.

The observation of damage caused by droughts is carried out using the **health monitoring form**, completed by rangers, on which problems and symptoms detected in the trees are recorded. These forms provide an idea of the **magnitude of the effect on species** and enable a **map of drought impacts** to be created according to species. They also enable indirect impacts to be recorded, such as plagues or diseases






The DSF also **monitors oak trees** in different massifs to quantify the initial point of a possible degradation, based on which a degradation scale is established. Tracking is done of 57 000 oaks from 2800 observation points using the DEPERIS method.

Other methods used by the DSF include:

- The Biljou method, a forest water balance model for assessing massifs with the greatest risk of water stress.
- Monitoring of plots of beech trees.
- Monitoring of droughts and the intensity of the associated damage to between 800 and 1000 plantations.
- Systematic network for monitoring damage to forest species in relation to climate.

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# How to manage forests and forest landscape to reduce drought impacts at a local scale

## Experiences from Castile and Leon, Spain. Forest management in the province of Valladolid. Adaptation to climate change scenarios

**Alfonso González Romero** (Regional Government of Castile and Leon)

The province of Valladolid has a very uniform landscape with scarcely any slopes and is prominently an agricultural region. It has a **continental Mediterranean** climate with extreme temperatures between summer and winter and a very low average annual rainfall of around 430 mm.

In the province, **two prevalent forest types** can be observed:

- Natural formations of stone pine (*Pinus pinea*) and maritime pine (*Pinus pinaster*) on rolling plains and barren land with very sandy soil. These areas are managed by the Regional Government of Castile and Leon and follow a sustainable forest management model, which in some cases covers 100 years of monitoring.
- Mature reforestations of Aleppo pine (*Pinus halepensis*) and stone pine (*Pinus pinea*) on gentle and steep slopes and very poor soil.

### Natural formations *Pinus pinea* and *Pinus pinaster*

Since the 1990s, there has been a severe decline of *Pinus pinaster* on the sandy areas and a fall in the natural regeneration of *Pinus pinea*.

Although **the severe decline and the fall in natural regeneration are worsening due to climate change**, knowledge of these processes in some areas dates back decades and are the result of overexploitation of groundwater on sandy areas in the central basin of the Duero through intensive horticulture.

### Adaptive management measures applied to these formations to improve their resilience to climate change:

**1**

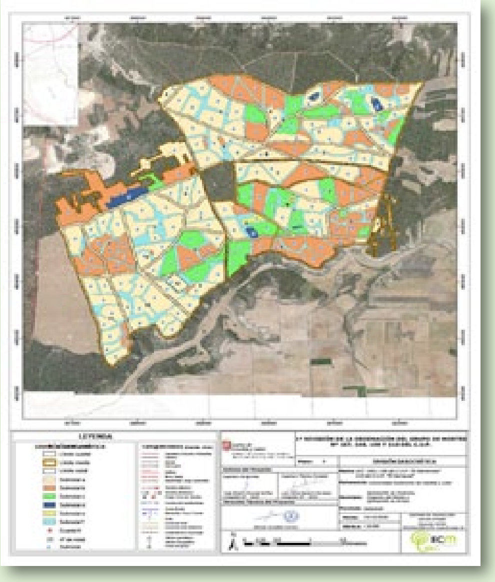
- **More flexible management methods in forest management documents**. The permanent felling compartments method for even-aged stands or the rotation by areas cutting method for uneven-aged stands has changed to the forest management by homogeneous stands method, allowing fellings to be adapted to episodes of natural regeneration, increasing the frequency of interventions.

**2**

- **Creation of an experimental system for studying regeneration**. This began in 2001 and there are currently 3000 permanent plots, allowing the study of the annual evolution of saplings. Monitoring results show that *Pinus pinea* regenerates better and is, therefore, more viable than *Pinus pinaster*, depending on climate conditions and those of the area.

3

- **Application of flexible forest management that maximises windows or episodes of regeneration**. *Pinus pinea* is a light-demander species with a tendency to semi-shade, which requires cover during the first few years of regeneration. Management must allow for a certain amount of shade from seed trees in the first few years and then carry out a final cutting of seed trees in the regenerated area.



## Mature reforestations of *Pinus halepensis* and *Pinus pinea*

These mature reforestations on gentle and steep slopes have been subjected to deforestation for hundreds of years due to overgrazing and agriculture, leading to the implementation of an ambitious reforestation programme as of 1955. Originally, reforestation was for protective purposes to stop erosion, protect crops on the lower rolling plains and create strips with a certain amount of biodiversity

Adaptive management methods applied:

- **Structural Measures**: High-density planting has been carried out of around 2000 trees per hectare. As they grow, thinnings are carried out that imitate nature, preventing the vertical and horizontal continuity of fuel and reducing the risk of fires.
- **Diversification Measures**: Enrichment planting with species of interest in the spaces created by the structural measures and which have not been colonised through natural regeneration.

**All these structural measures to reduce density are aimed at initiating natural regeneration processes as an additional method to increase biodiversity.**

## Lessons Learnt

- Need to use increasingly more flexible management methods. The method that best adapts is the **stand management** method.
- Management through **adaptive silvicultural** methods that harness each "regeneration window or episode" that comes about.
- Need to **protect *P. pinea* seedlings** that are viable, by ensuring a canopy cover that provides a certain amount of shade, followed by a **final cutting** of seed trees.
- The species used for the forestation of inclined plains and slopes on skeletal soils were **suitable**. They have a high survival rate and their protective function is maintained even with stocky phenotypes.
- **Structural measures** (through thinnings and clearings) and **diversification measures** (specific enrichment plantations) on inclined plains and slopes are the most suitable for increasing the resilience of these formations.

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## Experiences from France. Strategy and tools for the silvicultural management of public forests in France

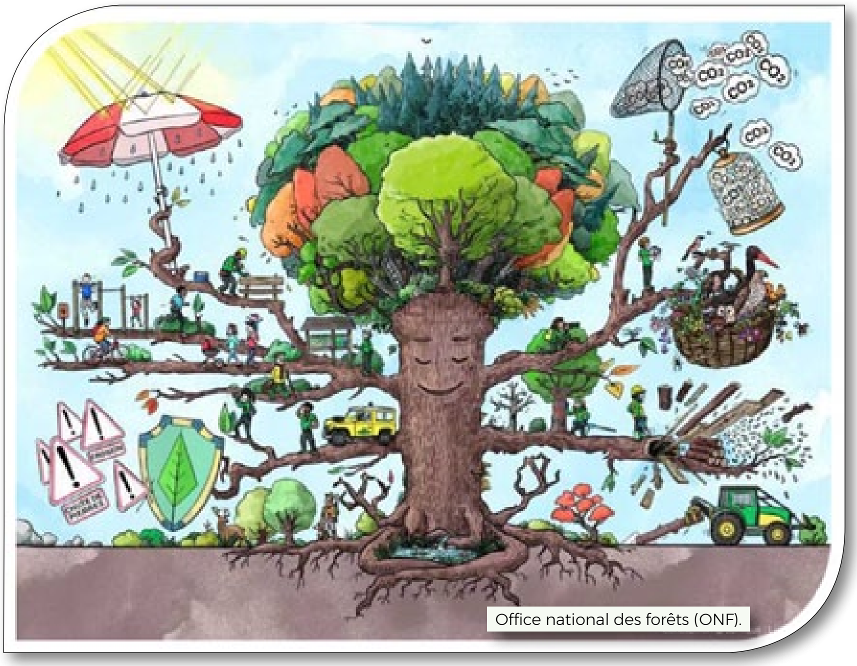
**Thierry Sardin** (French National Forestry Office, ONF)

France's ONF (National Forestry Office) consists of one directorate general in Paris, six regional departments that cover the whole of France and 50 agencies.

Currently, it is implementing a **national strategy for adapting forests to climate change**, for which each **regional department creates its own local and operational version**. The strategy will evolve as knowledge expands, feedback is received and successes and failures are shared.

The **pillars** of the strategy must guarantee the **multi-functional management** of forests, to ensure **their ecological, economic and social functions**. These functions translate into the valuing of wood resources, protection of the environment and biodiversity, prevention and management of natural hazards and welcoming the public to use the forests.

**Having observed the effects of climate change, we face social as well as technical problems**



Office national des forêts (ONF).

The national strategy focuses its measures on:

- Making the **forests more resilient** and developing this resilience in relation to production performance.
- Accompanying the **evolution** of ecosystems.
- Maintaining **biodiversity**.
- Facilitating the **role of forests in energy transition** through:
  - Carbon sequestration: storage in forests.
  - Storage of carbon in wood: in buildings, furniture, everyday objects, etc.
  - Replacing other materials with wood (eco-materials)..

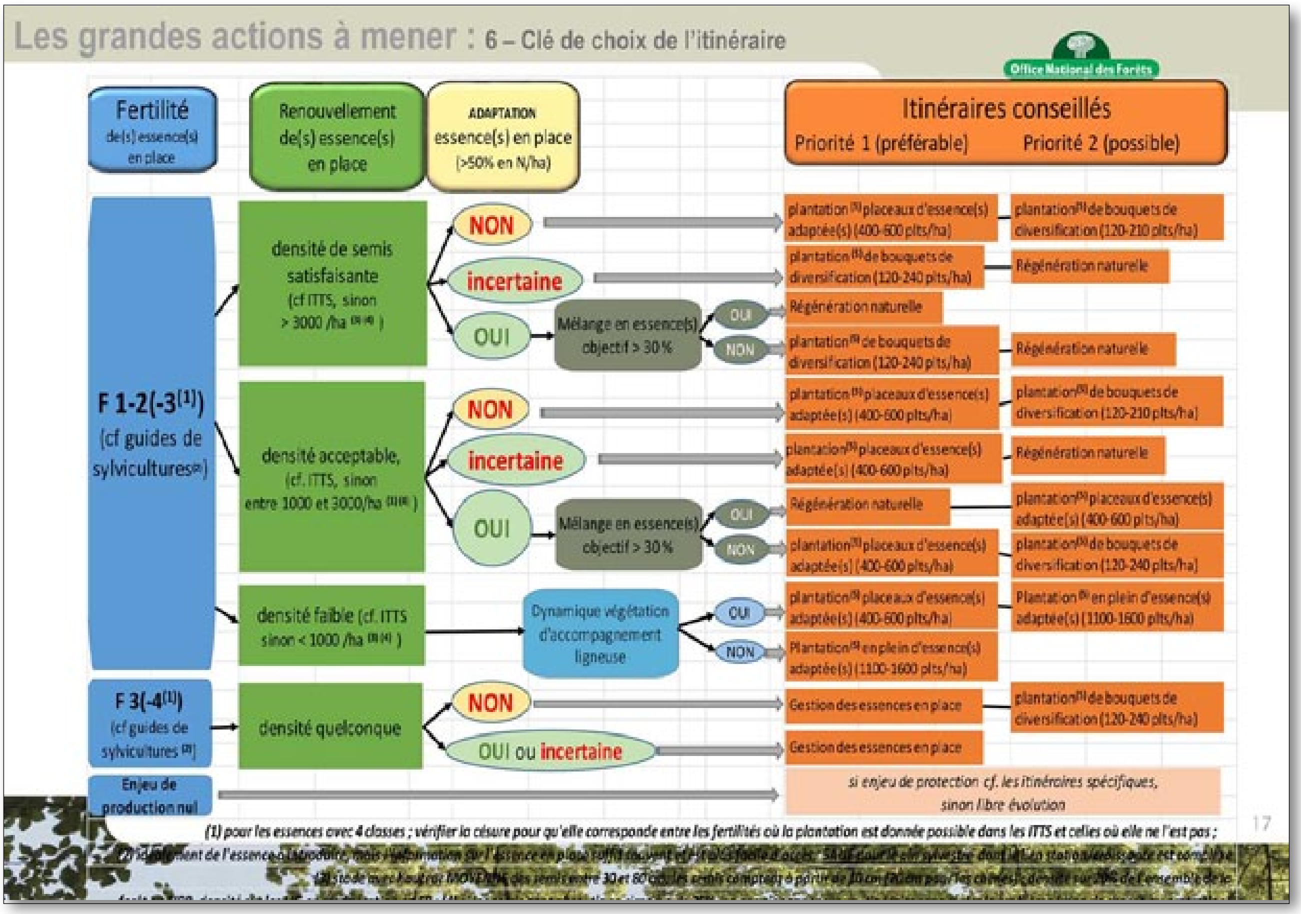
## Adaptation of this strategy to the forests in southern France

The main principles of this strategy, applicable to the forests in southern France are:

- Maintaining and restoring the balance between forests and hunting.
- **Applying cycles or rotations recommended by silvicultural guidelines**, increasing the frequency of interventions to manage a reasonable amount of forestry capital.
- **Diversifying**, on a massif scale, treatments (regular high forest, irregular high forest, coppice forest...) and silviculture (natural regeneration, forestation, species, objectives). .
- **Protecting the soil**, physical supports and reservoirs of water and mineral elements of forests. This is carried out based on a soil sensitivity diagnosis (PraticSOLS, etc.) and adapted methods.
- **Fostering the mixing of adapted species** according to the site quality and natural dynamics, using various species in the plantations, encouraging natural regeneration by planting seedlings in diversification clumps, etc.
- **Diversifying and fostering the mixing of species**, initially based on natural dynamics and later encouraging five adaptive itineraries:
    - **Itinerary 1**: Complete planting to introduce the main target species (1100 to 1600 trees per hectare).
    - **Itinerary 2**: Plot planting of the main target species (500 to 600 trees per hectare).
    - **Itinerary 3**: Planting of diversification clusters to introduce a species (120 to 210 trees per hectare). The aim is not to achieve a significant production of the first generation but to promote the dispersion of the species in the second generation.
    - **Itinerary 4**: Monitoring of the natural regeneration of species (through maintenance work or development of mixes).
    - **Itinerary 5**: Monitoring of the natural dynamics without interventions except for cuttings.

To achieve these principles the following actions are proposed:

1. Assess the need to recover or **renew degraded stands**. For example, using a mapping website.
2. Assess the **adaptation needs** of the populations.
3. Assess the **forest-hunting balance**, in terms of natural regeneration success and act accordingly.
4. Training in the description of soils (FOREVAL tool).
5. Create a list of **new species to try in future "islets"** (new plantation areas for testing new species under real forest management conditions).
6. Rethink the relationship between **species and site quality at a management level**.



# Experiences of the SUDOE MONTCLIMA Project. Adaptive forest management in a holm oak forest in the Montnegre-Corredor massif (Barcelona)

**Diana Pascual Sánchez** (CREAF)

Forest management of the holm oak forest in the Montnegre-Corredor massif is one of the five pilot actions of the MONTCLIMA Project. This action consists in the **application of adaptive forest management as a tool for reducing fire and drought risks in mid-mountain holm oak forests (Catalonia)**.

The pilot action is being developed on the Can Bordoi estate, located in the Montnegre-Corredor Natural Park. This location was chosen for various reasons:

- Willingness on behalf of the owner and livestock farmer in the area.
- Possibility of collaborating with the Association of Forest Owners of the Montnegre-Corredor.
- Ease of access and proximity to Barcelona.
- Possibility of analysing the effect of two of the natural hazards studied by MONTCLIMA:
  - Fire risk: the estate is part of the priority firebreak area for planning and is a strategic management point for fire prevention established by the Provincial Council of Barcelona.
  - Drought risk: the area was affected by droughts between 2012 and 2019, according to DEBOSCAT results. Drought does not affect holm oaks as much as pines. However, it does weaken the forests and has made them more susceptible to plagues of *Matsucoccus*, *Tomicus* and *Lymantria* in the area. The latter affected the pilot action in 2020 and led to a rethink of monitoring variables for the project.

**Action objectives:**

- **Reduce the fire risk** in the massif.
- **Reduce drought effects** and damage caused by plagues.
- **Maintain the measures in the medium and long-term** using livestock.

**Measures** implemented:

- **Adaptive forest management** of 5.4 ha: selective cutting and clearing of scrubland.
- **Control** plot of 1.87 ha.
- **Recovery of the agro-silvo-pastoral mosaic** for 4.7 ha: removal of logging residues and sowing of pastures.

**Adaptive Forest Management** (AFM) has been implemented according to the Sustainable Forest Management Guidelines of Catalonia (ORGEST) adapting it to the features of the Corredor, in other words, with **less intense and more frequent cuttings**, applying the following criteria:

- Elimination of fuel continuity to prevent a fire, should one occur, from passing to the canopy.
- Maintaining the Canopy Cover (CC)..
- Selection of sprouts.


*Condition of the forest before and after the action.*

This has led to changes in the forest structure, such as the reduction of the CC by 14 %, density by 19 % and the basal area by 8 %. Furthermore, the measures focused mainly on the understory, reducing cover by 77 % and biovolume by 97 %.

With regard to the recovery of the agro-silvo-pastoral mosaic, the intervention involved eliminating trees affected by *Matsucoccus* and *Tomicus*, removing logging residues and re-covering the area with pastures for grazing to prevent the growth of the understory and maintain the open space created.

This management was accompanied by the **installation of a monitoring network** formed by eight permanent circular plots (five under treatment and three for control) measuring 10 m in diameter, for which **forest structure, fuel continuity, vegetation water content and forest health** were monitored. In addition, sensors were installed in the plots to quantify soil moisture and temperature and relative air humidity.


This monitoring network makes it possible to quantify whether the AFM applied reduces the fire risk by monitoring three indicators:

- **Vegetation water content**, which is related to its **flammability**. Results obtained from the 2020 and 2021 campaigns show that in the managed area the vegetation has a greater water content and therefore a lower flammability and resulting fire risk. However, the results are still not statistically significant.
- **Fuel transects** (results expected in 2022).
- **Crown fire hazard** (results expected in 2022).

It also makes it possible to quantify whether the AFM improves the forest's resistance to droughts:

- Through monitoring **forest health according to discolouration, defoliation and mortality**. The results obtained for the 2020 and 2021 campaigns were highly affected by the *Lymantria* plague and are still inconclusive.
- By measuring **soil moisture** (results expected in 2022).

It must also be noted that the MONTCLIMA Project has a **website application** that includes a **map viewer**, making it possible to visualise information about the four natural hazards (fires, droughts, erosion and floods) covered by the project in the SUDOE territory, carry out temporal analyses of the evolution of the different risks, discover successful good practices in the handling of the four natural hazards and visualise mapping information on the project's pilot actions.

To see the application, go to : https://MONTCLIMA.eu/en/geoportal

# Experiences of the SUDOE MONTCLIMA Project. Rethinking forest resilience in a scenario of increasing droughts. Interaction of risk and protective forests (Andorra)

**Marc Font** (Andorra Recerca + Innovació)

The experience of Andorra is another of the pilot actions of the MONTCLIMA Project, corresponding to **forest fire risk prevention** actions and the **improvement of the forest's protective function** against **erosion and torrential movements** or landslides with **multi-risk planning**.

For forests, the present climate situation is marked by rising temperatures and the current summer drought (which contributes to the vegetation's water stress) and implications of this for the availability of fuel and the increased risk of fires. For the time being, fires in the Pyrenees are topographic and relatively small in size. However, what **functions** are affecting these forests? **Biodiversity, water cycle, air cycles**, etc. Furthermore, some of them have the particular feature of being **protective forests**.

Forests in the Pyrenees are growing and recolonising the upper reaches. When these forests are preventing or mitigating the effect of an underlying risk of a gravitational nature, be it block falls or landslides, they have an added value in socioeconomic terms.

For this reason, in the long run, allowing **these forests to suffer fires of a certain degree of severity**, with the resulting change to the forest cover, is **too much of a risk**. Therefore, the purpose of **multi-risk forest planning** is to manage the vulnerability to fire of a protective forest against falling blocks

One way of doing this is by identifying fire risk source zones to prevent the start or impact of fire hazards. In this case, the **strategy is to maintain the maximum forest cover in terms of density** but with the premise that the opening of canopies is sufficient to ensure that, in the event of a fire, this does not rise to the crowns. To this end, **firebreak zones for slowing down the fire** are also created.

However, there are questions. What is the **optimum density**? What **distances** must be considered for these firebreak zones for slowing down the fire? What **biophysical characteristics** of the territory should be contemplated for applying the most suitable measures? What interactions arise with other disturbances such as plagues?

This pilot action of the MONTCLIMA Project is being carried out in the **Maians Forest in Andorra la Vella** because, although there are no urban settlements, Andorra's waste treatment centre, considered an essential infrastructure for the country, is nearby.


Plana E., Font M. 2018.

**Action objectives:**

- **Categorise** the protection level of the forest.
- **Reduce the stand's vulnerability** to severe fire without affecting the level of protection.

To quantify the protective level of the forest, the silviculture management guide for protective forests in the Pyrenees has been used and an average protection level was obtained (Hazard Control Index, IMA: Indice de Maîtrise de l'Aléa) of 3.

To quantify the vulnerability of canopies to fire and mortality due to thermal shock, the Rothermel fuel models were used, together with key factors for identifying the crown fire hazard and the BehavePlus Fire Modeling System programme. The result was a Rothermel 7 model, a moderate B10 crown fire hazard and a high probability of surface mortality. The status of the scrubland cover was also assessed to adjust its structure. In this way, the risk of the fire spreading to the canopy is minimised, as is mortality, without altering the tree structure.

*Condition of the forest before the action.*

Based on these results, the objective of the measures in the pilot action was to reach a model of low crown fire hazard (C6 or C8) and obtain a Rothermel 6 model. To achieve this, the following **measures** were implemented:

- **Selective clearing** to reduce the cover, eliminating scrubland in direct contact with trees and regenerated trees.
- **Reduction of the height of the fuel ladder cover** until it reaches the fuel surface category.
- **Sanitation felling** of dead, dying and non-viable trees.
- **Protect and encourage resprouting tree species** to diversify the forest type so that in the event of a block fall they can recover more easily than pine.

*Condition of the forest after the action.*

# Modelling tools for increasing drought resilience throught the application of forest management strategies

## Experiences from Valencia, Spain. Forest management for multiple objectives, the LIFE RESILIENT FORESTS Project model (C.A.F.E.)

**María González Sanchís** (UPV - Universitat Politècnica de València)

The **EU's Forest Strategy** (2021) reinforces and promotes the:

- Multifunctional role of forests.
- Carbon sequestration.
- Increase in the resilience of the ecosystems.
- Protect and preserve biodiversity and other ecosystem services.

To this end, **quantification of forest management and the ecosystem services** it produces is necessary and essential, given that forest management provides wood and other goods and services. Therefore, the **added value of forest management** must be demonstrated **to society**. How? Through **process-based silviculture**. However, **forest management is complex** to the extent that there are very different species that result in very different forests, which, in turn, give rise to different forest systems and approaches depending on the objectives pursued.

To respond to these issues the **LIFE RESILIENT FORESTS Project** was created, co-funded by the EU's LIFE Programme. The project promotes **forest management at a basin scale** to **improve the resilience of forests to fires, water scarcity, environmental deterioration and other effects caused by climate change**.

Source: Millenium Ecosystem Assessment, 2005.

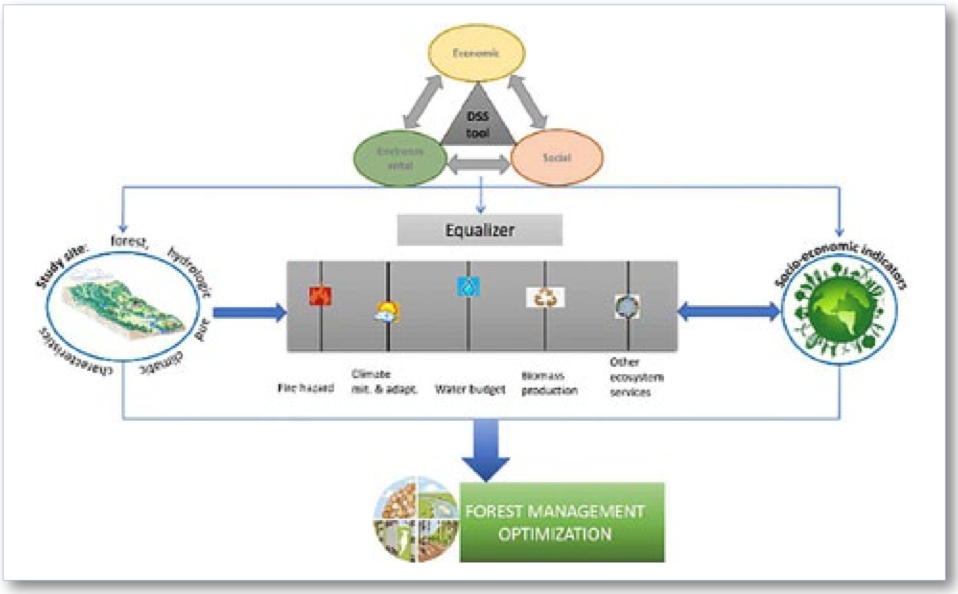
The project covers:

- The development of a **Decision Support System (DSS) tool** for forest management.
- **Demonstration** of the DSS tool at a basin and sub-basin scale in Germany, Portugal and Spain.
- Development of a **forest management approach** that demonstrates a positive impact on environmental and socioeconomic factors.
- **Transfer** of the approach on a European level.

# Forest management for multiple objectives, the LIFE RESILIENT FORESTS Project model (C.A.F.E.)

María González Sanchís

The decision support tool combines **multi-objective forest management** and the DSS by including up to seven possible management objectives: biomass production, water management, fire risk, carbon sequestration, climate resilience, biodiversity and others.

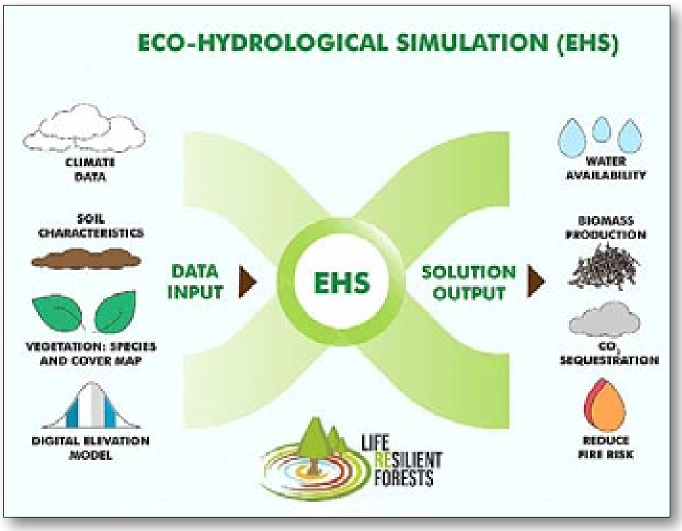



### How does the DSS work?

- Spatial scale: from stand to basin.
- Objectives: five to be selected out of seven. Users can weight each objective.
- Decision variables: how much, when, where and/or how.
- Combination of optimisation algorithms with eco-hydrological simulation, such as TETIS (UPV, Spain), RHESSys (UCSB, USA), Biome-BGCMuSo.
- Results: list of possible optimum solutions.

### What is needed to implement this DSS?

- Input data for the eco-hydrological model (digital elevation model, vegetation, soil, climate).
- Selection of objectives.
- Management possibilities (restrictions, location, species, structure, age, density and vulnerability).



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## Experiences from Portugal. Potential shifts of bioclimatic niches of forest species in Portugal

**João A. Santos** (Universidade de Trás-os-Montes e Alto Douro, UTAD)

**Forest areas in Portugal** cover almost **40 % of the country**. The Portuguese **forestry sector** represents approximately **5 % of national GDP** and represents 10 % of the country's total exports.

The objectives of the study of potential shifts of bioclimatic niches of forest species in Portugal are:

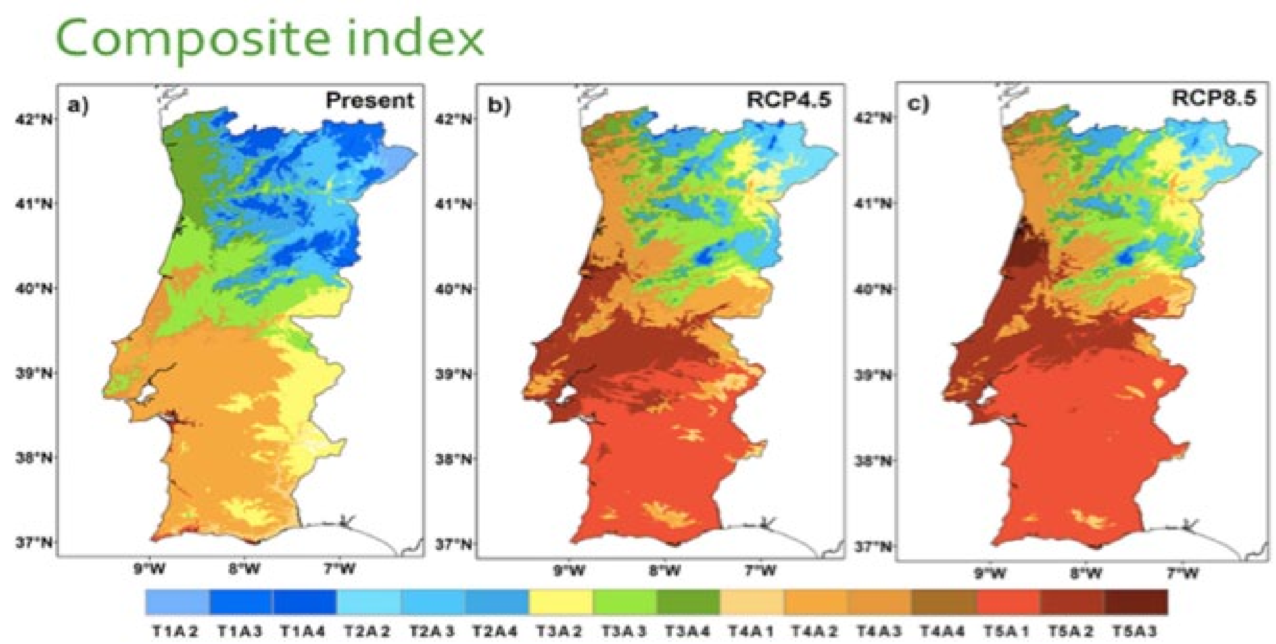
- To **identify typical climate conditions** associated with main forest species in Portugal, by overlapping their current range with suitable bioclimatic indices.
- To **assess future** shifts in bioclimatic zones under climate change **scenarios**.

An analysis was carried out using maps from the *Corine Land Cover*, inventory, a digital elevation model and a forest species location map provided by the Botanical Society of Portugal. In total, **49 forest species** were studied, which are considered representative of a wide range of climate conditions in the country.

A series of **climatic and bioclimatic indices (aridity index and thermicity index)** were used for the study. The bioclimatic indices were calculated for different time horizons (1950-2000 and **2040-2060**) using two IPCC emissions scenarios, RCP4.5 and RCP8.5. The results for 2040-2060 show a very clear **increase in aridity in southern Portugal** and a **clear reduction in the humid and subhumid climate in the northeast of the country**.

The **thermicity index** reveals a **significant increase of areas with a thermo-Mediterranean climate**, while meso-Mediterranean climates are located in the middle areas of the northeast of Portugal and supra-Mediterranean climates in high mountain areas. When these two indices are superimposed on the **RCP8.5 scenario**, there are four species (***Betula pubescens, Pinus sylvestris, Sorbus aucuparia and Taxus baccata***) that are shown as **particularly vulnerable to climate change**, with a reduction of suitable areas for their survival.

A **composite aridity and thermicity index** was also applied to the different species on the map of Portugal, in which **shifts in the location of different species** could be observed in future scenarios.




Costa, R. *et al*. Implications of future bioclimatic shifts on Portuguese forests. Reg Environ Change 17, 117–127 (2017).

## In conclusion:

- **Climate change**, particularly changes in temperatures and rainfall, will create **changes in the different native Portuguese species. Some conifers and also broadleaved trees may not survive** under future climate conditions.
- The most effective adaptation measures will likely be the **gradual and science-based replacement of these species and subspecies in different regions**. This will mitigate and reduce the damage, such as losses from a decrease in wood production and quality and from environmental impacts, such as tree mortality and fires.
- **New forest species** may appear and could be used as substitutes for the more traditional species, particularly in the southwest of Portugal, in drier and more arid regions.
- New **species** may be introduced that could be **invasive** and, therefore, care must be taken regarding environmental problems they may cause.
- The most relevant species from an economic viewpoint, such as eucalyptus and maritime pine could be **relocated or replaced with more suitable and sustainable species** from an environmental perspective or even with improved or genetically modified hybrid species so that similar economic incomes are obtaineds.
- The **Portuguese *montado* zone will be very resilient** to future climate conditions. In this regard, **cork production** could compensate for eucalyptus or pine wood production. *Montado* is a Portuguese term that refers to savannahlike grassland, usually scattered with both holm and evergreen cork oaks and without any scrub undergrowth, used for grazing by livestock.
- Other species, such as *Pinus pinea*, *Quercus rotundifolia* and *Ceratonia siliqua* or carob, may be **species of great interest** from an **economic** viewpoint for the future of Portugal.
- The most important mitigation measure is the **role of forest carbon sequestration policies**, which will be crucial in the selection of species and forest planning.
- This study assesses the shifts of bioclimatic zones in Portugal under different climate change scenarios for several forest species. However, **future distributions will also depend on ecological and physiological aspects** that have not been considered in this study, such as the interaction between species, $CO_2$ absorption and changes in the species' environment, as well as the soil and disturbances.

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# Experiences from France. CLIMESSENCES: A tool for understanding the evolution of forest species in the context of climate change

**Xavier Bartet** (French National Forestry Office ONF - RMT AFORCE)

CLIMESSENCES is a **decision-making tool** developed by several stakeholders from the forestry sector, with the support of the (AFORCE) (Adaptation of Forests to Climate Change) research network.

The tool has three objectives:

1. **Report on probable climate changes** and related variables.
2. **Provide information on the vulnerability, sensitivity and adaptation** of tree species to these climatic changes, which is also known as the compatibility of species with climate change.
3. Provide **as much information as possible on a wide range of species** (approximately 150).

For environmental rangers, CLIMESSENCES could be **useful for three reasons**:

1. For **creating management plans**, a document that will establish the guidelines and actions for forests for the next 20 years. With this tool, they can include climate change in their plans.
2. In the face of the **decline** of certain species, fellings or reforestation will be necessary but, which species should be planted? Species that adapt to these climate changes. In other cases, the exploitation of some species in decline must be anticipated, ones which are unlikely to resist in the future.
3. As a **communication support** tool, to explain to the general public and to politicians, the impact that climate change will have on forests.

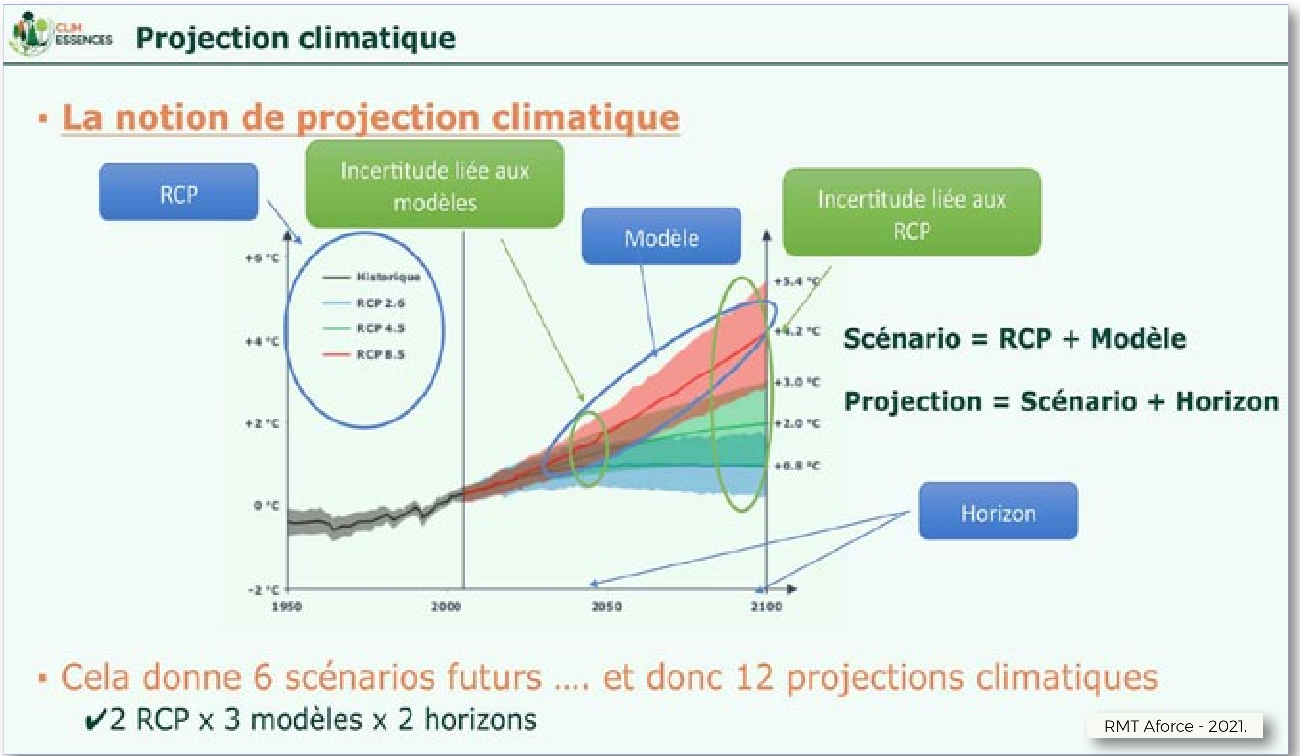
CLIMESSENCES uses a series of **indicators that represent a limiting factor** for the presence of species:

- The **annual water deficit**: a limitation caused by drought.
- The **minimum annual temperature**: limited by the cold in winter.
- The **sum of degree days**: limitation due to a lack of heat (energy).

Based on the IPCC's climate change scenarios, **CLIMESSENCES has developed three possible scenarios**, according to the data model used, for time horizons of 2050 and 2070:

- **Optimistic scenario**, similar to RCP4.5, based on the CNRM-CM5 model of MétéoFrance.
- **Intermediate scenario**, similar to RCP6.5, on an average of 18 models.
- **Pessimistic scenario**, similar to RCP8.5, based on the HadGEM2-CC model from the Hadley Centre in the United Kingdom.

Using these scenarios, the conclusion is that the **greatest moment of uncertainty occurs for the 2050 time horizon** and the further we move away in time, **the uncertainty is related more closely to the climate trajectory**.



RMT Aforce - 2021.

CLIMESSENCES is a **purely climatic model**, a simplified representation of the climate that does not take into account other factors, such as extreme phenomena, forestry, soil compaction, biotic factors, the soil's capacity to store water, etc. Furthermore, it also takes a very simplified view of the usable water reserve. This means that the tool is a **very optimistic model** because it does not consider these variables.

What are the **two functions** of this tool?

- **Climatic analogy**, which answers the question as to where you can find a climate today that is similar to the future climate of where you are currently located.
- **Climatic compatibility**, which assesses how compatible each species will be with the future climate.

# Field visit

## Experimental plots of the SUDOE MONTCLIMA Project in the Montnegre-Corredor Massif (Llinars del Vallès, Barcelona).

Forestry experts, Lídia Guitart and Martí Rosell from the Association of Forest Owners of the Montnegre-Corredor, together with CREAF researchers, Diana Pascual and Eduard Pla, were responsible for explaining the pilot action carried out in this area as part of the SUDOE MONTCLIMA Project.

### The Montnegre-Corredor massif and its characteristics regarding fire risk

The pilot action was implemented on the Can Bordoi estate in the Montnegre-Corredor Natural Park, which is part of the Provincial Council of Barcelona's network of parks. The area is divided into a mountainous zone where chestnuts, holm oaks and cork oaks proliferate and an area towards the sea, where there is a larger number of stone and maritime pines.

The park, close to Barcelona, is **under significant pressure from public use**. It is also part of a priority firebreak for the prevention of forest fires. Furthermore, the Can Bordoi estate is part of a **strategic management point** (PEG in its Spanish acronym), meaning that it is a **suitable area for firefighters to carry out attack or containment manoeuvres for large wildfires**. These areas require good access, safe zones and a vegetation structure that prevents canopy fire.

The delimitation of the PEG was carried out to prevent large wildfires, in other words, to prevent 100-metre fire jumps. Planning was supported by a study by the Pau Costa Fundation and the Provincial Council of Barcelona's Office for Fire Prevention. The following points were taken into consideration:

- The predominant wind direction that generally occurs in the area at moments of high fire risk.
- The need to use a non-linear type of infrastructure against fires.
- Measures on the northern edge of the park to be prioritised to make it difficult for fires to advance towards the south.

### The SUDOE MONTCLIMA Project's pilot action

The pilot action is being developed on the Can Bordoi estate and focuses on three areas:

- An area of 5.4 ha where **adaptive forest management** has been implemented.
- An area of 4.7 ha where the **agro-silvo-pastoral mosaic** has been recovered.
- A control area of 1.87 ha, which has been left untouched.

The first stop on the visit was on a ridge zone located next to a track, where the **silvopastoral landscape** has been recovered. Measures involved cutting and removing all the *Pinus pinaster* because they had been significantly affected by plagues and their future viability had been compromised. In this way, **open space was created within the PEG** where, in the event of a fire, firefighters could act, control the fire and prevent it from spreading to canopies. However, the holm oak layer below was left, with the idea that it would create a *devesa* in the future. Devesa is a Catalan term that refers to savannah-like grassland, usually scattered with both holm and evergreen cork oaks and without any scrub undergrowth, used for grazing by livestock.

Also in the area, there is a farmer who has 800 sheep and a few goats that will maintain and improve the new space created as they graze. The area will likely be planted with grass seed to improve the animals' food and guarantee the area's upkeep. In this way, a *devesa*-type landscape has been created and the forestry intervention has been supported by a management method that makes use of the **livestock activity in the area**.

## Actions implemented in the forest

Adaptive forest management has been applied to a 5.4-hectare area, in an uneven-aged **holm oak forest mixed** with pine and cork oak with a very dense arboreal and shrubby understory. This area has a very high vertical and horizontal continuity of fuel. The aim was to break this continuity and, at the same time, reduce the density and cover of the understory, fostering the growth of holm oaks, which do not burn as quickly as pine. Part of the understory species, mainly the tree heather (*Erica arborea*) and strawberry trees (*Arbutus unedo*), were tree-like and in the intervention, they were treated as trees.

Another important criterion in the management applied was to **maintain the forest's cover** (canopy cover) **and prevent too much sunlight from reaching the soil**, to reduce understory regrowth and the loss of soil moisture, as the soil is sandy. The actions implemented were very gentle and have focused mainly on the management of the understory's biomass to prevent vertical continuity in the event of a fire.

## Monitoring of actions

To follow the actions implemented, a **monitoring network** has been installed, consisting of **eight permanent circular plots**, five in the managed area and three in the control zone. The monitoring of different variables has been carried out in these plots since 2020:

- Forest structure (diameter, growth, etc.).
- Fuel continuity.
- Forest decline (discolouration, defoliation, mortality).
- Vegetation water content.
- Soil moisture.
- Relative humidity and temperature.

As a result of the data gathered in 2020 and 2021, it has been possible to verify, for example, that there is a **difference between the water content of holm oak and heather in the treated area and that of the control area**. Initial results show a **greater water content in the treated area**, indicating **lower flammability of the fuel**. However, these differences are not statistically significant.

The **annual visual recognition of discolouration, defoliation and mortality** has also been carried out, to determine if adaptive forest management increases the resilience of these forests to the impacts of drought and plagues. However, the *Lymantria* plague in 2020, which affected more than 3800 ha in the natural park, resulted in the defoliation of approximately 50 % of the canopy in the study area, with the same impact on the managed area as on the control area. **More years of monitoring** are needed to discover whether the management strategies applied have a bearing on the recovery of the forest to this attack compared to the control zone.

# Conclusions and orientations: lessons learnt

During this third seminar of the SUDOE MONTCLIMA Project, **experiences regarding the impact of droughts on mountain forests in the SUDOE territory** were shared, allowing **practices and research in Portugal, France, Andorra and Spain to be compiled and compared**.

**Eva García-Balaguer** (Coordinator of CTP-OPCC, current lead partner of the MONTCLIMA Project) opened the seminar, insisting on the need to share information and experiences to improve the management and prevention of natural hazards in the southwest of Europe in view of the context of climate change. **The multi-risk perspective is crucial and cooperation between the different stakeholders in the region, essential**.

**Rosa Amorós i Capdevila** (Secretary General of CTP-OPCC) emphasised the importance of **cooperating in the fight against climate change** and natural disasters at a time when the scientific community has once again brought to light the global climate emergency in the 6th IPCC Report. In this regard, initiatives like the **Pyrenees Climate Change Strategy** are crucial.

**Joan Pino Vilalta** (Director of CREAF) underlined the growing stress that our forests are under as a result of the greater frequency and intensity of climate extremes. In this sense, the **study and knowledge about forest ecology and interaction with human activities** is a fundamental part of the adaptation of forests to climate and global change.

**Sergio M. Vicente-Serrano** (Pyrenean Institute of Ecology, IPE-CSIC) created the backdrop for the seminar, explaining the risks of drought in the SUDOE space, reviewing historical data and providing future projections. **Drought** has proven to be a **recurrent and complex phenomenon that is difficult to predict** and has had a **high spatial and temporal variability** throughout history. Therefore, signs of a greater frequency or intensity of this phenomenon are not particularly clear. Greater atmospheric water demand stemming from rising temperatures has a direct effect on evapotranspiration levels. This leads to negative effects in forests when water availability is low — fundamentally in summer — creating water stress (closure of stomata, deterioration, reduction of carbon fixing, etc.). If **future scenarios of rising average temperatures are confirmed**, this would mean **significant stress on the forests**, particularly if accompanied by an increase in the frequency and intensity of droughts. Therefore, **water demand will increase in the future as the average temperature increases due to global warming**.

**Jordi Martínez-Vilalta** (CREAF) underlined that there are gradually more cases of **forest decline at a global level due to drought**, particularly in **mountain areas**. Furthermore, all **future models coincide in the prediction of a higher incidence** of this phenomenon in coming decades, although it is difficult to accurately model the impact of droughts on forest mortality. In addition to decline, changes in the distribution, density and composition of forests are also expected. In this context, **when and where a catastrophic event is going to occur is much harder to predict due to the compensation**

**mechanisms (and natural resilience)** of forest stands. We already have some clues as to which factors must be taken into consideration. The main historical changes detected in forests result, above all, from **changes in land use and other human factors**. Similarly, it has been observed that **functional diversity** increases the resilience of forests to disasters. However, there is still a long way to go in understanding which variables and processes are involved in mechanisms that cause mortality due to drought. **It is essential for all the disturbances that affect forests to be considered and therefore monitoring and tracking programmes are crucial**.

## How to monitor drought impacts on forests

**Célia Gouveia** (Universidade de Lisboa) presented a study based on **the analysis of satellite images** for analysing surface alterations and vegetation deterioration on the Iberian Peninsula, using the NDVI index. This index allows the impact of droughts on vegetation to be defined. Results of the study show that **evergreen trees appear to be more resilient to drought**.

**Mireia Banqué** (CREAF) presented the **DEBOSCAT programme**, which has been **monitoring the decline** of Catalan forests for the last ten years. The programme's objective is to detect where decline episodes are occurring, their recurrence and how the forests recover after an episode. The conclusions of these monitoring processes are crucial for defining **priority areas and helping with the adaptive forest management in the area**.

**Morgane Goudet** (French Forest Health Department, Ministry of Agriculture and Food, DSF) presented the different tasks being carried out by the department to monitor forest health in the country. The system, using field forms, helps carry out detailed monitoring of the areas affected by droughts. The huge **database** on decline, plagues, etc. is crossed with **weather information and future climate projections, allowing the most vulnerable areas to be identified**.

## How to manage forests and forest landscape to reduce drought impacts at a local scale

**Alfonso González Romero** (Regional Government of Castile and Leon) presented the **sustainable forest management strategies** that are being implemented in pine forests in **Valladolid**. In this region, forest stands of *Pinus pinaster* are particularly affected by decline, which is caused by a combination of climate, human and geological factors. Strategies developed to limit the phenomenon of decline include the use of **increasingly flexible management methods** (by stands), **adaptive forestry** that takes advantage of each window or episode of recovery that occurs, **protecting seedlings, structural measures** (through thinnings and clearings) and **diversification measures** (specific enrichment plantations), among others.

**Thierry Sardin** (French National Forestry Office, ONF) presented the **forestry management strategies and tools** that are being implemented in **public forests** in France. The objective of these tools is to ensure that the **multi-functional** nature of forests is maintained and to increase their **resilience to climate change**, based on suitable decisions and measures. **Fostering the diversity of species, increasing the frequency of interventions and protecting the soil**, among others, appear to be key measures.

**Diana Pascual Sánchez** (CREAF) presented the **pilot project experience of the SUDOE MONTCLIMA Project** on **adaptive forest management** applied to a holm oak forest in the Montnegre-Corredor massif (Barcelona). Variables including forest structure, vegetation water content, fuel continuity and forest decline (defoliation, discolouration, mortality) were monitored in eight permanent plots (five in the management area and three in a control area with no intervention), to assess whether **adaptive forest management could play a key role in increasing the resilience of mid-mountain forests to droughts and fire risk**.

**Marc Font** (Andorra Recerca + Innovació), presented the **pilot project experience of the SUDOE MONTCLIMA Project in relation to multi-risk forest planning**, focusing on the management of the vulnerability to fire of **forests that protect** from block falls. To this end, the action objectives focused on classifying the protection level of the forests and on reducing the crown fire hazard without affecting the protection level. This led to different measures, including **selective clearing** to reduce cover, **reducing the height of the fuel ladder cover, sanitation felling** of dead, dying and non-viable trees and the **protection of resprouting tree species** to diversify the forest.

## Modelling tools for increasing drought resilience through the application of forest management strategies

**María González Sanchís** (Universitat Politècnica de València, UPV) presented the C.A.F.E. model of the LIFE RESILIENT FORESTS Project. This project assesses different forestry treatments for improvement and regeneration, which lead to operational improvements in management and support in decision-making. The project has also created a **Decision Support System (DSS) tool** that aims to foster the **sustainable management of forests by including up to five objectives** weighted according to the user's interests and providing a list of possible solutions.

**João A. Santos** (Universidade de Trás-os-Montes e Alto Douro, UTAD) presented the results of a study on the **possible shifts in climate niches of the main forest species** in Portugal (49 species studied). The model consists of weighting two observed bioclimatic indices (aridity and thermicity indices), which are then analysed using different climate change scenarios. The affected distribution areas were seen to be **colonised by thermophilic species that are better adapted to the new conditions**. The study also served to predict which species should be reforested so that Portugal continues to have economic strength in its GDP thanks to the forestry sector

**Xavier Bartet** (French National Forestry Office ONF - RMT AFORCE) presented the **CLIMESSENCES tool**, created to model the **evolution of different forest species**

**resulting from climate change**. This is a useful tool for creating management plans, guidelines and actions to be implemented in forests in the coming 20 years. The model is based on IPCC scenarios to obtain future species distribution scenarios (probability of presence/absence). The model creates two types of maps: **analogue climate maps**, which answer the question as to where you can find a climate today that is similar to the future climate of where you are currently located and **climate compatibility maps**, which assess how compatible each species will be with the future climate.

**Juan Terrádez** (CTP-OPCC) gave a final presentation that covered the conclusions of each of the presenters, thus bringing the seminar to a close with a reminder of the main ideas and key points.

Finally, **Eduard Pla** (CREAF), leader of the seminar together with Diana Pascual (CREAF), thanked all those who had made the event possible, from presenters to technicians and translators, as well as those attending and those who were following the seminar online. The exceptional circumstances of the pandemic meant that the organisation had to make an extra effort to reach the greatest number of people possible through a hybrid seminar system, to ensure that the knowledge and experiences regarding the **impacts of droughts on the SUDOE mountain forests and the management options for dealing with this serious hazard of climate change** could be shared.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