MEDACC

Demonstration and validation of innovative methodology for regional climate change adaptation in the Mediterranean area

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Authors

Robert Savé, Carme Biel, Inma Funes, Eduard Pla, Diana Pascual, Roberto Serrano

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Executive summary

Climate change can cause temperatures to rise at the regional or global scale. At the regional level, not all of the Earth's regions will be affected by the same changes in environmental conditions, and consequently, more exposed places will be potentially more vulnerable to climate change.

The Mediterranean Basin is the only region of the Earth where most models coincide in predicting less precipitation, above all, in the warm half of the year. In our case north-eastern (NE) Spain and by extension the Mediterranean ecosystem is characterized by a double stress, caused by cold winter temperatures and summer drought, which simultaneously promote plant and water deficit in crops and forests. In summer, low soil water availability, along with high vapour pressure deficit at the atmospheric level, promote inhibitions in plant growth and have various negative effects on their development.

This report exhibits the field protocols which will be applied to the demonstrative activities. The objective of these protocols is to monitor the effects of the experiments in the watershed. The report details the management objectives, the type of treatments, the variables that will be measured continuously in each plot, the frequency of the monitoring and the methodology employed to measure the variables.

Contents

1. Introduction

The Mediterranean region might become one of the most vulnerable areas in Europe and even in the world regarding climate change. Observational studies have already revealed a global trend toward warmer conditions over the last decades and changes in seasonal rainfall patterns. Also, recent climatic models predict that the climate of the Mediterranean region will become warmer and drier at the end of the 21st century, with changes in the seasonal distribution of precipitation . At the same time, land cover change processes are showing a general increase in forests and irrigated lands, which have increased water demand, given the increased evapotranspiration rates of these land cover types. All these processes are driving a decrease of the water availability in large regions of the Mediterranean, which is expected to be more severe in the coming decades.

The significant vulnerability of water resources, agriculture and forestry to climate variability makes these sectors highly susceptible to climate change projections for Catalonia. For this reason, an accurate quantification of the impacts of climate change scenarios on these sectors, the development of capacity-building approaches and the demonstration of adaptation measures are essential to reduce vulnerabilities, ensuring a successful impact of the project results.

Agriculture in the Mediterranean Basin involves a high number of crops, the productivity of which is limited by environmental conditions. Nowadays, however, improvements have been made by means of agronomic methods and systems based on the ecophysiological and genetic knowledge of the cultivated species. But despite this degree of specialization, agriculture remains highly sensitive to climate variability, which is the main source of global yearly variability in production.

Climate change can cause temperatures to rise at the regional or global scale. At the regional level, not all Earth’s regions will be affected by the same changes in environmental conditions, and consequently, more exposed places will be potentially more vulnerable to climate change and consequently to direct or indirect losses of agricultural productivity.

The Mediterranean Basin is the only region of the Earth where most models coincide in predicting less precipitation, above all, in the warm half of the year. In our case north-eastern (NE) Spain and by extension the Mediterranean ecosystem is characterized by a double stress, caused by cold winter temperatures and summer drought, which simultaneously promote plant and water deficit in crops and forests. In summer, low soil water availability, along with high vapour pressure deficit at the atmospheric level, promote inhibitions in plant growth and have various negative effects on their development.

Some climate models predict that the NE Spain will be affected by long-term droughts after 2060 more frequently than at present. It is known that a changing global climate, together with an enhanced interannual variability in the agricultural sector due to economic conditions, will increase the difficulties and risks in the agricultural sector in southern Europe.

The main important approach for agriculture in 21st century is focused on technology options that analyze how farming management concepts, practices and technologies, including plant breeding, could enable sustainable intensification of crop production, with the aim of increasing production and quality and support production supply.

The aim of sustainable intensification is to increase the productivity of the same region while reducing the environmental impacts, under social and economic beneficial conditions.

This approach is appropriate for agriculture in developing countries as well as in industrialized countries, small-scale and large-scale farming, extensive and intensive agricultural production systems, and low- and high-tech production practices.

In this context, water and energy are and will be key, permitting the necessary level of productivity in order to maintain socioeconomical and cultural sectors, which should seek to reduce impacts on environment.

There is recent evidence of the effect of climate variability in **forests**, causing episodes of mortality and defoliation and increasing fire risk, which are clear and early signs of the impact of climate change. Thus, a progressive increase in the effect of temperature on tree growth and a decrease in the effect of precipitation have been observed in Catalonian forests. This suggests a higher frequency of years in which climate conditions limit tree growth as a consequence of induced temperature-related water stress. Thus, increased annual temperature is favouring forest growth during humid years, but it has the opposite effect in the more frequent dry years.

Forest fires are one of the most relevant risks in the Mediterranean region. Some studies have pointed out the correlation between changes in climate and the surface area affected by fires. Vegetation structure is an indicator of forest flammability, which measures the quantity of combustible material in the forest, and has a direct influence in the propagation of an initiated fire.

2. Agriculture

2.1 Muga watershed

The fluvio-deltaic aquifer surface of the Muga and Fluvià rivers hosts an alluvial plain where agriculture is very dynamic and is an important part of the regional economy. The irrigation communities of the right and left banks of the Muga river manage the agricultural infrastructures related to water management. They collect the water from the Boadella reservoir. On the left bank of the river, these infrastructures provide service to the locality of Vilanova de la Muga, meanwhile, on the right bank service is provided to Fortià. The rest of the agricultural land is irrigated by wells connected to the aquifer.

Recently, an increase in groundwater salinity has occurred in the A zone (Figure 1) due to dredging of the final part of Muga river and the Empuriabrava marina. This can also be attributed to a decline in water quantity in this part of the aquifer. For this reason, some irrigated crops of this zone have been abandoned.

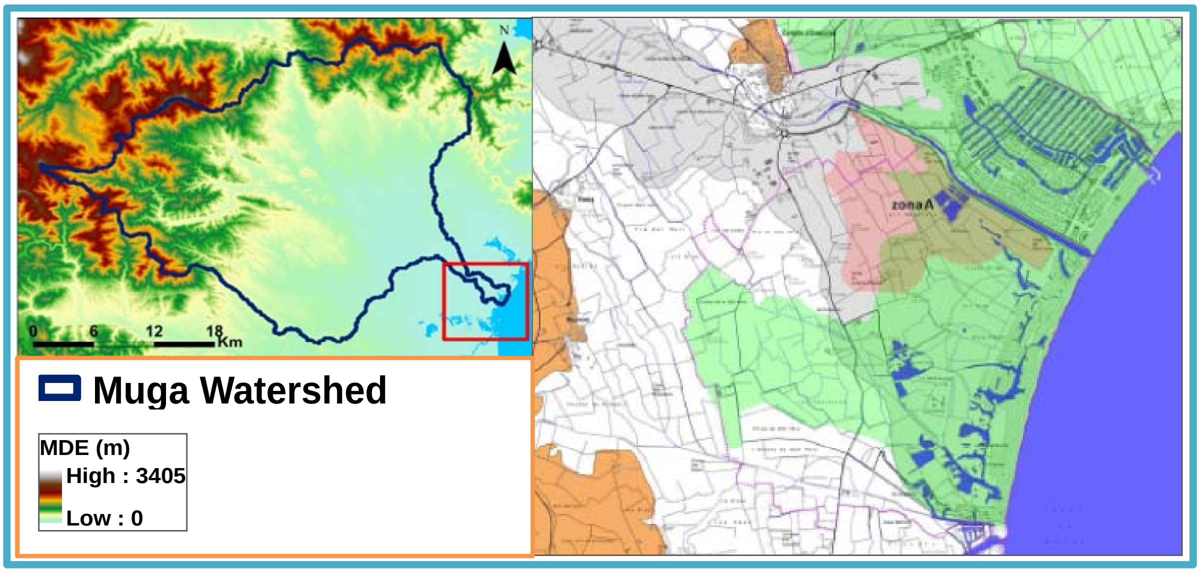

Figure 1. Location map of the area in the Muga watershed (left). Map of the coastal aquifer of Muga River (right). Zone A (brown color) shows the area affected by salinity .

The main agricultural crops irrigated in this area are corn, forage crops, rice fields and to a lesser extent fruit tree plantations.

According to field studies carried out in 2012 and 2013 by Fundació Mas Badia- IRTA with the collaboration of Geoservei S.A. consultancy, it was determined that depending on yearly water availability, the aquifer water level could be raised with a reduction in water extractions, and this could potentially combat salinity.

Based on this evaluation, in order to minimize the expansion of salinity in the aquifer, it can be proposed, among some other supplementary actions, a general reduction of water use or a reduction of agricultural water use in unaffected areas in order to reduce aquifer extractions and to maintain the saline/fresh water equilibrium.

The creation of an irrigation advice system in the area, conducted with the support of the Cooperativa de Castelló and the irrigation communities of the left and right banks of the

Muga river, needs to lead to an increase in irrigation efficiency while maintaining levels of crop production in the same territory and season.

In this context, the main objective of the Life+ MEDACC demonstrative activities is the implementation of an irrigation advice system for the farmers who grow irrigated crops in the Muga's area, in order to facilitate the savings in irrigation water without reducing crop production.

2.1.1.1 Management objectives and treatments

The implementation of an irrigation advice system in order to give tools and information to farmers of the plain of Muga has to take into account the real demands of evapotranspiration of the main crops of the area, and to take advantage of soil water content created by spring and summer rains which can be known due to different sensors installed in the kinds of soil of the zone.

These irrigation recommendations are distributed weekly by email during the maize and alfalfa irrigation seasons. Recommendations include crop evapotranspiration details (based on daily measurements over the last 15 days and also including a week's prediction), precipitation (last 15 days and 7 days prediction), in addition to soil humidity information gathered on implemented plots.

On test plots, during the growing season, soil water content and weather conditions will be monitored in order to develop an irrigation schedule. Also, pesticides, fertilizers and energy use (fuel, electricity and laborers) will be recorded. At the end of the assay, yield will be evaluated as fresh and dry weigh of collected products.

2.1.1.2 Monitoring summary

This irrigation advice system helps to connect each farmer's plot with a specific AWC (available water capacity), determined and classified as medium or high, according to Agriculture Department (AD)'s soil map.

Irrigation starts when readily available or usable soil water (UW) is depleted. The UW is measured by soil water sensors installed in representative plots of each established plot of AWCs.

On traditional irrigated plots, the suggested date for next irrigation will be provided when Etc values minus effective precipitation reach UW values for each soil type. In drip irrigation plots, a high frequency irrigation (1-3 days) is applied, therefore quantity of needed water will be the Etc value minus effective precipitation of the period.

Success of this activity depends on having the support of agricultural organizations within the territory, especially the Cooperativa of Castelló d'Empúries, and irrigation communities of the right and left banks of the Muga.

2.2 Ter Watershed

The Lower Ter irrigated lands are situated in the alluvial plain of the Ter river, between the regions of Gironès and Baix Empordà. Their surface is about 9000 ha and they are managed by four different irrigation communities: Presa de Colomers, Molí de Pals, Regadius de Sant Julià de Ramis, Medinyà, Cervià de Ter, Sant Jordi Desvalls, Colomers i Jafre, and la Sèquia Vinyals.

All communities collect surface water from the lower course of the Ter river through a dam, and they distribute the water by gravity to various plots pertaining to 24 political localities. Despite having major water concessions, these communities usually consume less water than attributed, about 70 Hm^3 of water. Outside the field of the irrigation communities there are agricultural lands irrigated by wells which collect water from the plain's fluvio-deltaic aquifer of the Ter river.

Main crops of the area dominated by surface water irrigation are: maize (31%), other cereals (19%), alfalfa (6%), fruit trees (12%), rice (15%), nurseries of ornamental plants (3%), and other minority products or those not registered in DUN 2013 (Declaration of eligible agricultural area for Common Agricultural Policy payments, Catalonian Government; annual) (Figure 2).

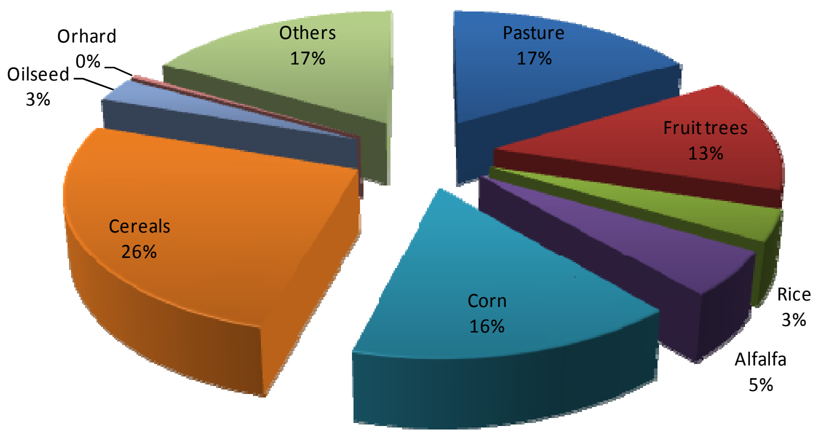

Figure 2: Crops distribution according to DUN 2013in the Lower Ter irrigation communities.

Some of the irrigation structures are medieval, but recently different modernization projects have been underway, affecting the Presa de Colomers and the Molí de Pals. These projects have improved water intakes and have replaced the open soil channels with fibrocement or PVC pipes.

The investment of about 30 million euros has allowed a first step in modernization and the only remaining task is the improvement of the secondary pipes of sèquia Vinyals.

Water distribution in each plot determines actions taken by the irrigation communities. Although information about good irrigation practices is vital for planning water allocations in the different parts of the irrigation community structure were water is distributed, this information is still lacking.

Encouraging the transformation of traditional irrigation can allow communities to change water management which promotes a reduction in water consumption of crops, without affecting productive potential, and also providing better services to irrigators. For example, adding pressure to irrigation water systems could allow the use of drip irrigation systems on permanent crops (fruit trees) or annual row crops (corn).

Despite changes in irrigation infrastructures and management improvements for almost ten thousand plots in Lower Ter irrigation communities, achieving the target improvement of irrigation efficiency and sustainability is still difficult. An important goal is to sensitize agricultural producers about being more efficient in production processes, in the same way that the improvement of farm management has been done in last decades.

In this context, the main objective of the Life+ MEDACC demonstrative activities is to demonstrate the economic and technical viability of drip irrigation systems in corn among Lower Ter irrigators. This is based on a demonstration test comparing the traditional irrigation system and drip irrigation, using both economic and technical perspectives.

2.2.1.1 Management objectives and treatments

We will choose one maize plot in the study area and this will be divided into two areas: one part will be irrigated using the traditional system and the other will use a drip irrigation system (Figures 3 and 4).

The traditional irrigated part will be irrigated based on the agriculturist's judgment, while drip irrigation zone will be irrigated following the advice of GIROREG 2014, which describes crop water requirements based on evapotranspiration reference (ETo) and soil water readings obtained from selected plots with well-known edaphic data.

Drip irrigation system will be installed with an irrigation head with, at least, a volumetric counter, a manometer and a valve. At the same time, in the drip irrigation area, 3 FDR sensors will be installed to measure soil water content. Sensors will be connected to a data logger which reads every 15 minutes. Sensors will be placed at different soil depths (15, 30 and 45 cm).

In the traditional irrigated zone, water consumption will also be measured, and soil water content will be measured by 2 FDR sensors connected to data loggers. The frequency of measurement will be also be every 15 minutes, and sensors will be placed at 30 and 60 cm depth.

The differences in the depths at which soil water content is measured is due to the use of different soil bulbs developed from water supply methods.

During the growing season soil water content and weather conditions will be monitored in order to develop an irrigation schedule. Also, pesticides, fertilizers and energy (fuel, electricity and laborers) will be recorded. At the end of assay, yield will be evaluated as fresh and dry weight of collected products.

Figure 3 and 4: Details of drip irrigation system for maize (3) in contrast with the traditional irrigation system (4).

All operations done on this plot will be documented and there will be technical and economical monitoring of each sub-plot, providing the basis for explanations about benefits and handicaps of this efficient irrigation system (drip irrigation).

To carry out this demonstrative activity we have the support of the irrigation communities of:

- Presa de Colomers,
- Molí de Pals
- Sant Julià de Ramis, Cervià de Ter, Sant Jordi Desvalls, Colomers and Jafre.

2.3 Segre Watershed

Viticulture is very sensitive to climate and changes in wine production have been used as a proxy to elucidate past climate change. Temperature and moisture regimes are among the primary elements of *terroir*, the most important characteristic of a wine. The growing season temperature is important for delimiting regions suitable for growing wine grapes (*Vitis vinifera*). Mediterranean climate regions (warm and dry summers; cool and wet winters) are particularly suitable for viticulture, while at the same time are global biodiversity hotspots based on the high levels of biodiversity, endemism, and their level of threat by human pressure and habitat loss.

Vineyards have long-lasting effects on habitat quality and may significantly impact freshwater resources. Vineyard establishment involves removal of native vegetation, typically followed by deep plowing, fumigation with methyl bromide or other soil sterilizing chemicals, and the application of fertilizers and fungicides. Mature, producing vineyards have low habitat value for native vertebrates and invertebrates, and are visited more often by non-native species. Thus, where vineyards are established, how they are managed, and the extent to which they replace native habitats have large implications for conservation.

Water use by vineyards can conflict with conservation of freshwater habitats. In a warming climate, water use may increase as vineyard managers attempt to cool grapes on the vine to reduce quality loss from heat stress and to reduce drought stress.

Potential damage to freshwater environments is generally highest where water is already scarce. Climate change may cause decreases in precipitation in some regions, increasing irrigation needs, which may result in impacts on freshwater ecosystems.

Traditional vineyard irrigation may moderate or accentuate these water use issues. Overall, how vineyards are established and managed is important for conservation, and these systems may be significantly impacted by climate change (Hannah et al., 2013).

In this context, the Life MEDACC project proposes two different demonstrative activities in the Segre watershed: 1) the RAIMAT assay and 2) the Bodegas Miguel Torres assay.

2.3.1 RAIMAT assay

In order to reduce the water use and consumption of other resources in vineyards, a strategy using a mulching treatment should be taken into consideration (Pinamonti 1998; Chan et al. 2010; Zhanga et al 2014). Also, the development of new vegetative and reproductive structures in deciduous perennial crops such as vines following winter dormancy is very sensitive to soil temperatures. For this reason, in early spring root zone temperature is important to mobilize water, nutrients and reserve carbohydrates from the rhizosphere, and first from roots to buds, then to leaves, to flowers, etc. But if temperatures are too high root respiration can use a significant amount of reserves which reduces growth of new structures (Rogiers et al. 2013).

2.3.1.1 Management objectives and treatments

The assay will be located in an experimental plot in Raïmat (Lleida, Spain). The location (Figure 5) is within the Segre watershed (13.000 km^2), which is the most important agricultural area of Catalonia (4.420 km^2), with 1.400 km^2 under irrigation.

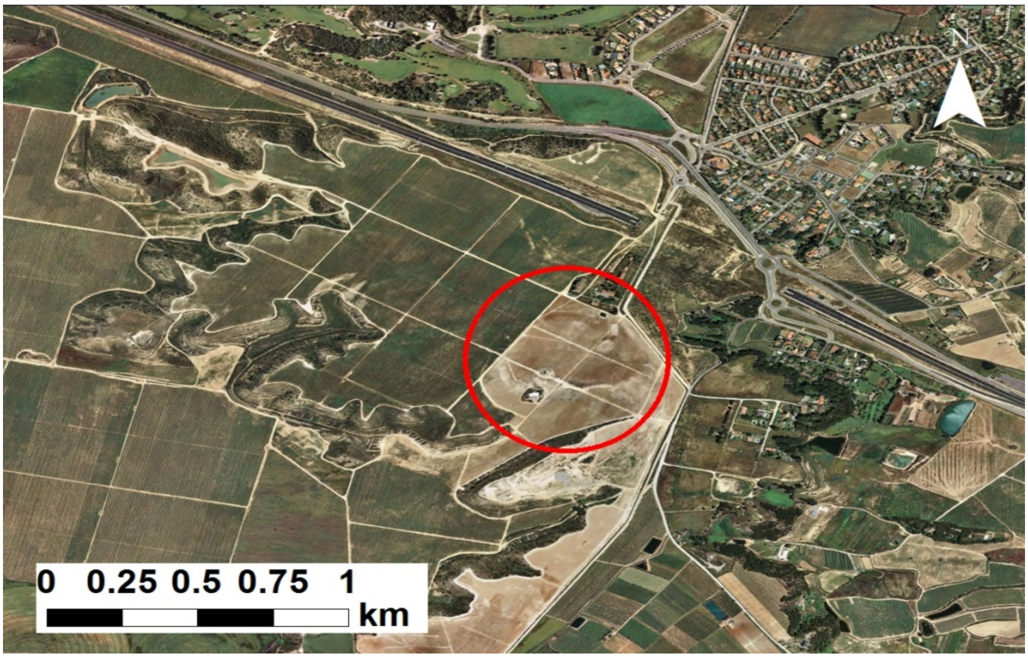

Figure 5: RAIMAT plot location

The vineyard is property of Raïmat, a part of Codorniu Group, (41º 39’ 40.30”N, 0º 31’ 4.23”E) at 300 m altitude. The lands form part of the Costers del Segre D.O. (Designation of Origin), which are very varied, ranging from plains to hillsides (figure 5). The area has a marked continental climate characterized by temperature extremes.

This very dry area (rainfall around 300 mm/year) was positively affected by the building of the Aragon and Catalonia Irrigation Channel in 1910, which permitted the irrigation of these vineyards.

Despite this resource, climate change is expected to reduce the water availability and to increase the crop water demand, promoting large water deficits and productivity losses.

The objective of this demonstrative activity is to evaluate the effects of mulching on crop water availability and the effects on productivity. We will perform two parallel experiments:

A. - Assay in a new vineyard plantation

The assay will be conducted in a new plantation of Cabernet Sauvignon variety grafted onto 110R rootstock, irrigated with a dose of 235 mm/year. The crop will receive a fertilization input of 28 N, 65 K, 15 P fertilizer units. This will be planted in March of 2015.

Two mulching treatments will be evaluated, control without mulching, and organic mulching. There will be 3 replicates of 10 plants in every treatment.

Evaluated parameters will be:

1) Soil water content by means of 3 volumetric water content sensors distributed in every replication of each treatment. This parameter will be recorded weekly

2) Plant survival and growth: survival and vine trunk diameter of young vines will be recorded during the season in order to assess the effects of treatment in vineyard establishment

B. - Assay in an adult vineyard plantation

The assay will be conducted in a vineyard of 4-year old Cabernet Sauvignon grafted onto 110-R rootstock (figure 6), irrigated with a dose of 235 mm/year. The crop will receive a fertilization input of 28 N, 65 K, 15 P.

Figure 6: General view of mulching assay in the vineyard plot

Three mulching treatments will be evaluated: control without mulching, organic mulching and BASF mulching film. There will be 3 replicates of 10 plants in every treatment.

Evaluated parameters will be:

1) Soil water content by means of 3 volumetric water content sensors distributed in every replication of each treatment. This parameter will be recorded weekly

2) Yield (kg/ha) and basic grape quality parameters (sugar content at 20º BRIX, pH and total tartaric acidity (TTA, g/l)) at harvest

3) Pruning weight

2.3.2 Bodegas Miguel Torres assay

Shifting patterns of agricultural production in response to climate change have received little attention as a potential pathway of impact on ecosystems. Wine grape production provides a good test case for measuring indirect impacts mediated by changes in agriculture, since viticulture is sensitive to climate and is concentrated in Mediterranean climate regions that are global biodiversity hotspots.

Climate change may cause establishment of vineyards at higher elevations, increasing impacts on upland ecosystems and possibly leading to conversion of natural vegetation as production shifts to higher latitudes in areas such as the Pyrenees. Attempts to maintain wine grape productivity and quality in the face of warming may be associated with increased water use for irrigation and cooling of grapes through misting or sprinkling, creating a potential for impacts on freshwater conservation. Agricultural adaptation and conservation efforts are needed that anticipate these multiple possible indirect effects.

2.3.2.1 Management objectives and treatments

The demonstrative assay has been located in Finca San Miguel (Bodegas Miguel Torres, figure 7) with an area of 202 ha located in the Sierra de Gurb (Lleida, Spain), in the municipality of Tremp at 950m altitude. This assay is located on 124 ha of vineyards developed in the late twentieth century. It was established with the intention of growing the vineyard in colder weather as an adaptative strategy to future climatic conditions.

The current average rainfall is 650 mm with maximum precipitations in spring and autumn. The average annual temperature is 13ºC; the coldest month is January with an average temperature of 3ºC and the warmest July with 24ºC. The soil is calcareous soil with deposits of gravel.

The cultivated varieties are mainly Sauvignon Blanc, Riesling and Chardonnay (white) and Merlot and Pinot Noir (black), grafted on SO4 and R110 rootstocks, planted at 2.20 x 1 m. The conduction/ pruning system is mostly Royat 2 buds and 6 heads and buds, but there is Guyot in some specific plots. Fertilization and drip irrigation are applied by crop demand. Yield is between 4000-5000 kg/ha.

Figure7: General view of altitude assay in Finca Sant Miquel

The objective of this demonstrative activity is to obtain information about the response of short cycle varieties to cool climates, because excessive temperature can reduce the quality of the grapes.

In this sense, this demonstrative plot will be compared with others placed in warmer areas at lower altitudes.

Evaluated parameters will be:

1) Yield (kg/ha) and basic grape quality parameters (sugar content at 20º BRIX, pH and total tartaric acidity (TTA, g/l)) at harvest
2) Pruning weight
3) Phenological changes

2.4 Agriculture indicators for field protocols

	Variable	Goal	Indicator	Thresholds that indicates a positive trend	Means
Agriculture	Growth and productivity	Ensure current average crop growth and productivity	Relative growth rate	>= 0	By measuring crop diameter in the case of woody crops, and height in the case of herbaceous crops, monthly or more depending on crop life span and seasonality.
			Crop yield		By measuring fresh/dry weight of fruits collected in the plot depending on crop life span.
			Crop quality		By using quality standards for fruits (size and colour).
	Health	Improve health status	Pest infection	< AV (*)	By measuring field samples and pesticide applications.
	Water use	Decrease in water use	Volume of water used	<= 5-10%	By using water meter of the plot pipe system.
	Fertilization needs	Decrease in fertilizers needs	Amount of fertilizers used	< AV (*)	By documenting amount of fertilizer used in each campaign.

	Variable	Goal	Indicator	Thresholds that indicates a positive trend	Means
	Laborers and energy needs	Decrease in labor and energy needs	Number of laborers and fuel amount used	< AV (*)	By counting the number of laborers and the amount of fuel used in each campaign.

(*) AV = Actual value

3. Forest.

3.1 Muga Watershed

3.1.1 Holm oak forests (Quercus ilex)

3.1.1.1 Management objectives and treatments

As described in the project proposal, the objective of the demonstrative activities is to demonstrate and quantify how management can make forest less vulnerable to climate change impacts. Management practices will address three main objectives: reduction of forest water stress and fire risk and increase of wood production/carbon sequestration, when possible. In the case of Holm oak, adaptive management practices will mainly be thinning (to different degrees and using different strategies), in order to reduce tree density and to promote mature structures with bigger trees and fuel discontinuity.

In the selected area, three pilot treatment areas of approximately 1 hectare have been assigned to different adaptive management practices. The C plot is the control plot, with no intervention. Two management strategies will be compared: T1 will be a low thinning to adapt the forest to a regular structure. T2 will be a selection system in order to adapt the forest to an irregular structure and to stimulate forest regeneration.

3.1.1.2 Monitoring summary

The forest pilot in Muga watershed is located in a Holm oak forest in the lower part of the Eastern Pyrenees (Natural Protected Area of l'Albera), specifically, in the Requesens estate. It is a private estate within the municipality of Jonquera (Girona province). It is close to the sea, near the Spain-France border. Coordinates (Lat, Long): 42.436001, 2.941144. Altitude: 400 masl.

This is a summary of the monitored variables in the Muga forest pilot.

Information type	Methods	Variables	Frequency
Forest structure	Forest inventory	Tree density Diametric class distribution Tree height Understorey biovolume Resprouting	Initial, following treatment and yearly survey
Forest fuel continuity	Fuel identification and classification: surface fuel, ladder fuel, aerial fuel	Fuel type cover (%) Fuel height (m) Distance between fuel types (m)	Initial, following treatment and yearly survey
Fuel moisture	Forest fuel sampling	Relative water content (RWC)	Seasonal and twice a month (summer)
Soil moisture	TDR Time-domain reflectometry method	Soil water content (SWC)	Seasonal and twice a month (summer)
Stand temperature and relative humidity	Sensor measurements	Temperature and relative humidity	Continuous
Site meteorological conditions	Meteorological station	Maximum temperature, minimum temperature, rainfall and radiation	Continuous

3.1.1.3 Data collection description

Forest inventory

In each treatment and control, three circular plots (radius 10 m) have been defined for the stand inventory. Plot location in each treatment area is uniformly distributed and pre-assigned in a map. The central point of these plots will remain marked for periodic surveys. In each plot, the number of trees/resprouts of each species is counted and the diameter at breast height (DBH) and the height of each tree is measured. In addition, two strip biomass transects (10 m) to estimate understorey biovolume are defined in each plot. In each transect, the maximum height and cover of shrubland species are measured in 50x50 cm quadrat plots.

Fuel identification and classification

Using a field key, forest fuel cover, height and the distance between fuel types are estimated. The key determines the role of surface fuel, ladder fuel and aerial fuel in the vertical/horizontal fuel continuity in the stand. This method is based on CVFoC Manual (Piqué et al. 2011).

Fuel moisture sampling

A sample of branches from 5 random trees and shrubs is collected through a Fiberglass Pruning Pole (Jameson JE). The samples are conserved in a cool-box until processing in the laboratory. In the laboratory samples are weighed to obtain fresh weight (W), after which the sample is immediately hydrated to full turgidity for 4h under normal room light and temperature. After 4 hours the samples are taken out of water and are quickly and lightly dried of any surface moisture using filter paper, and immediately weighed to obtain fully turgid weight (TW). Samples are then oven dried at 80 ºC for 24h and weighed to determine dry weight (DW). This allows the determination of relative water content:

RWC (%) = [(W-DW) / (TW-DW)] x 100, where W is sample fresh weight, TW is sample turgid weight and W is sample dry weight.

TDR Time-domain reflectometry method for soil moisture measurement

Soil water content (SWC) is assessed every season and twice a month (during summer period) using a time-domain reflectometry (TDR) device (Tektronix 1502C, Beaverton, Oregon, USA) (Gray & Spies, 1995). Three stainless steel cylindrical rods, 15 cm long, are permanently left fully driven into the soil at five selected points uniformly distributed in each treatment area (15 sensors per area). The time domain reflectometer was connected to the ends of the rods in each measurement.

Sensor measurements of stand temperature and relative humidity

In each monitored treatment area, 5 temperature and relative humidity data loggers (HOBO Pro v2 (U23-001) by Onset Computer Corporation) are installed to register data from TDR sensors. These HOBO loggers are located 130 cm above the ground. The recording interval was set to 60 min.

Meteorological station

Daily values of meteorological variables, including maximum temperature, minimum temperature, rainfall, radiation and wind speed are calculated through hourly data recorded by an automatic weather station, a Vantage Pro2 Station (Davis Instruments, Hayward, California, USA).

3.2 Ter Watershed

3.2.1 Scots pine forests (Pinus sylvestris)

3.2.1.1 Management objectives and treatments

As described in the project proposal, the objective of the pilot experiment is to demonstrate and quantify management which can make the forest less vulnerable to climate change impacts. Management practices will address three main objectives: reduction of forests water stress, improvement of tree health status, and increase of wood production/carbon sequestration (when possible). In the case of this pilot forest experiment, adaptive management practices will be mainly understorey clearing and thinning in order to reduce tree competition. In addition, another pilot experiment objective is to assess the possibility of oak replacement of Scots pine under conditions of climate change.

In the selected area, four pilot treatment areas of approximately 1 hectare have been designed according to different adaptive management practices. The C plot is the control plot, with no intervention. Three management strategies will be compared: T1 and T2 will be different understorey clearing intensities in Scots pine forests. T3 will be a treatment to accelerate the replacement of Scots pine by oak.

3.2.1.2 Monitoring summary

The forest pilot in Ter watershed is located in a Scots pine (*Pinus sylvestris*) forest in the Pyrenean foothills region, specifically, in Montesquiu Castle Park (protected natural area). It is a public estate pertaining to the Diputació de Barcelona (province government) in Montesquiu Municipality (Barcelona province). Coordinates (Lat, Long): 42.116028, 2.217342. Altitude: 700 masl.

This is a summary of the monitored variables in the Ter forest pilot.

Information type	Methods	Variables	Frequency
Forest structure	Forest inventory	Tree density Diametric class distribution Tree growth Tree height Understorey biovolume Regeneration	Initial, following treatment, and yearly survey
Forest health status	Forest decline identification key	Mortality (%) Defoliation (%) Foliage discoloration (%)	Initial, following treatment and yearly survey
Soil moisture	TDR Time-domain reflectometry method	Soil water content (SWC)	Seasonal and twice a month (summer)
Stand temperature and relative humidity	Sensor measurements	Temperature and relative humidity	Continuous
Site meteorological conditions	Meteorological station	Maximum temperature, minimum temperature, rainfall and radiation	Continuous

3.2.1.3 Data collection description

Forest inventory

In each treatment and control, three circular plots (radius 10 m) for stand inventory have been defined. Plot location in each treatment area is uniformly distributed and pre-assigned in a map. The central point of these plots will remain marked for periodic surveys. In each plot, the number of trees of each species is counted and the diameter at breast height (DBH) and the height of each tree is measured. Also, two strip biomass transects (10 m) to estimate understorey biovolume are defined in each plot. In each transect, the maximum height and cover of shrubland species are measured in 50x50 cm quadrat plots. Regeneration is estimated by counting saplings in a subplot of 3 m radius centered in the inventory plot. Tree growth is measured by core sampling of 5 trees at the end of the project.

Forest decline

Using a field key, stand decline status is assessed through visual estimation of tree mortality percentage (dried crowns), defoliation percentage (non-present leaves in relation of leaves present on a healthy tree) and foliage discoloration percentage (non-green leaves in relation of green leaves on a healthy tree). This field identification method is based on the DEBOSCAT project (Banqué et al, 2013) and the Spanish Forest Monitoring Network (Level II www.magrama.gob.es).

TDR Time-domain reflectometry method for soil moisture measurement

Soil water content (SWC) is assessed every season and twice a month (during summer period) using a time-domain reflectometry (TDR) device (Tektronix 1502C, Beaverton, Oregon, USA) (Gray & Spies, 1995). Three stainless steel cylindrical rods, 15 cm long, are permanently left fully driven into the soil at five selected points uniformly distributed in each treatment area(15 sensors per area). The time domain reflectometer was connected to the ends of the rods in each measurement.

Sensor measurements, stand temperature and relative humidity

In each monitored treatment area, 5 temperature and relative humidity data loggers (HOBO Pro v2 (U23-001) by Onset Computer Corporation) are installed to record data from TDR sensors. These HOBO loggers are located 130 cm above the ground. The recording interval was set to 60 min.

Meteorological station

Daily values of meteorological variables, including maximum temperature, minimum temperature, rainfall and wind speed are calculated in hourly data recorded by an automatic weather station pertaining to the Agro-meteorological Network of Catalonia (XAC, www.meteocat.cat).

3.3 Segre Watershed

3.3.1 European black pine forests (Pinus nigra)

3.3.1.1 Management objectives and treatments

As described in the project proposal, the objective of the pilot experiment is to quantify and demonstrate that management can make forest less vulnerable to climate change impacts. Management practices will address three main objectives: reduction of fire risk, reduction of water stress of forests, and increase in wood production/carbon sequestration (when possible). In the case of this pilot forest experiment, adaptive management practices will be mainly clearing and thinning in order to reduce tree competitiveness.

In the selected areas, five pilot treatment areas (corresponding to different stands) of approximately 1 hectare have been designed according to different adaptive management practices. The C plot is the control plot, with no intervention. In Llobera forest pilot, two management strategies will be compared: T1 will be selective understorey clearing and low thinning and T2 will be selective clearing and intensive tree thinning. In Madrona, T1 will be understorey selective clearing, and T2, in addition to selective clearing, will also have intensive tree thinning.

3.3.1.2 Monitoring summary

The forest pilot in Segre watershed is located in two different European black pine (*Pinus nigra*) forests in the Pyrenean foothills region, specifically, in the Solsonès region. They are private estates called Madrona (in Pinell del Solsonès municipality) and Llobera (Llobera municipality), both in the province of Lleida(Fig. 35). Coordinates (Lat, Long): Llobera: 41.951635, 1.469974. Altitude: 800 masl. Madrona: 41.968325, 1.336292. Altitude: 500 masl.

This is a summary of the monitored variables in the Segre forest pilot.

Information type	Methods	Variables	Frequency
Forest structure	Forest inventory	Tree density Diametric class distribution Tree height Understorey biovolume Regeneration Mortality (%)	Initial, following treatment and yearly survey
Forest fuel continuity	Fuel identification and classification: surface fuel, ladder fuel, aerial fuel	Fuel type cover (%) Fuel height (m) Distance between fuel types (m)	Initial, following treatment and yearly survey
Fuel moisture	Forest fuel sampling	Relative water content (RWC)	Seasonal and twice a month (summer)
Soil moisture	TDR Time-domain reflectometry method	Soil Water content (SWC)	Seasonal and twice a month (summer)
Stand temperature and relative humidity	Sensor measurements	Temperature and relative humidity	Continuous
Site meteorological conditions	Meteorological station	Maximum temperature, minimum temperature, rainfall and radiation	Continuous

3.3.1.3 Data collection description

Forest inventory

In each treatment and control, three circular plots (radius 10 m) for stand inventory have been defined. Plot location in each treatment area is uniformly distributed and pre-assigned on a map. The central point of these plots will remain marked for periodic surveys. In each plot, the number of trees of each species is counted and the diameter at breast height (DBH) and the height of each tree is measured. Also, two strip biomass transects (10 m) to estimate understorey biovolume are defined in each plot. In each transect, the maximum height and cover of shrubland species are measured in 50x50 cm quadrat plots. Regeneration is estimated by counting saplings in a subplot of 3 m radius centered in the inventory plot. The inventory includes forest health status (% mortality).

Fuel identification and classification

Using a field key, forest fuel cover, height and the distance between fuel types are estimated. The key determines the role of surface fuel, ladder fuel and aerial fuel in the vertical/horizontal fuel continuity in the stand. This method is based on the CVFoC Manual (Piqué et al. 2011).

Fuel moisture sampling

A sample of branchesfrom 5 random trees and shrubs is collected through a Fiberglass Pruning Pole (Jameson JE). The samples are conserved in a cool-box until processing in the laboratory. In the laboratory samples are weighed to obtain fresh weight (W), after which the sample is immediately hydrated to full turgidity for 4h under normal room light and temperature. After 4 hours the samples are taken out of water and are quickly and lightly dried of any surface moisture using filter paper, and immediately weighed to obtain fully turgid weight (TW). Samples are then oven dried at 80 ºC for 24h and weighed to determine dry weight (DW). This allows the determination ofrelative water content:

RWC (%) = [(W-DW) / (TW-DW)] x 100, where W is sample fresh weight, TW is sample turgid weight and W is sample dry weight.

TDR Time-domain reflectometry method for soil moisture measurement

Soil water content (SWC) is assessed every season and twice a month (during summer period) using a time-domain reflectometry (TDR) device (Tektronix 1502C, Beaverton, Oregon, USA) (Gray & Spies, 1995). Three stainless steel cylindrical rods, 15 cm long, are permanently left fully driven into the soil at five selected points uniformly distributed in each treatment area (15 sensors per area). The time domain reflectometer was connected to the ends of the rods in each measurement.

Sensor measurements of stand temperature and relative humidity

In each monitored treatment area, 5 temperature and relative humidity data loggers (HOBO Pro v2 (U23-001) by Onset Computer Corporation) are installed to register data from TDR sensors. These HOBO loggers are located 130 cm above the ground. The recording interval was set to 60 min.

Meteorological station

Daily values of meteorological variables, including maximum temperature, minimum temperature, rainfall, radiation and wind speed are calculated through hourly data recorded by an automatic weather station, a Vantage Pro2 Station (Davis Instruments, Hayward, California, USA).

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