Adapting Mediterranean forests to the effects of climate change by modifying management

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This article presents two trials, undertaken within the framework of the European Med ForClimadapt project, involving forestry management measures to facilitate the adaptation of Mediterranean forest stands to worldwide climate change: reducing their vulnerability to massive forest fires; promoting diversity in single-species forests.

Worldwide climate change: potential impact on Mediterranean forests

Of all the world's bioclimatic regions, the Mediterranean area is considered to be one of the most vulnerable to global climate change (EEA, 2008). Apart from the climatic aspect, the Mediterranean regions are stamped by a combination of socio-cultural characteristics which, when it comes to foreseeing the possible impact of climate change, add enormous complexity.

To be able to foresee the negative effects of worldwide climate change on Mediterranean forests and woodlands, it is necessary to take into account their vulnerability. This vulnerability depends as much on the nature and magnitude of the change as on the forests' sensitivity and capacity to adapt. Consequently, any impact will be a function of the species involved, its geographical situation, the history of its management, its present state etc.

The foreseeable impact of worldwide climate change on the forests and woodlands of the Western Mediterranean has been discussed in many studies (ex. Camarero *et al.*, 2004; Peñuelas *et al.*, 2004; Resco *et al.*, 2007; Regato, 2008, Serrada *et al.*, 2011). Some of the most serious negative effects include overall weakening of the stands, degeneration and mortality, problems of regeneration and the frequency and intensity of massive forest fires.

In every case, the relationship between the factors involved in climate change and their negative effects is not obvious for either element, i.e. a given factor can generate various effects and, conversely, a given impact can result from the combined effect of several factors linked to climate change. Thus, it is vital to stress the strong inter-relationship and the retro-action which exist between the various effects, as well as the importance of a perspective which combines the phenomenon of climate change itself with the measures required for adapting to it (Vericat *et al.*, 2012).

Pictures 1 & 2: Silvicultural operations and models for developing forests with greater resilience and resistance to crown fires are presented to the partners in the ForClimadapt project by Miriam Piqué (CTFC) (October 2012).

Examples of measures in forestry management for the adaptation of Mediterranean forests to climate change

Among the main group of management measures that can be taken for adaptation to climate change, of particular note are: intervention favouring a stand's enhanced vitality and capacity for regeneration, action to reduce the forests' vulnerability to wildfire, reinforcement of a heterogeneous profile as regards the structure and make-up of the stands, landscape etc.

In what follows, this article describes two experiments, carried out within the framework of the Med ForClimadapt project, on measures in forestry management for the adaptation of Mediterranean forests and woodlands to worldwide climate change; specifically, measures to reduce vulnerability to massive wildfire and measures fostering greater diversity in the forests' make-up and functions.

Reducing vulnerability to massive wildfire

Aims of the experiment

The overall aim of this experiment was to set up and develop by field trials the guidelines and silvicultural operations for the enhancement of a forest's resistance and resilience when subjected to natural disturbances brought on by massive wildfire.

The objective of the guidelines is to significantly hinder the vertical spread of the fire from the ground up to the canopy, to reduce the intensity of the wildfire along with its rate of spreading, and to maintain low costs of intervention and maintenance.

Materials and method

Area under study

The area studied was 9.5 ha in the catchment area of the Rialb in the Lower Pyrenees region of Catalonia (Spain). The forests are generally made up of Spanish black pine stands (*Pinus nigra* Arn. ssp. *salzmannii*), both pure and mixed with oaks (*Quercus faginea* Lam.) or evergreen holm oak (*Quercus ilex* L.). On the whole, the

stands have lost their value as equity on account of longstanding intensive exploitation for timber or firewood. The current average growth rate is fairly low, around 2 m^3/ha/yr, with annual rainfall close to 700 mm/yr.

Pilot area and data gathering

Several strategic locations within the catchment area were identified by a team from the GRAF (specialised forest unit belonging to the Catalonia fire brigade). These key spots in the development of massive forest fires (MFF) are crucial in the firefighting operations to put out the wildfire. They are determined by the ground cover and the current structure of the stands, along with topographical details and positioning.

These strategic spots have been ranked in order of priority for intervention, the last pilot area listed representing the most important strategic location in the entire catchment area vis-à-vis the improved prevention of MFF.

After the pilot area had been described, an inventory was carried out to assess the vulnerability to the risk of a crown fire (Piqué e*t al.*, 2011) by measuring several of the stands' structural variables such as the amount of combustible matter in the ladder i.e. the cover by storey or horizontal layer (%), distance from the ground level or higher storeys to the crown fuel (m), distance from the ground level fuel to the different storeys, amount of crown fuel (%) and amount of fuel in the ground cover (%).

A plot was also chosen on which to gather the data specific to fuel types which are required in the use of the NEXUS simulator.

Conception of guidelines for forestry management and silvicultural intervention

Using the data from a stand along with other available information made it possible to define the desired low-vulnerability structure. This structure featured the concrete data on the total cover represented by the fuel storeys, or horizontal layers, and the distances between them which, together, enable a stand to be classified in the category of stands that hinder or prevent the propagation of crown fires. Guidelines were drawn up for the definition of stand characteristics which will enable it to retain its low-level vulnerability throughout its growth and which include determination of the rotation period.

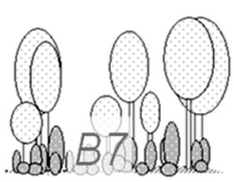
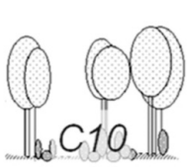
Results

Description of the stands before and after intervention

The differences in the characteristics of the stands were not significant whereas the vulnerability of the structure fell to low. Table 1 shows the defined structural parameters before and after silvicultural intervention. The two stands (pure and mixed) are repesented by these data. The structure bearing the code "C10" was identified as the desired low-vulnerability structure. Table 2 lists the instructions given to the workers in the light of the differences between the initial structure "B7" and the target structure "C10".

The total cost of the interventions was €859/ha, wages equivalent to 5 days work full-time.

Table 1:
Structural parameters measured before and after intervention

Initial structural parameters in relation to stand vulnerability		
Ladder fuel cover	25-70%	
Mean distance between ladder and crown fuels	<5 m	
Mean distance between surface and ladder fuels	<3 m	
Aerial fuel cover	50-70%	
Ground fuel cover	<60%	
		Medium vulnerability
Structural parameters desired in relation to stand vulnerability		
Ladder fuel cover	**<25%**	
Mean distance between surface and ladder fuels	<4 m	
Aerial fuel cover	50-70%	
Ground fuel cover	**<30%**	
		Low vulnerability

Treatments carried out
Reduction of ground and ladder fuels to a cover ≤30 %:
Selective clearings, affecting understory and small trees (D < 7.5 cm) with live crown under 1.3 m. *Keep small trees (priority for* Quercus *sp.), where there are no other trees near and no problem of vertical continuity.*
Elimination of broken trees (3-4 trees/ ha from D < 20 cm).
Management of slash from treatments:
Cut up slash with diameter > 5 cm into pieces 0.8 - 1 m long. Distribute the slash on ground, avoiding piles >30 cm.
Keep slash 10 m away from roads (Forest Fire Prevention Law).
Lopping/pruning *Quercus* sp. (approximately 200 trees/ha) in the case of stand 2:
Lop/prune the trees higher than 4 m, leaving live crown at 1.5-2 m, measured up-slope.

Table 2: Operational instructions to workers.

Simulation of behaviour faced with wildfire before, after and one year after silvicultural operation

In all situations, the differences in behaviour before, after and one year after were significant with wind speeds < 20 km/hr. Before the silvicultural operation, the simulation showed a passive crown fire. On the other hand, after the intervention the simulation showed a fire at ground level. The information for the case one year after treatment, compared to the case immediately after, showed that the layer of ground fuel became more compact over time; thus the ground fire developed even with strong winds (cf. Fig. 1).

Conclusions

This study assessed the efficacy of a silvicultural operation by evaluating the stands' reduction in vulnerability to the risk of wildfire. One year after the operation, the structure of the forest was less vulnerable to crown fire in comparison to immediately before and after the intervention. This state ensured greater protection for the whole area studied, first of all because the MFF was limited at a strategic location and, secondly, because the features established in this crucial location provided better possibilities for putting out the fire.

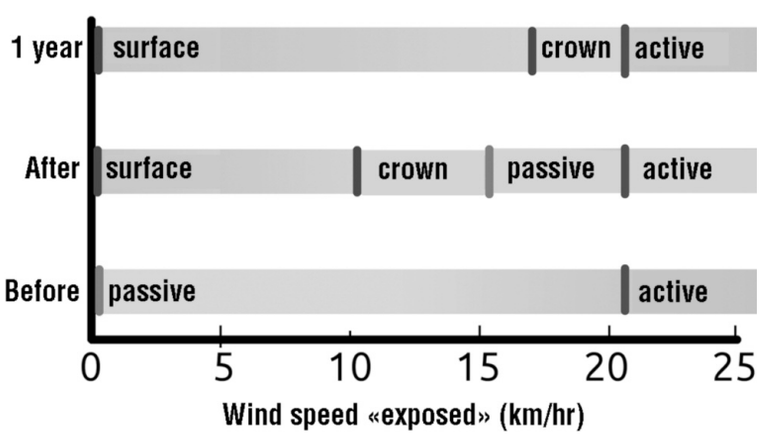


Figure 1: Assessment of the risk of crown fire for two cases: immediately after and 1 year after.

The main change in the state of the stands was the creation of gaps in the vertical continuum of fuel between the ground and the crown. The top storey was slightly affected but the stand thus helped maintain the principle characteristics of the trees. The structural vunerability in the event of a crown fire decreased. Additionally, the upper storey should make the future growth of shrubs and bushes more difficult.

In economic terms, the aim of efficiency was attained insofar as the overall costs were less than those for traditional fire prevention operations. However, as this type of silvicultural intervention differs from the tradition sort that also aims at fire prevention, previous training for the workers was necessary to ensure the work was well done. Concerning the cost of this type of operation, it is expected that the more its use is generalised, the less it will cost.

Promoting diversity in pure stands

Aims of the experiment

The idea was to establish an ensemble of enrichment stands within sub-Mediterranean forests in the north-east of the peninsula. The aim of the trial was to evaluate the capacity of response of the main broadleaved species accompanying sub-Mediterranean pine forests, considering both intra- and inter-species response, in various conditions of, principaly, luminosity, temperature and habitat.

Materials and method

Area under study and design of experiment

The plantations were established in the central Lower Pyrenees, around the River Sègre, in three forested mountain areas at middle altitudes (Figure 2). All three sites

face north and provide an altitude gradient going from 1,000 m to 1,600 m. The forest, taken as a whole, is undergoing a transition from pure pine forest (*Pinus nigra* Arn. ssp. *salzmannii*) to pure Scots pine (*Pinus sylvestris* L.). For each of the three sites, three levels of altitude were chosen: the lowest at 1,000 m; a middle altitude at 1,300 m; and a higher altitude at 1,600 m. On all three sites, two 12 m x 12 m plots were established, making sure that they spanned a broad range of luminosity.

The four broadleaved species with a capacity for regrowth appearing most frequently as accompanying species in the area were chosen for the stands: the evergreen holm oak (*Quercus ilex* L.), sessile oak (*Quercus faginea* Lam.), the downy (or white) oak (*Quercus pubescens* Willd.) and the service tree (*Sorbus aria* (L.) Crantz.). Among these species, two different provenances were selected, one local and the other more thermo-/xerophilic. Two other species were included: beech (*Fagus sylvatica* L.) and the kermes oak (*Quercus coccifera* L.) which, though they appear only occasionally on these sites or not at all, were planted to study the development of the beech growing in more drought-like climatic conditions than normally, and, in the case of the kermes oak (which generally grows in much drier conditions), to test its viability for planting in stands used for assisted migration.

Two-year-old plants were used for the planting except for the kermes oak whose seedlings were one year old. On each of the 18 plots, 7 repetitions, each with 10 combinations of species x provenance, were planted randomly throughout the plot on a square pattern of 1 m x 1 m.

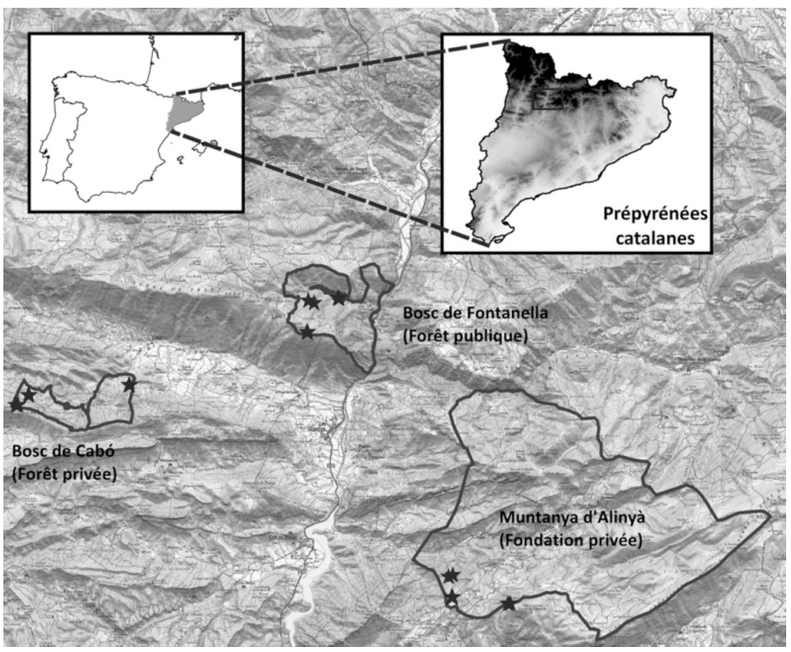


Fig. 2 & picture 3: Locations of the three forests and view of seedling.

First results

The partial results for survival after the first growing season are presented below but without any thorough analysis of the environmental factors affecting the plants (light, competition, immediate environs etc.); these will be measured during the growing seasons to come. During the first winter after planting, plant mortality reached 14.8%, affecting in large measure the beeches (39.2%), the kermes oak (29.4%) and the holm oak (especially the Mediterrean provenance with 39.7% mortality). This winter mortality was just as bad in the plots in the higher zones (cf. Table 3). Opening up the canopy did not generally have a big impact on mortality though, for the kermes and holm oaks, there was a higher rate in the open cover plots than in the closed.

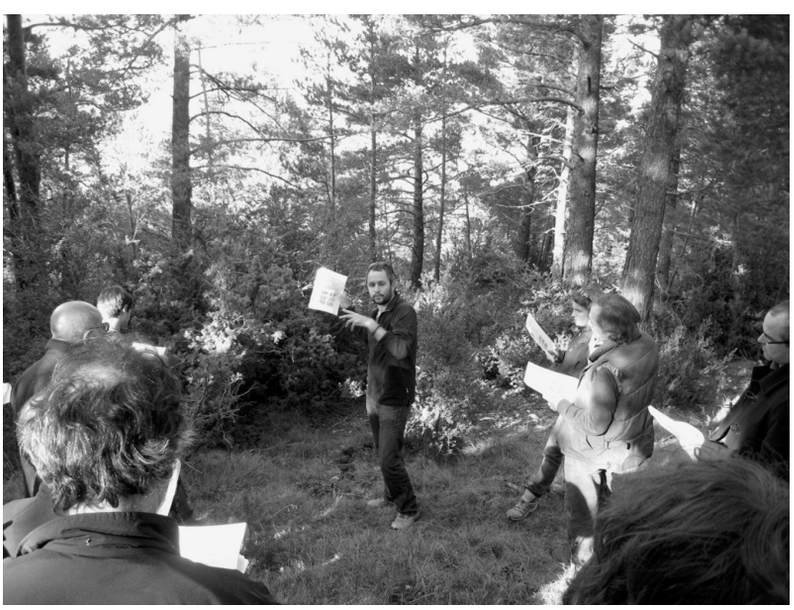
During the first growing season, plant mortality reached 10% overall (cf. Table 4), affecting in large measure the beech (32%), the sessile oak (12.7% for the local provenance and 19.8% for the Mediterranean provenance) and the downy oak of Mediterranean provenance (17.5%).

Species	*Fs*	*Qc*	*Qf*		*Qp*		*Qi*		*Sa*		Total
Provenance	L	L	L	M	L	M	L	M	L	M	
Highest level	16,0 %	18,3 %	3,2 %	4,0 %	2,4 %	4,8 %	6,4 %	20,6 %	0,0 %	1,6 %	7,7 %
Middle level	15,2 %	5,6 %	2,4 %	0,8 %	0,8 %	0,8 %	2,4 %	10,3 %	0,0 %	0,0 %	3,8 %
Lowest level	8,0 %	5,6 %	1,6 %	0,8 %	0,8 %	0,0 %	7,2 %	8,7 %	0,0 %	0,0 %	3,3 %
Total	39,2 %	29,4 %	7,1 %	5,6 %	4,0 %	5,6 %	16,0 %	39,7 %	0,0 %	1,6 %	14,8 %

Table 3:
Winter mortality by species and provenance (L : local, M : Mediterranean) in relation to altitude.
FS : Fagus sylvatica ; QC : Quercus coccifera ; Qf : Quercus faginea ; Qp : Quercus pubescens ; Qi : Quercus ilex ; Sa : Sorbus aria

Species	*Fs*	*Qc*	*Qf*		*Qp*		*Qi*		*Sa*		Total
Provenance	L	L	L	M	L	M	L	M	L	M	
Highest level	1,6 %	0,0 %	2,4 %	1,6 %	1,6 %	1,6 %	0,8 %	1,6 %	1,6 %	2,4 %	1,5 %
Middle level	9,6 %	0,0 %	3,2 %	9,5 %	0,8 %	4,8 %	1,6 %	0,8 %	0,0 %	1,6 %	3,2 %
Lowest level	20,8 %	0,8 %	7,1 %	8,7 %	0,0 %	11,1 %	0,8 %	4,0 %	0,0 %	0,0 %	5,3 %
Total	32,0 %	0,8 %	12,7 %	19,8 %	2,4 %	17,5 %	3,2 %	6,3 %	1,6 %	4,0 %	10,0 %

Table 4:
Summer mortality by species and provenance (L : local, M : Mediterranean) in relation to altitude.



Pictures 4 & 5:
Luis Coll presenting to the partners in the FORCLIMADAPT project the operational features permitting the enrichment of single-species pine stands. A very steep incline provides a gradient differential for measurements (October 2012).

Considering altitude, the lowest level was the most affected, the highest the least. Overall, summer mortality was observed mainly in plots with open cover.

Conclusions

This article presents the results of monitoring subsequent to the first growing season: for his reason, they should be interpreted cautiously. Even so, they show the beech's poor ability to adapt to these conditions (much arider than their usual conditions) and the difficulty for the kermes and holm oaks to survive at the higher altitudes. High rates of mortality were also recorded for beech, sessile and downy oak seedlings after a relatively dry summer period, particularly when they were growing without any protection from a canopy. These are the species with the greatest need for water and, with the progressive rise in the frequency of summer drought forecast in the context of climate change, their development in the study area may well be in doubt. A number of interesting patterns were also recorded which call for further close study in the coming years: the great capacity of the sessile oak of local provenance to reshoot in autumn after suffering from summer drought (not

shown here) and the major negative impact of summer drought on downy oak of Mediterranean provenance. Results from the growing seasons to come will confirm or refute the trends described.

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Summary

It is forecast that climate change will affect Mediterranean forests and woodlands in many ways. Consequently, the managers of these areas are faced with the need to take decisions aimed at enhancing the areas' capacity to adapt to such changes. This is the context which gave rise to the For Climadapt project (within the European MED programme). This article presents as examples two trials in the Lower Pyrenees of Catalonia with the double aim of reducing the vulnerability of forest stands to massive wildfire and enhancing the adaptability and resilience of forests by establishing an ensemble of enrichment stands within sub-Mediterranean single-species pine forests to improve their characteristics. In the first experiment, a number of silvicultural measures were carried out designed to interrupt the vertical continuity of combustible growth in pure and mixed stands of black pine (*Pinus nigra* Arn. ssp. *salzmannii*) and oaks (*Quercus faginea* Lam., *Quercus ilex* L.) The results of these measures, in terms of the behaviour of the wildfire, were assessed with the help of the NEXUS simulator which showed the efficacy of the operations in reducing the vulnerability of the stands under threat from crown fire (with wind speed below 20 km/h). In the second experiment, an ensemble of improvement stands using broadleaved species (*Sorbus aria, Fagus sylvatica, Quercus* sp. pl.) were established along an environmental gradient within single-species sub-Mediterranean pine forests. The first results show major differences between the species (and provenances) in the survival of the seedlings, depending on the environmental conditions of the plantations (as much climate as luminosity). Results from the growing seasons to come will confirm or refute the trends described.

Résumé

Il est prévu que les changements climatiques auront de nombreux impacts sur les peuplements forestiers méditerranéens. Les gestionnaires de ces espaces sont donc confrontés au besoin de prendre des décisions orientées pour améliorer leur capacité d'adaptation face à ces changements. C'est dans ce contexte que le projet ForClimadapt (programme européen Med) est né. L'article présente deux actions démonstratives conduites dans les Pré-Pyrénées catalanes visant d'une part la réduction de la vulnérabilité des peuplements forestiers face aux grands feux de forêt et, d'autre part, l'augmentation de l'adaptabilité et de la résilience des forêts par la réalisation d'un ensemble de plantations d'enrichissement en pinèdes sous-méditerranéennes monospécifiques. Dans la première expérience, un ensemble de traitements sylvicoles destinés à réduire la continuité verticale du combustible ont été réalisés dans des peuplements purs et mélangés de pin noir (*Pinus nigra* Arn. ssp. *salzmannii*) et chêne (*Quercus faginea* Lam., *Quercus ilex* L.) Le résultat de ces traitements en termes de comportement du feu a été abordé à l'aide du simulateur NEXUS qui a montré l'efficacité des actions concernant la réduction de la vulnérabilité des peuplements face au risque de feu de cime (en conditions de vent inférieures à 20 km/h). Dans la deuxième expérience, un ensemble de plantations d'enrichissement à l'aide d'essences feuillues (*Sorbus aria, Fagus sylvatica, Quercus* sp. pl.) ont été établies dans des pinèdes monospécifiques subméditerranéennes suivant des gradients environnementaux. Les premiers résultats des expériences montrent des différences importantes entre espèces (et provenances) dans la survie des plantules selon les conditions environnementales des sites de plantation (aussi bien climatiques que de disponibilité en lumière). Les résultats correspondant aux prochaines périodes de végétation permettront de confirmer ou réfuter les tendances décrites.

Resumen

Se prevé que los efectos del cambio climático produzcan importantes impactos en los bosques mediterráneos. Ante este contexto, mejorar la capacidad de adaptación de los bosques frente al cambio constituye uno de los principales retos a los que debe hacer frente el gestor forestal y el núcleo del proyecto ForClimadapt (programa europeo Med). El artículo presenta dos experiencias piloto realizadas en el Prepirineo catalán con el objeto de (1) reducir la vulnerabilidad de los bosques frente a los incendios forestales de alta intensidad y (2) aumentar la capacidad de adaptación y resiliencia de los pinares puros submediterráneos por medio de plantaciones de enriquecimiento. En la primera experiencia, se efectuaron un conjunto de tratamientos selvícolas orientados a romper la continuidad vertical del combustible en bosques puros y mixtos de pino laricio *(Pinus nigra* Arn. ssp. *salzmannii*), roble (*Quercus faginea* Lam.) y encina (*Quercus ilex* L.). El resultado de los tratamientos en términos de comportamiento del fuego se evaluó con la ayuda del simulador NEXUS que mostró la eficacia de las actuaciones en lo que concierne la reducción del riesgo de ocurrencia de fuegos de copas (en condiciones de viento inferiores a 20 km/ha). En la segunda experiencia, se establecieron un conjunto de plantaciones de enriquecimiento de 6 especies frondosas rebrotadoras (*Sorbus aria* L., *Fagus sylvatica* L., *Quercus* sp. pl.) a lo largo de un gradiente altitudinal y de luminosidad bajo tres pinares puros prepirenaicos. Tras el primer período vegetativo se observaron diferencias importantes entre especies (y procedencias) en la supervivencia de las plántulas en función de las condiciones ambientales en las que se establecieron. Los resultados procedentes de los siguientes períodos vegetativos permitirán confirmar o rechazar las tendencias descritas.