Climate change adaptation measures and recommendations for cork oak forests

Life+ SUBER

Life

Climate change adaptation measures and recommendations for cork oak forests

Climate change adaptation measures and recommendations for cork oak forests

Jointly published by
Forest Consortium of Catalonia (CFC), The Forest Ownership Centre (CPF), Forest Science and Technology Centre of Catalonia (CTFC), Amorim Florestal, SA.

Publication Coordinators
Roser Mundet (CFC), Teresa Baiges (CPF), Mario Beltrán (CTFC), Antonio Torrell (Forestal Catalana)

Project Manager
Joan Rovira (Forest Consortium of Catalonia)

Committee of Experts for the Project
Antoni Bombí (Barcelona Provincial Council), Francisco Carvalho (Amorim Florestal), Rosendo Castelló (CFC), Xavier Clopés (Ministry of Agriculture, Livestock, Fisheries and Food, DARP DARP by its Catalan acronym), Jaime Coello (CTFC), Enrique Enciso (Grupo Sylvestris), Juli Garcia (CIDE-CSIC), Antoni Gorgot (Forestal Empordà, SL), Joan Homs (CPF), Raúl Lanzo (CICYTEX-IPROCOR), David Meya (DARP), Renaud Piazzetta (Institut Méditerranéen du Liège), Joan Puig (Francisco Oller, SA), Josep M. Riba, Josep M. Tusell (CFC), Nuno Ribeiro (University of Évora), Ramon Riera (Barcelona Provincial Council), Mariano Rojo (DARP), Míriam Piqué (CTFC), Ramón Santiago (CICYTEX-IPROCOR), Enrique Torres (University of Huelva), Philippe Van Lerberghe (Centre National de la Propriéte Forestière), Pau Vericat (Agricultural School of Solsonès)

First edition: June 2018

Design and layout
Elizabeth Fernández (The Forest Ownership Centre)

Photographs
Introduction (AGS-CTFC); Section I (The Forest Ownership Centre); Section II (Fire Service of the Regional Government of Catalonia); Section III (Forest Consortium of Catalonia); Section IV (Forestal Catalana).

Translation and linguistic advice
Anexiam, S.L.

Print run: 200 copies

Deposit legal: B 25140-2018

Recommended citation:
Mundet, R.; Baiges, T.; Beltrán, M.; Torrell, A. 2018. Climate change measures and recommendations for cork oak forests. Life+Suber Project.

Life+Suber Project partners
Forest Consortium of Catalonia (coordination), Forest Science and Technology Centre of Catalonia, The Forest Ownership Centre (Regional Government of Catalonia), Forestal Catalana, SA and Amorim Florestal, SA.

Support and co-financing
Barcelona Provincial Council, Amorim Florestal Mediterráneo, SL and the Catalan Cork Institute.

Index

Introduction

Mario Beltrán
Míriam Piqué
Pau Vericat

Introduction

Cork oak forests in Catalonia and the Mediterranean

Quercus suber L. cork oak forests constitute a habitat of Community interest (9330, Directive 92/43/EEC), in which the tree species itself is one of the most unique elements. Cork oaks are remarkable for their bark. This comprises a series of layers of suberised cells that, on unstripped trees, can be more than 30 cm thick (Vieira, 1950) and may have evolved as an adaptive response to fire (Pausas et al., 2009). This bark, or cork, can grow back if it is extracted without removing the mother layer, and an entire forestry culture has developed around this characteristic. The first growth is called virgin cork; after the first harvest it is known as secondary cork; and after the second harvest the growth is referred to as reproduction cork.

Cork oak forests are a characteristic element of the Mediterranean landscape and not found in many parts of the world. They are associated with a lengthy economic and sociocultural process. This process consists of several parts, mainly the cork harvesting system, although other aspects of the habitat and associated biodiversity are also important (Figure 1). Cork is one of the most important forest products in the Mediterranean, even though the trees are not used for timber, and several unique forest management practices, like subericulture (cork oak cultivation), have arisen due to its specific characteristics and need for specialisation.

Cork oak forests are mostly found in the western Mediterranean, predominantly

Figure 1. The bark is the most characteristic feature of the cork oak. Its sustainable harvesting generates unique forest structures in the Mediterranean ecosystem.

concentrated in the south-west of the Iberian Peninsula (Figure 2). There are significant differences across the range of this species, in terms of both forest formation characteristics and standard management practices. The cork oak forests in the western part of the peninsula are usually pure or mixed forests that include other quercines (*Quercus ilex* and *Q. faginea*), with pasture structures that combine silviculture with animal grazing. In contrast, the eastern part of the peninsula is dominated by dense forests that are often mixed with conifers and broad-leaved trees (pines and oaks), where there are typically several vegetation layers.

In Catalonia, data from the Forest Map of Spain (Mapa Forestal de España, DGDRPF, 2016), indicates that cork oak forests (areas where cork oak is the dominant species) occupy some 69,000 ha, of which around 29,000 ha are pure forests. In addition, approximately 55,000 ha are forests dominated by another species in which the cork oak exists as a secondary or accompanying species. Four distribution areas have traditionally been defined for the cork oak in Catalonia based on mainly ecological factors: L'Empordà, Montseny-Guilleries (Figure 3), Les Gavarres, and El Montnegre-Corredor.

The cork oak is a clearly ericaceous species and grows almost exclusively in acidic substrate. It is usually found on granite, slate, gneiss, and quartzite, which give rise to well-drained and

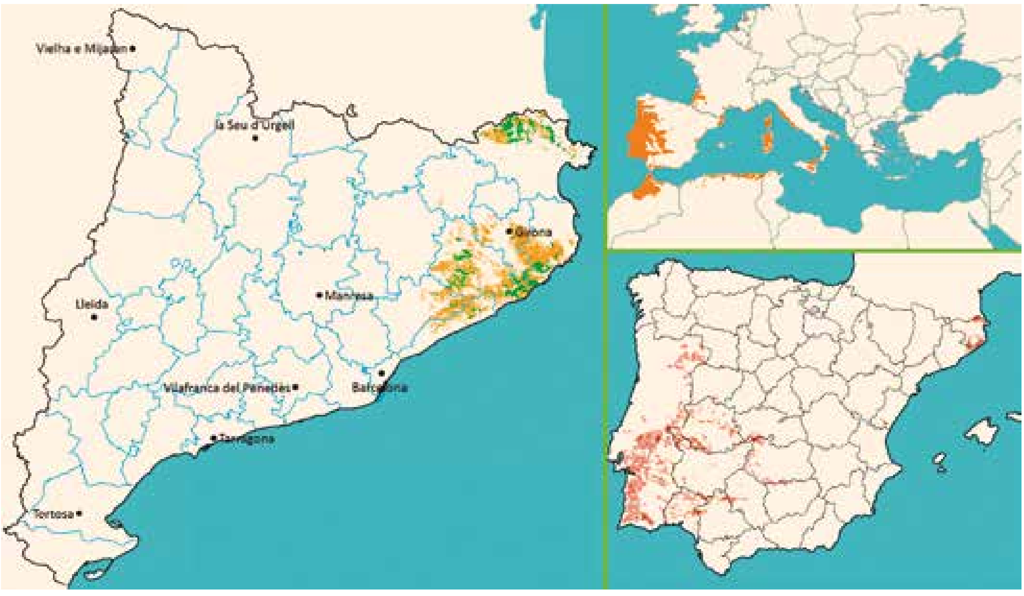


Figure 2. Estimated cork oak forest distribution in the Mediterranean (EUFORGEN, 2009), on the Iberian Peninsula (6IFN Portugal, 2010); MFE Spain, 2016), and in Catalonia (MFE, 2016). In Catalonia, a distinction is made between pure forests (green) and mixed forests (orange) dominated by or with a significant presence of cork oak.

Figure 3. Cork oak forest are a characteristic feature of the landscape in the Montseny Massif.

aerated soils. In terms of climate, this species requires warm and relatively humid conditions with a mild summer drought, or none at all, and no frost. These conditions hinder its presence in the more continental parts of the meso-Mediterranean zone (Díaz-Fernández et al., 1995; Ruiz de la Torre, 2006).

In Catalonia, the optimum ecological conditions for the cork oak (Piqué et al., 2014) correspond to zones with an average annual rainfall in excess of 600-700 mm and an average summer rainfall of more than 100 mm. Shady or semi-shady orientations are the most suitable, but sunny slopes are also suitable if there is sufficient soil and a high level of summer rainfall. They can be found at altitudes of up to 1,000 m, provided that the orientation and a maritime influence limit the low temperatures.

Tree density and slow growth owing to forest station conditions mean that Catalan cork is very dense, giving it a series of characteristics that are highly sought after for the manufacture of natural bottle stoppers for still wines, the cork product with the greatest added value (Figure 4). However, the cork is usually rather uneven and presents a higher percentage of waste than in other cork producing regions, meaning that the percentage of quality cork is usually low. Nonetheless, and despite the widespread decrease in forest management and the primary processing industry during the second half of the 20th century, Catalan cork oak forests continue to be the basis for an important sub-sector in terms of both regional and industrial socioeconomic factors.

Cork is used for numerous and varied purposes. Perhaps it is most commonly known for the manufacture of bottle stoppers, but it is also an important component for the shoe industry, for insulation in construction and industrial installations, for the automotive, naval, aeronautical, and chemical industries, and so on. All these applications have different requirements in terms of raw material characteristics and processing. The main factors include the type of cork (virgin, secondary, or reproduction cork), thickness,

Figure 4. Bottle stoppers for sparkling and still wines are one of main products made from cork.

and any defects (excessive porosity, high permeability, excessive density, insufficient elasticity, cracks, biotic damage, irregular underside, etc.).

At tree level, the main parameters that impact productivity in terms of cork quantity are growth thickness (calibre), cork density by surface area (kg/m^2) and the stripping height. The calibre at a certain age mainly depends on station quality and height on the trunk (Vieira, 1950).

Overall, Catalan cork oak forests are multifunctional and simultaneously serve a number of different functions for society (goods and services). They currently focus on the production of cork and, occasionally, firewood. In a social sense, these forests predominantly correspond to landscape composition and recreational environments, in addition to the heritage value often assigned to cork oak forest harvesting. Their main environmental functions are water regulation, erosion control, atmospheric CO_2 capture, and as biodiversity reserves.

The management of cork oak forests and cork harvesting generate a significant volume of economic activity in rural environments, as cork production is one of the most labour-intensive forestry activities. Cork stripping, forest improvement processes (scrub removal, improvement cutting), and the technical aspects of this activity (planning, marking cut lines, and activity control) help maintain populations in the rural environment at all qualification levels.

Furthermore, the cork oak plays an important role in the Mediterranean due to its ability to withstand fire. This species is outstandingly resilient to forest fire, subsequently resprouting and recovering the forest structure (Figure 5). In a modern context, it is one of the main assets in the resistance and resilience of Mediterranean woodland to forest fires.

Figure 5. The cork protects the vital tissues within the cork oak, which are capable of resprouting after a fire.

The effects of climate change on cork oak forests

Climate change represents a serious threat to cork oak forest conservation, the sustainable production of cork and the value chain associated with this product. The Mediterranean zone, where the cork oak is a characteristic element, is considered one of the bioclimatic regions most vulnerable to climate change (EEA, 2008). Various studies point to three major impacts on cork oak forests (Regato, 2008; Díaz et al., 2009; Pereira et al., 2009; Vericat & Piqué, 2012):

- Reduced water availability, which will lead to reductions in growth, cork production, and carbon capture. This will also lead to increased cork oak forest decline and mortality.
- Increased incidence of pests and diseases. The drier, warmer environmental conditions and tree weakness will encourage attacks by pests and diseases, particularly those that affect the production and quality of cork.
- More frequent, intense, and larger fires (large forest fires) owing to the warmer and drier weather conditions (lower fuel humidity, higher air temperature, and more frequent, intense, and longer-lasting heatwaves), in combination with the increased quantity and continuity of biomass.

These impacts will have some clearly negative effects on the productive, environmental, and social functions of cork oak forests: less product, less carbon capture capacity, loss of habitat quality for many species and biodiversity, increased erosion, and loss of landscape quality and value as a tourism and recreational environment. Furthermore, they will negatively impact the conservation status of this habitat.

Given that sustainable forest management for cork production is one of the most important assets for cork oak forest conservation, the pests and diseases that can potentially affect this product deserve special attention. The most significant are the impacts caused by the Wellenbindge oak splendour beetle (*Coraebus undatus*) (Figure 6), bot canker *(Diplodia corticola*) and ants (*Crematogaster scutellaris* and *Lasius brunneus*).

Vulnerability to climate change of cork oak forests in Catalonia

One of the main actions taken by the Life+Suber project has been to characterise the climate change vulnerability of Catalan cork oak forests. This is the first step towards defining and quantifying the risk, although it involves highly complex and uncertain processes that must be continuously monitored, using indicators, to better predict both the spatial and temporal effects of climate change.

Vulnerability depends on both the nature and magnitude of the impact, and the sensitivity and adaptability of the forest. For this reason, vulnerability will vary according to the type of impact, the geographical location of the forest, its management history, current conditions, and so on.

Figure 6. Adult specimen of *Coraebus undatus*, one of the main threats to cork production.

An analysis has been made of the vulnerability of *Quercus suber* L. forests to the three main types of climate change impact predicted for these formations, i.e., reduced water availability, large forest fires, and the damage caused by *Coraebus undatus*. A zoning map has been produced for the degree of vulnerability to these impacts within the cork oak forest range in Catalonia.

Reduced water availability

Water deprivation stemming from climate change poses a risk to the cork oak because it limits its vitality, growth, and ability to respond to change and other threats. Generally speaking, limited vitality can lead to replacement by other species that are more competitive in the new conditions, leading to substantial changes in the ecosystem. In turn, this directly affects the value chain associated with cork production. To assess vulnerability to water deprivation, the level of ecological suitability of existing cork oak forests to long-term climate scenarios has been determined. Specifically, two categories have been established: zones of lower ecological suitability and zones of higher suitability. In the zones of higher suitability, the cork oaks present increased growth and vitality with greater potential from a forestry production point of view (growth).

The current models used for future climate projections predict rainfall with less certainty than temperature. However, generally speaking and with a 50-year outlook, the models point to a situation with much greater inter- and intra-annual variability but with little change in the total annual rainfall when compared to current figures. It is therefore necessary to use parameters that combine rainfall with other environmental variables, such as potential evapotranspiration (PET), in order to increase the representativeness of climate change effects. Increased PET represents greater water deprivation for the ecosystem, even when the total annual rainfall is similar to current values.

The forest station qualities defined by Piqué et al. (2014) for cork oak forests show that the best locations in terms of rainfall are those with an annual total of more than 700 mm and a summer total of more than 100 mm. Using the series of comparable data from 1985 to 2015, it is possible to identify the zones in which the average annual and summer (June, July, and August) rainfall exceeds these thresholds, differentiating the cork oak forests into those that are located in suitable zones and those located in less suitable zones.

In order to identify the threshold between suitable and unsuitable zones in terms of PET, the PET values have been analysed in relation to rainfall. The equivalence between rainfall and PET is not direct because many more factors influence PET. However, a threshold PET value equivalent to 700 mm of annual rainfall can be set. At any point below this PET value, water stress is low enough to determine that the zone is suitable for cork oak forests, while higher values indicate zones of lower suitability.

In order to assess the impact of water deprivation from climate change in terms of increased PET, a climate projection has been made based on the standardised regional CCLM4-8-17 model with the RCP4.5 representative concentration pathway for the period 2020 to 2050. The regional model narrows down global climate predictions to a smaller scale, while the scenario attempts to incorporate the effect of certain changes on current trends into the equation. In this case, a scenario has been considered that incorporates certain adaptation and mitigation measures. With the climate projection for the period 2020 to 2050 an average annual PET value is obtained, and suitable zones are defined as those with an estimated value below the threshold set and lower suitability zones are defined as those where a higher PET value is expected.

Figure 7 shows the classification of Catalan cork oak forests based on the level of ecological suitability for vulnerability to water deprivation. It shows that 65% of cork oak forests would be classified as being within zones of lower suitability.

Therefore, extensive areas of existing cork oak forest are at risk of suffering a major negative impact as a result of future water deprivation. In any case, the vegetation (density, stratification, specific composition, and development status) plays a decisive role in water use, as do certain physical factors (gradient, orientation, and soil). Forestry management to regulate competition and ecological facilitation within the forest is key in easing the impact of water deprivation (Figure 8). The forest structure should be managed in order to maximise water use efficiency and concentrate, as far as possible, the greatest resources on cork oak forests, species of biogeographic interest, and facilitators (e.g., those that capture horizontal precipitation in areas of frequent mist).

Large forest fires

Large forest fires, with the greatest reach and intensity, are one of the most visible effects of climate change. Although several factors come into play, vegetation is one of the most decisive given that increasing forest size and tree densification increase the quantity of fuel available. Ever more frequent extreme climate events aggravate this problem by maintaining adverse weather conditions over longer periods of time: mainly heat, dry vegetation, and dominant winds. In order to assess the vulnerability of cork oak forests to large forest fires, three categories have been defined: highly vulnerable, moderately vulnerable, and slightly vulnerable. Structural variables (cover continuity, most likely fire type in the zone, and therefore recurrence based on historical data) are used to assess this.

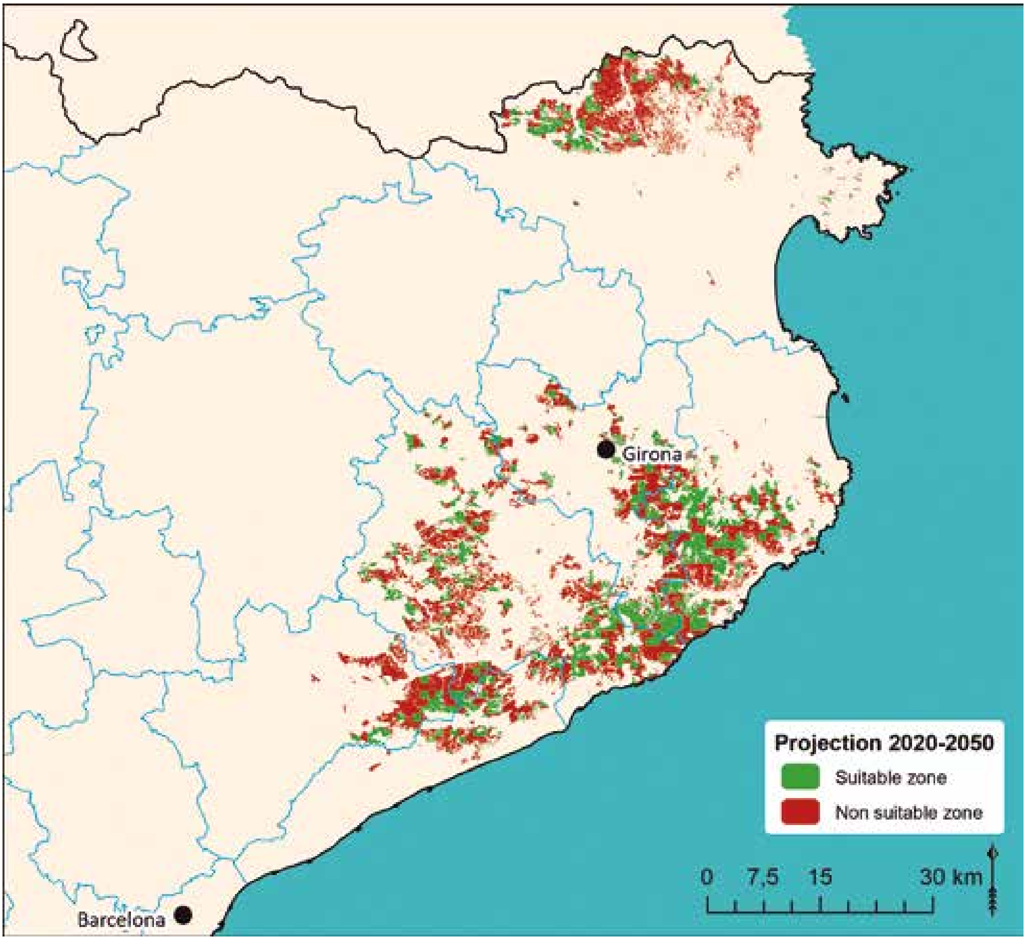


Figure 7. Classification of Catalan cork oak forests based on level of ecological suitability for vulnerability to water deprivation stemming from climate change (2020-2050 Projection) Suitable zone; Unsuitable zone.

Variables defining forest structure, such as cover of the various vegetation layers and the vertical distance between these, strongly influence fire intensity and propagation. However, these factors can change a great deal at a small scale, both temporally and spatially, and can also be affected by management activity.

For this reason, vulnerability to large forest fires is assessed in stages. Firstly, information is gathered on fire trends based on historical forest fire records without considering the current forest structure. A fire risk map is used for this, such as that produced by Piqué et al. (2011), which identifies the zones at greatest risk of a large forest fire (LFF) based on historical forest fire records.

To determine the level of vulnerability to LFF, the information provided by the typical fire risk map has been used. The information on structural vulnerability

Figure 8. A stand in the Life+Suber project two years after the work. The most vital cork oaks should be maintained, along with accompanying species that do not hinder their development, and certain shrub cover of species of interest that help limit direct exposure to sunlight and capture horizontal precipitation in the case of frequent mist.

provides another indication that the degree of vulnerability also depends on stand conditions. Figure 9 shows the levels of vulnerability to LFF based on the information on typical fire risk. From this it is determined that 78% of cork oak forests are highly vulnerable and 20% are moderately vulnerable.

To incorporate forest structure into fire vulnerability assessments, it is necessary to use data on forest cover and consider the scale of change over both space and time. An initial regional estimate can be made using data from the National Forest Inventory, assuming that changes have occurred since this data was collected, and performing a spatial generalisation assuming there have been small-scale changes. The third National Forest Inventory (NFI3) is the most spatially representative field data inventory.

By using the Crown Fire Hazard Assessment Charts (CFHAC) (Piqué et al., 2011) with data on the plots in the NFI3, at each inventory point structural vulnerability has been analysed and divided into three categories (high, moderate, and low). Subsequently, the values from each point have been spatially generalised in order to predict structural vulnerability, in a continuous manner throughout the cork oak forest zones (Figure 10). In total, 56% of the cork oak forests in Catalonia are classified as highly vulnerable structurally and 39% as moderately vulnerable structurally.

In any case, LFF constitute a risk that should always be examined and tackled at landscape level, in terms of planning, management, and monitoring. Based on the concepts and methods established by Costa et al. (2011) and

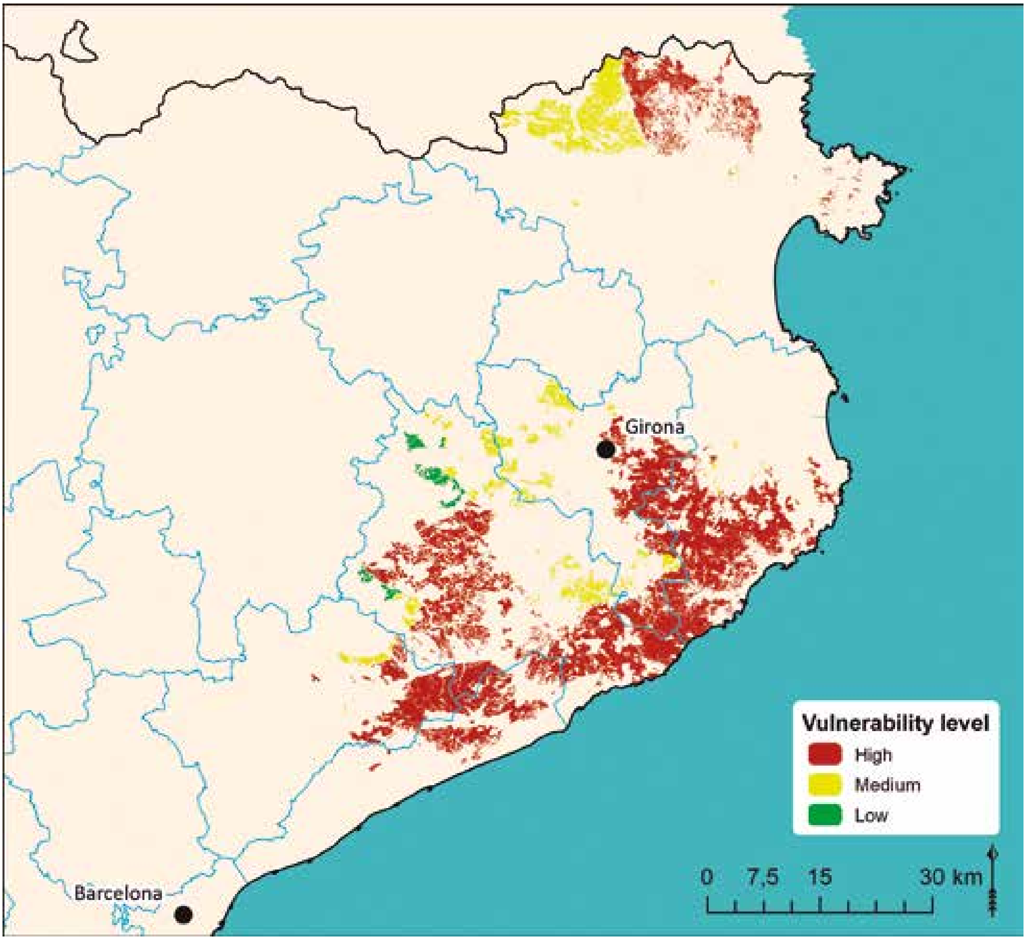


Figure 9. Classification of Catalan cork oak forests based on the level of vulnerability to large forest fires (Level of vulnerability: High, Moderate, Low).

Piqué et al. (2011), the key factor for preventing large fires is managing the behaviour and propagation of the fire at certain strategic points.

Despite the limited information on plant cover at a regional level, the importance of forest structure is clearly obvious in terms of cork oak forests vulnerability to large fires. For this reason, forest management for preventing large fires should mainly tackle the generation and maintenance of structures with low vulnerability to high intensity fires in the stands located at strategic points for fire behaviour (Figure 11).

Damage caused by the Wellenbindge oak splendour beetle

Several pests can significantly affect cork oak forests, although the Wellenbindge oak splendour beetle is the most important because it harms the production of quality cork. The damage caused by this insect has

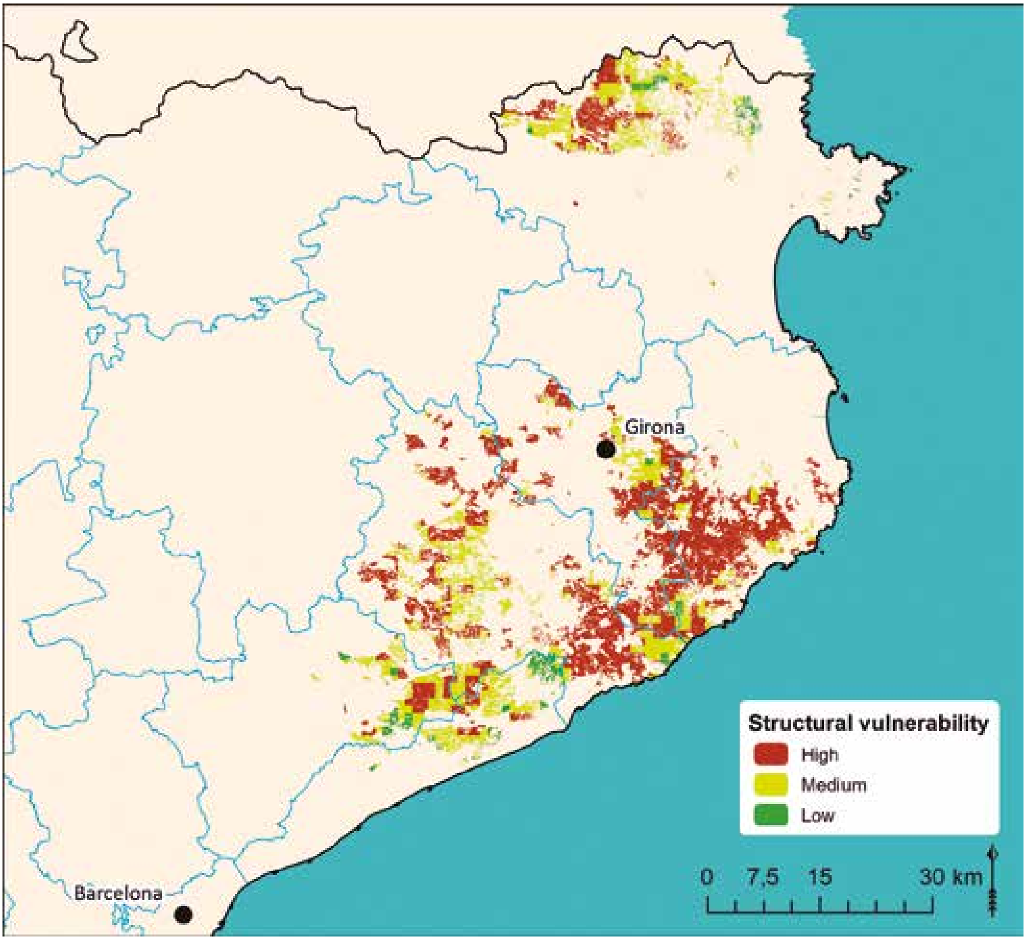


Figure 10. Spatial generalisation of structural vulnerability in cork oak forest zones, assessed according to data from the NFI3 plots and applying the CFHAC of Piqué et al. (2011) (Structural vulnerability: High, Moderate, Low).

increased significantly in recent years, despite the fact it was already present in cork oak forests. It is a relatively unknown insect in terms of its biology, population patterns, behaviour, and distribution. It is also possible that changing environmental conditions may have altered certain biological and behavioural aspects in recent years. To assess the level of vulnerability to Wellenbindge oak splendour beetle damage, ecological variables and data from past *Coraebus undatus* damage at plot level have been used to establish two levels: those zones that are the most vulnerable and least vulnerable to high impacts.

The capture data from campaigns in 2015, 2016, and 2017 carried out for the Life+Suber project have been used to model the capture level based on ecological parameters that may be related to the insect's biology or that may influence population levels. The model produced serves as an algorithm

Figure 11. A stand in the Life+Suber project two years after the work. Structures with low vulnerability to high intensity fire are created at strategic points for fire behaviour. In addition, a pasture structure can make grazing compatible with fire prevention and cork production.

for assigning levels of vulnerability to high impacts, assuming that a higher number of adult insects caught relates to a higher impact from larval galleries. In order to improve the predictive capabilities of the model, data has been added from captures carried out by Forestal Catalana in 2012 to 2014 at various cork oak stands in Catalonia, as well as five stands where no Wellenbindge oak splendour beetles have been recorded.

As the predictive variable, the final model uses the accumulated annual precipitation, from July to June, two years prior to the capture of the adult insects. This corresponds to the year before the eggs were laid of the insects caught two years later.

Annual rainfall patterns also provide variability for capture prediction. Furthermore, although other environmental or geographical variables may not have significantly improved the predictive capability of the model, there are still many other variables that may have significantly influenced the damage caused by the Wellenbindge oak splendour beetle, including those related to vegetation (and forest management).

In order to define the most and least vulnerable zones, the model developed to predict the captures in 2018 was used, with a fixed threshold value. The most vulnerable zones are those where the predicted capture level is higher than the threshold value (Figure 12). The result shows that 56% of cork oak

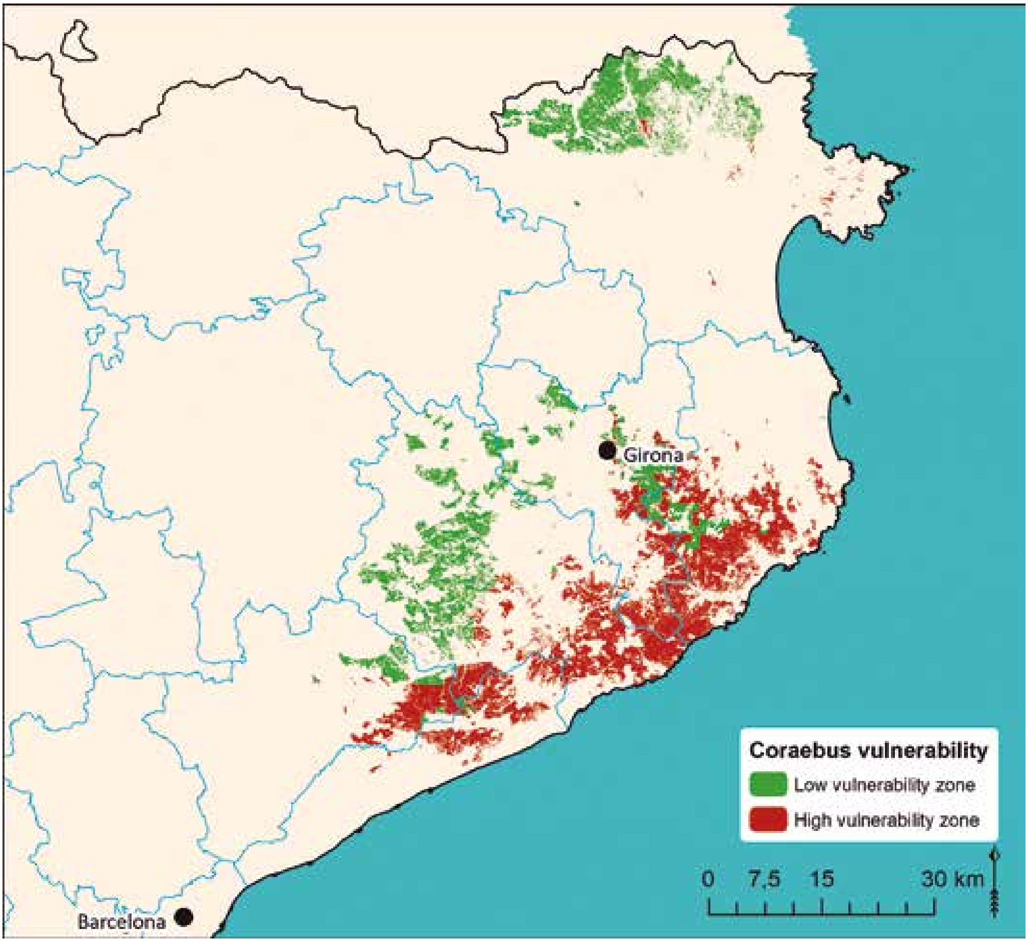


Figure 12. Classification of cork oak forest zones according to Wellenbindge oak splendour beetle capture prediction, differentiating the least vulnerable zones (green) from the most vulnerable zones (red) (Vulnerability to Coraebus: Least vulnerable zone, Most vulnerable zone).

forests are located in more vulnerable zones.

In any case, it is clear that the predictive capability of capture levels should be improved, in particular by introducing spatially better-distributed data that represents all cork oak forest zones.

Even so, there is a high level of uncertainty involved in predicting the damage caused by the Wellenbindge oak splendour beetle. For this reason, this initial assessment of cork oak forest vulnerability to this insect should be considered with caution. The available data seems to indicate that vegetation characteristics do not appear to directly determine damage levels, although an adapted forest structure may improve trap effectiveness (Figure 13). Population levels for this insect are affected by several factors, including the insect's own biology, with little-known characteristics and potentially recent changes induced by the new climate conditions. The damage caused by the Wellenbindge oak splendour beetle is one of the main effects of climate change. Monitoring activities should focus on this to improve our knowledge and future prediction capabilities, among other things.

Figure 13. A stand in the Life+Suber project where traps have been set to catch adult Wellenbindge oak splendour beetles and where silviculture action has been taken to improve the forest structure. The traps primarily work because of their shape, colour and location, so managing the surrounding vegetation improves their effectiveness.

References

Costa, P.; Castellnou, M.; Larrañaga, A.; Miralles, M.; Kraus, D. 2011. *La prevención de los grandes incendios forestales adaptada al incendio tipo*. GRAF-Technical Unit, Ministry of Home Affairs, Regional Government of Catalonia, Barcelona. 87 p.

De Cáceres, M.; Martin, N.; Cabon, A. 2017. *meteoland: Landscape Meteorology Tools*. R package.

DGDRPF. 2016. *Mapa forestal de España. Escala 1:25.000. Catalunya*. Directorate-General of Rural Development and Forestry Policy. Ministry of Agriculture, Food and Environmental Affairs, Madrid.

Díaz-Fernández, P. M.; Jiménez, M. P.; Catalán, G.; Martín, S.; Gil, L. A. 1995. *Regiones de procedencia: Quercus suber* L. ICONA. Ministry of Agriculture, Fisheries and Food. ETSI Montes, Madrid.

Díaz, M.; Pulido, F. J.; Pausas, J. D. 2009. «9330 Alcornocales de *Quercus suber*». In: VV.AA. (ed.). *Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España*. Ministry of the Environment, Rural and Marine Affairs. Madrid, p. 58.

EEA. 2008. *Impacts of Europe's changing climate - 2008. An indicator-based assessment (EEA Report No 4/2008)*. Office for Official Publications of the European Communities, Luxembourg.

EUFORGEN. 2009 *Distribution map of cork oak (Quercus suber).* European Forest Genetic Resources Programme. www.euforgen.org.

Pausas, J. G.; Pereira, J. S.; Aronson, J. 2009. «The tree». In: Aronson, J.; Pereira, J. S.; Pausas, J. G. (eds.). *Cork Oak woodlands on the edge: ecology, adaptive management, and restoration.* Island Press. Washington DC, p. 11-21.

Pereira, J. S.; Vaz Correia, A.; Joffre, R. 2009. «Facing climate change». A: Aronson, J.; Pereira, J. S.; Pausas, J. D. (eds.). *Cork oak woodlands on the edge: ecology, adaptive management, and restoration*. Island Press. Washington D. C., p. 219- 226.

Piqué, M.; Castellnou, M.; Valor, T.; Pagés, J.; Larrañaga, A.; Miralles, M.; Cervera, T. 2011. *Integració del risc de grans incendis forestals (GIF) en la gestió forestal: Incendis tipus i vulnerabilitat de les estructures forestals al foc de capçades. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST).* The Forest Ownership Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia, Barcelona. 122 p.

Piqué, M.; Vericat, P.; Cervera, T.; Baiges, T.; Farriol, R. 2014. *Tipologies forestals arbrades. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST)*. The Forest Ownership Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia, Barcelona. 346 p.

Regato, P. 2008. *Adaptación al cambio global. Los bosques mediterráneos*. UICN Centre for Mediterranean Cooperation, Màlaga, Espanya. 254 p.

Ruiz de la Torre, J. 2006. *Flora mayor*. National Parks Autonomous Agency, Ministry of the Environment, Madrid. 1756 p.

Vericat, P.; Piqué, M. 2012. «El cambio global: impactos probables sobre las formaciones de *Quercus* y gestión para la adaptación». In: Vericat, P.; Piqué, M.; Serrada, R. (eds.). *Gestión adaptativa al cambio global en masas de* Quercus *mediterráneos*. CTFC. Solsona, p. 29-46.

Vieira, J. 1950. *Subericultura*. Dir. Directorate-General for Forestry and Aquaculture Services, Lisbon.

Section I

Climate change adaptation in cork oak forests

Teresa Baiges
Mario Beltrán
Roser Mundet

Current status of Catalan cork oak forests

Characteristics of Catalan cork oak forests

Catalan cork oak forests belong to the group of mountain cork oak forests. They can be found in phytoclimatic areas more commonly associated with holm oak forests. They are generally high density due to management that has clearly favoured the species over the last 150 years, albeit with certain intervals of decline based on the profitability of cork production.

From a biogeographical point of view, there are four main cork oak forest ranges in Catalonia, with different ecological characteristics (González et al., 1993). Each of these also has its own history of management and fire, leading to a great deal of structural diversity (Table 1, Figure 14).

Table 1. Surface area and percentage surface area occupied by cork oak in Catalonia, by type. Based on the map of forest types in Catalonia (Piqué, et al., 2014).

FT	Alt Empordà ha (%)	Gavarres ha (%)	Montseny-Guilleries ha (%)	Montnegre-Corredor ha (%)
PURE CORK OAK FORESTS	**9,334 (77%)**	**13,117 (42%)**	**5,309 (47%)**	**266 (4%)**
CORK OAK FORESTS MIXED WITH CONIFERS	**163 (1%)**	**12,789 (41%)**	**1,485 (13%)**	**4,666 (78%)**
Cork oak and Aleppo pine forests	67	240	0	189
Cork oak and stone pine forests	84	11,190	880	4,477
Cork oak and maritime pine forests	12	1,359	605	0
CORK OAK FORESTS MIXED WITH BROAD-LEAVED TREES	**2,651 (22%)**	**5,111 (16%)**	**4,445 (40%)**	**1,027 (17%)**
Cork oak and other broad-leaved tree forests	292	30	2,303	34
Cork oak and holm oak forests	1,469	2,122	1,428	750
Cork oak and strawberry tree forests	879	2,436	308	161
Cork oak and English oak forests	11	523	405	82
Other mixed forests dominated by cork oak	448	54	105	13
Total surface area with cork oaks	**12,148 (100%)**	**31,017 (100%)**	**11,239 (100%)**	**5,958 (100%)**

<table>
<tr><th colspan="2">Humid mediterranean</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Montseny - Guilleries. These cork oak forests are located in colder areas, sometimes at altitudes of >600 m, on granitic substrates. Areas of high forest management activity, frequently mixed forests with broad-leaved trees or pines resulting from repopulation</td><td>Alt Empordà. Well-preserved cork oak forests, although with signs of ageing, at altitudes of 100 to 600 m, often pure or forming mixed forests with holm oak. In 2012, a forest fire burned 10,476 ha, most of which was cork oak forest.</td></tr>
<tr><th colspan="2">Dray mediterranean
(coastal, with elevated areas that may be more humid)</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Montnegre - Corredor. Exclusively granitic rock substrates. Cork oaks forming mixed forests with pines (stone pine, maritime pine), holm oaks, and strawberry trees, many of which are not actively managed. Mostly located in the northern region of the massif.</td><td>Gavarres. On various substrates and forming mixed forests with pines (stone pine, maritime pine), holm oaks, and strawberry trees, all of which have a competitive advantage over the cork oaks. Limited management in areas regenerated following previous fires.</td></tr>
</table>

Figure 14. General description of the four Catalan cork oak forest zones based on González et al. (1993), with illustrative photographs from estates managed as part of the Life+Suber project.

At a stand scale, and based on the ecological requirements of the species, Piqué et al., (2014) define three station qualities for Catalan cork oak forests:

- High quality (A). Optimal stations for cork production: rainfall >700 mm (100 mm in summer), area with no heavy snowfall, not exposed to northerly or westerly winds, altitude <1,000 m and soil depth >50 cm. Quality cork production is between 200 and 300 kg/ha per year or more.

- Moderate quality (B). Sub-optimal stations for cork production: rainfall >600 mm (>100 mm in summer), area with no heavy snowfall, not exposed to northerly or westerly winds, altitude <1,000 m and soil depth >40 cm. Less production than the high-quality stations.

- Low quality (C): stations not suitable for cork production: rainfall <600 mm (100 mm in summer), area with prevailing dry winds, stony soils with depths <300 cm and rocky outcrops.

The typical scrub of Catalan cork oak forests is abundant and tree-like, with heights, densities, and cover that compete with the cork oaks for light, water, and nutrients.

Current cork oak forest management: silviculture or arboriculture?

Despite the differences between regions and forest station qualities, a common cork oak forest management pattern can be identified throughout Catalonia, which follows the logic of **sustainable and periodic production of quality cork**. Cork is one of the most economically important non-timber products. Its harvest does not require the felling of the tree, which means the management techniques are more in line with the criteria associated with arboriculture than silviculture. Indeed, they have given rise to an art and science with its own name: subericulture —the cultivation of cork oaks.

Figure 15. A pile of cork sheets in a forest.

Management associated with the priority goal of cork production has led to the maintenance of **irregular-looking structures**, with cork harvesting every 12-16 years followed by gentle improvement cutting based more on phenotypic criteria associated with cork production (poor quality sheets, extraction difficulty, etc.) than on encouraging regeneration. Back in 1893, based on his experience in Catalan and French cork oak forests, the French forestry engineer Lamay stated that «no owner cuts productive cork oak forests to obtain a regenerated future» (cited in Montero et al., 1994). Cutting usually takes place between the first and third year following harvest and, in some instances, the year before. Management of cork oak forests with a regular structure is highly insignificant at ground level and applied to young plantations.

As regards **scrub management**, following a period during which it was common to see total scrub removal around stripping time and sometimes twice each cycle, scrub removal has now been limited to the minimum surface area required to guarantee trafficability and safety during activities related to cork harvesting. This has been influenced by the reduced profits from operations in recent years owing to the falling percentage of quality cork obtained.

Effects on vitality and production

The continued application of this type of management tends to lead to monostratification, despite the presence of trees with varying diameters and ages. This structure leads to less production, excessive scrub development, less water available for individual trees, and a greater risk of and vulnerability to fire.

Lack of viable regeneration is a common problem, above all in seeds, which aggravates the problem of ageing stumps and entails low genetic diversity. This also leads to few young and vital specimens being available to replace less productive cork oaks or for recovery after a fire. It is estimated that 50% of the cork oak forests in Catalonia have some sort of degradation problem.

Figure 16. A cork oak forest in production, with a high tree density, that has been managed for over 200 years (Montseny. Girona).

Silviculture for improving cork oak forest adaptability to climate change

Although it is highly likely that Mediterranean forests are able to adapt to climate change without the need for human intervention (Regato, 2008), it is worth considering whether, in the short term, we could assume the social and territorial cost involved. This becomes even more relevant when focusing on cork oak forests given their economic, ecological, social, and heritage roles. These aspects are very difficult to compare to any other forest formation and are closely linked to their present-day, highly anthropized structure.

The basic assumption is, therefore, a desire to maintain the current roles of cork oak forests and their associated value chain, something that requires active intervention by forest managers. Bearing in mind that any management applied today will be required to generate forests capable of facing greater aridity, and more frequent and intense disturbances in the future, we should ask ourselves: is there such a thing as «adaptative silviculture»?

Sustainable forest management already involves, more or less intentionally, many of the biological, physical, and social actions that are needed to respond to the projected changes (Spittlehouse, 2005). Nonetheless, we can see that better silviculture can be designed aimed at streamlining this management under adaptation criteria.

Atributes of adaptive silviculture

Given that the main characteristic of global change is uncertainty, the above recommendation stems from common sense and seeks **flexibility** in long-term goals, keeping various possible forest development options in mind, including sudden large-scale changes (for example, the widespread death of the species).

Secondly, it should be understood that **adaptive management** must include a combination of measures capable of increasing forest **resistance and resilience** to unfavourable conditions or disturbances, in other words, the capacity to maintain its structure and basic functions and, eventually, to **respond and recover** in the new conditions (CCSP, 2008).

These measures may address a specific effect of the change, generate synergies between one another, or even combine to become counterproductive (as illustrated below in the case of scrub removal). To that end, **there is no global recommendation** and local solutions must be sought based on the constraints of each stand and the priority management objectives; for this, the impact of the various treatments applied to forest adaptation capacity must be known. This document seeks to discuss exactly this final point.

Lastly, and in general, it is preferable if this is **autonomous adaptation**, which can be intentionally accompanied by the proposed silviculture.

In the specific case of Mediterranean *Quercus* species, one of the first management approaches to climate change adaptation is that undertaken by Vericat et al., (2012), which identifies **five main blocks of adaptation measures to be considered for *Quercus***, based on the main negative impacts detected (Figure 17):

1. *Improved forest mass vitality.*
2. *Adaptation in regeneration actions.*
3. *Reduced vulnerability to large forest fires (LFF).*
4. *Encouraging heterogeneity.*
5. *Facilitation of genetic adaptation.*

Furthermore, *the improvement of habitat quality and the conservation role of biodiversity* is considered to be a cross-cutting adaptation measure.

This section proposes a definition of adaptative silviculture for cork oak forests based on two key factors:

- The adaptation criteria to be considered in management for increasing cork oak forest resistance and resilience; and

- The identification of management models and synergies between these, optimised for cork production and improved cork oak forest adaptation capacity.

The theoretical argument follows the structure of the adaptation measures proposed by Vericat et al., (2012) for Mediterranean Quercus, although it is restricted to only those measures applied at **stand scale**.

Forest management planning at a landscape scale is necessary in relation to climate change, and this is considered in the introductory chapter of this guide (including vulnerability maps), as well as in the section on fire prevention.

Management criteria for increasing cork oak forest adaptation capacity

Improving tree vitality

Water is undoubtedly a key factor to consider in adaptive silviculture for the Mediterranean countryside, in terms of increased forest vitality. In this regard, increasing water availability and water use efficiency **at the level of individual trees** is just as important as measures aimed at retaining as much water as possible **at a stand level**.

- Reducing competition. Improving tree vitality depends on forest structure (density) and the initial conditions relating to station quality (Serrada, 2001). In Catalan cork oak forests, especially in medium or low-quality stations, the thickets are extreme, sometimes even those growing from single stumps. This weakens the forest, especially those that have been coppiced on several occasions (particularly in fire-affected areas), making it costly to maintain a considerable underground structure. There is a need to undertake **treatments that reduce competition, to increase individual vitality, and foster**

Main NEGATIVE IMPACTS

Reduced growth and carbon capture capacity, mainly due to water deficit.

Weakened forests, decline, and mortality, due to water deficit, extreme drought, and changes in cultural practices. Increased forest densification.

Regeneration problems owing to lower seed production, seeds with less reproductive capacity, more arid edaphoclimatic conditions, and the decoupling of fruiting processes from the optimum conditions for the installation and survival of seedlings. Increased predation and herbivory.

Increased frequency of larger, more intense fires.

Increased soil erosion and degradation processes.

Falling, topping, and breaking due to episodes of storms and high-energy disturbances, enhanced by forest densification and increased height (instability).

Increased growth in areas of water deprivation owing to higher temperatures, [CO_2] and N deposition.

Direct damage from chemical contamination and the effect of increased BVOCs (Biogenic Volatile Organic Compounds) associated with rising temperatures and less water availability.

Very severe and more frequent episodes of pests and diseases. Increase in pests and new diseases.

Alteration of plant communities: changes in composition and genetic changes: extinction, migration. Invasive species.

Main ADAPTATIVE MEASURES

Improvement of forest vitality

- Application of silviculture techniques to reduce density: thinning and clearing; with different patterns based on other priority goals (fire prevention, erosion control, water regulation, etc.).

Adaptation in regeneration actions

- Favouring natural sexual regeneration: lengthening regeneration periods, harnessing advanced regeneration, strengthening through sowing and clearing, and maintaining natural selection processes.
- Reforestation adaptation: species, genotypes, and land preparation and planting techniques.
- Restoring degraded areas and fire-affected areas.

Reduced vulnerability to LFF

- Modifying the fuel model to stand scale using silvicultural techniques: clearing and thinning, selective scrub removal, pruning, waste treatment.
- Configuring fire-smart landscapes: design of strategic areas, controlled use of fire, creating a forest cover pattern that hinders propagation, encouragement of heterogeneity at a landscape scale.

Encouraging heterogeneity

- Encouraging mixed forests. Diversifying the undergrowth.
- Diversifying structures (mosaic of different structres).
- Maintaining and favouring atypical stands of special interest.

Facilitating genetic adaptation

- Maintaining genetic diversity.
- Reducing fragmentation and low forest densities.
- Preserving «genetic reserves».
- Assisted migration.

Figure 17. Measures for adapting Quercus formations to global change, at both stand and landscape levels, based on the main negative impacts identified. Source: adapted from Vericat et al. (2012).

forest rejuvenation, to increase water use efficiency, encouraging regeneration by seed. The abundant Mediterranean scrub can also be significant competition for the trees; this needs to be assessed on a case-by-case basis. Nonetheless, generally speaking, the benefits of maintaining scrub in a climate change context outweigh its potentially negative impact on tree growth.

- Maintaining/increasing water availability in the stand. This is mainly based on environmental humidity management, in which scrub and cutting waste management play a fundamental role. For this reason, maintaining certain scrub cover in dry areas or those with low tree cover can improve water availability, mainly through reducing evaporation loss by protecting the ground from direct exposure to sunlight. In misty coastal areas, species with a higher Leaf Area Index (LAI), such as heather (*Erica*), act as horizontal precipitation catchers and increase water availability in the stand. In Gavarres, it has been observed that the water from horizontal precipitation can be twice that from rainfall, in addition to being more frequent (Botey, 2013). In this same cork oak forest, other positive effects from maintaining scrub have been observed in terms of water: the possibility of recovering water from plant transpiration, buffering the temperature; and the presence of species that accumulate water *(Arbutus and Viburnum)*, increasing system efficiency and reducing stand flammability. If cutting waste is distributed over the surface of the stand, it can generally help maintain soil moisture during moderately heavy rainfall situations, in a similar way to scrub. Nonetheless, a number of experts have documented situations in extreme rainfall events (very high or very low intensity) where the effect of this cutting waste has been counterproductive. Given that climate change forecasts predict an increased recurrence of such extreme events, we recommend further study of this phenomenon.

- Limiting physiological stress from stripping. Stripping causes significant water and sap loss through transpiration from the stripped surface, during the peak heat and low humidity season. Tree growth slows for several days and, in the long term, the life of the tree is reduced. In many regions, such as Catalonia, the technical criteria defining the annual cork harvest period and the weight (minimum diameter and harvesting height) are regulated by law. Climate change has highlighted the need to amend these criteria in most cork regions throughout the peninsula, **as well as to bring forward the standard harvesting period to May and increase the minimum harvest diameter from 65 to 70 cm.** (Figure 18) and recommended from 80 to 85 cm.

Encouraging heterogeneity

- Encouraging species heterogeneity. The **presence of individuals of different species, even if sporadic**, guarantees the existence of the characteristic biodiversity associated with certain species (Camprodon, 2013). The various functional strategies of the different species also allow greater recovery opportunities in the event of disturbances. Species heterogeneity refers to both trees and shrubs. In Catalonia, approximately half of the formations with cork oaks are mixed forests; in other words, other tree species, including the strawberry tree, occupy more than 20% of the Basal Area (BA). In the management of cork oak forests, even though the dominance of this oak is encouraged, it is important to maintain sufficient quantities of other species to keep recovery options open (Figure 19). It is recommended to have as much scrub diversity as possible while considering the behaviour of the different species with regard to water (retaining or storing water), fire (pyrophitic or not), and the associated biodiversity (fruit producing or not), as well as reproduction strategies (resprouting versus germinating) that will determine how they are controlled.

- Phenotypic heterogeneity: facilitating genetic adaptation. Maintaining the high phenotypic diversity inherent to cork oaks and other *Quercus*, favours the **in situ *adaptation*** of their populations

Figure 18. Recently stripped cork oaks. The new harvest has drastically reduced the excessive height of the previous harvest (for reasons of stripping operation profitability), favouring tree vitality.

(Benito Garzón, 2011). Phenotypic diversity —which encompasses morphological differences (e.g., appearance), phenological differences (e.g., sprouting period), and physiological differences (e.g., reproductive strategies and resistance to drought)— is an indicator of **genetic diversity** and the **phenotypic plasticity** of a population. Genetic diversity increases the long-term capacity to adapt and facilitates migration while phenotypix plasticity offers a short-term response and lessens any negative impacts (Figure 20).

- Structural heterogeneity. The presence of various vegetation layers (herbaceous, shrubby, arboreal) is key, not only because of

Figure 19. Treatment in a mixed cork oak-holm oak forest in Montnegre where most of the holm oak trees have been removed.

the different biodiversity associated with each, but also because of the role they play in the conservation of environmental humidity in the stand, as stated above.

- Attention to regeneration. The presence of young specimens in cork oak forests is important because they allow for ongoing forest improvement and, as they are less susceptible to fire because they have not yet been stripped, they allow rapid renewal after a fire, episodes of decline, or other unforeseen circumstances. There are few young trees in Catalan cork oak forests. The high phenotypic variability may generate forests that look irregular, but which comprise no more than two contiguous age classes. The presence of new individuals should be encouraged: i) favouring the development of the next regeneration; ii) based on saplings (stump or root) from older or non-productive coppiced trees; and iii) seeking the appearance of new regeneration from seeds, which also helps increase the genetic heterogeneity of the forest. In addition, scrub offers protection for regeneration, by hiding saplings from possible predators and guaranteeing

Figure 20. Morphological variability in a 20-years-old cork oak plantation in Gavarres.

them a favourable microclimate during their first months or years of life, key factors in stands exposed to strong winds (Figures 21 and 22).

Improved habitat quality and increased biodiversity

Promoting the mentioned heterogeneity in the system is, itself, a biodiversity improvement measure. It encourages complexity and the production of food (fruit and arthropods) that, in turn, encourages the presence of complex auxiliary fauna, both arthropods (parasites and predators) and birdlife (Camprodon & Brotons, 2006), which is vitally important for controlling various pests (e.g., *Lymantria dispar*). However, there is a series of **key factors for biodiversity** to which special attention must be paid:

- Large trees and trees housing diverse microhabitats. These provide vital food, breeding locations, and shelter for specific fauna. In this regard, Quercus species, and the cork oak in particular due to the characteristics of its bark and commercial exploitation, are better hosts for microhabitats than other groups of tree species because of their characteristic morphology and resprouting ability, as well as the fact these are generated at an earlier age

Figures 21 and 22. Top: cork oak regenerated from seed, developed under the protection of scrub in a stand exposed to northerly winds. Bottom: 60 cm diameter stump that has not resprouted. It has been found that when holm oak stumps are 50 cm in diameter or more (150-250 years old), 20% do not resprout. (Serrada et al., 2004).

(Emberger, et al., 2016). Combined with cork production not requiring the tree to be cut, this means that retaining these characteristics in the stand does not conflict with its productive purpose (Figure 23).

- Large dead trees (diameter >20 cm) that are still standing and timber in the soil in various states of decomposition, encourage saproxylic species that depend on the presence of dead wood for some part of their life cycle.

- Other factors that encourage shelter, breeding and diet of various wildlife species. These include flowers that produce fleshy fruits, the presence of small clearings with herbaceous vegetation with flowers, and rocky or aquatic elements.

Figure 25 shows some examples of the unique elements present in a stand in Alt Empordà, giving it strong potencial for housing biodiversity..

Figure 23. The particular morphological characteristics of the cork oak and its management make it an excellent species for housing microhabitats that are key to biological diversity.

Figure 24. Cork oak forests have a long biodiversity chain associated with them.

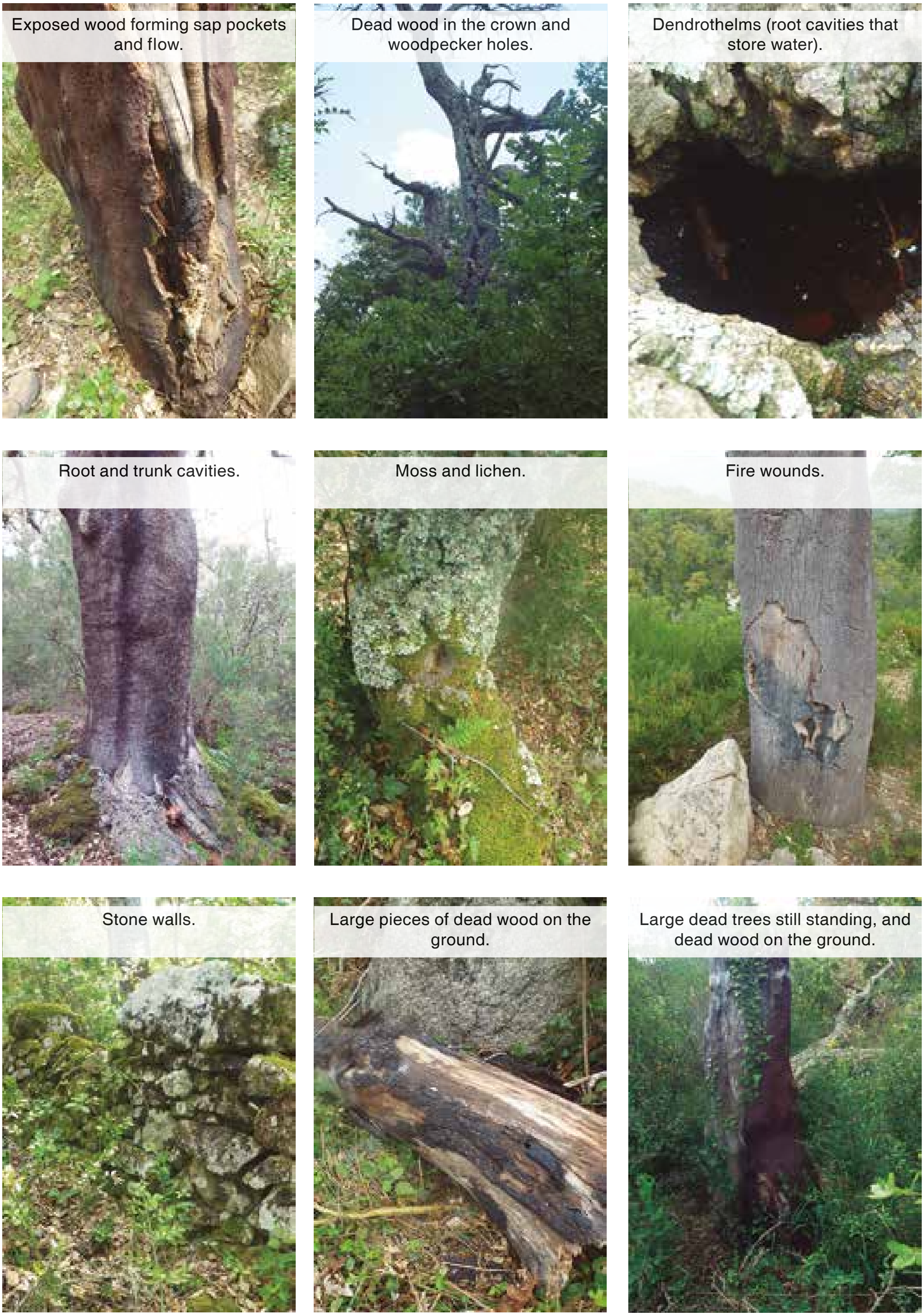


Figure 25. Some examples of key elements of biodiversity, identified in a cork forest in Alt Empordà.

Management models that optimise cork production by improving vitality and resistance to large fires: the example of the multifunctional ORGEST models in Catalonia

Generally speaking, **sustainable forest management already includes many of the traits defined for adaptive silviculture for climate change.** However, the particular characteristics of cork oak forest management (with low-weight clearing and little attention to regeneration) have some room for improvement.

In this regard, the application of already existing forest management models streamlined for cork production may, besides better long-term productivity, provide a series of adaptive benefits that are related to a greater increase in tree vitality with respect to conventional management. This is because they tend to propose low densities to concentrate production into fewer, larger trees.

If efforts are optimised from a multi-functional perspective, they can provide additional benefits related to aspects including measures to prevent large fires and a focus on regeneration, like the proposals in the Catalan ORGEST models.

The Catalan Guidelines for Sustainable Forest Management, or ORGEST, define innovative silviculture models that describe optimum management for the main forest species within a multifunctional context. For cork oaks, the ORGEST models (Vericat et al., 2013) outline three preferred goals:

- Cork production
- The prevention of large forest fires
- The improvement of cork oak forest vitality

The models defined for irregular cork oak forest structures (Figure 26) propose a series of silviculture models based on three basic criteria:

- *Definition of control parameters at forest level —basal area (BA) and canopy cover fraction (CCF)— **based on station quality**.* For high-quality stations, the structure optimising the goals of production, prevention, and vitality involves a **BA close to 20 m²/ha**, under cork. Meanwhile, for low-quality stations, it is a **BA of approximately 16 m²/ha**, always maintaining a **canopy cover fraction (CCF) of 60-70%** and a size group proportion favouring larger diametric classes.

- *Promotion of capitalised forests* with **larger trees** but less tree density per hectare. This seeks to maximise cork production over the cycle and harness the positive effect of high levels of cover on scrub control (thereby reducing the vertical fuel load and continuity as well as scrub removal costs) and on protection against erosion.

High station quality. Cork production and fire prevention.
Irregular structure with small copses. Reference distribution: $Dmax_{under\ cork}$: 55 cm; N: 390 trees/ha; $BA_{under\ cork}$= 20 m²/ha; CCF: 65%. Selection cutting in each cork stripping period (12-14 years) with removal of up to 20% of the initian BA.

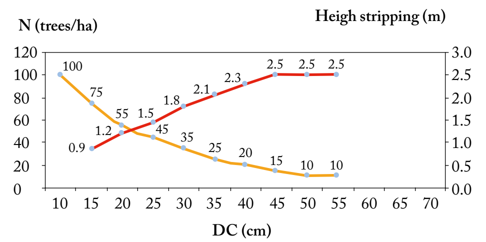
Qs01 MODEL

Products and functions

In each stripping period (12-14 years), approximately 4,000 kg/ha of cork is obtained, of which around 350 kg/ha corresponds to virgin cork (fresh weight). It is also possible to obtain approximately 15 t/ha of commercial firewood from selection cutting.

Silviculture parameters of the model

Size group	DC	Reference			
		N (trees/ha)	BA (m²/ha)	BA (%)	CCF (%)
Non inv.	5	>150	_	_	5
Small	10-15	175	2.1	10	10
Medium	20-30	135	6.4	31	22
Large	35-40	45	4.9	24	15
Large	≥45	35	6.7	33	19
Entire forest (CD≥10)		390	20.2	100	~65



Low-quality station. Cork production and fire prevention.
Irregular structure with small copses. Reference distribution: $Dmax_{under\ cork}$: 40 cm; N: 495 trees/ha; $BA_{under\ cork}$= 16,5 m²/ha; CCF: 60%. Selection cutting each cork stripping period (12-14 years) or every two seasons (28 years), removing up to 20% of the initial BA weight.

Qs07 MODEL

Products and functions

In each stripping perior (14 years), approximately 2,000 kg/ha of cork is obtained, of which around 250 kg/ha corresponds to virgin cork (fresh weight). It is also possible to obtain approximately 10 t/ha of commercial firewood from selection cutting.

Silviculture parameters of the model

Size group	DC	Reference			
		N (trees/ha)	BA (m²/ha)	BA (%)	CCF (%)
Non inv.	5	>150	_	_	5
Small	10-15	280	3.5	21	16
Medium	20-30	165	7.7	47	27
Large	35-40	50	5.3	32	16
Large	≥45	--	--	--	--
Entire forest (CD≥10)		495	16.5	100	~60

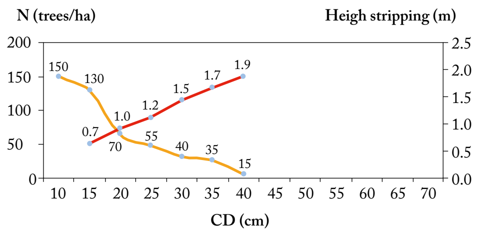


Figure 26. ORGEST models for uneven-aged cork oak forests in high quality sites (A-above) and low quality sites (C-below).

- *Structuring forests into* **small copses that encourage regeneration** and closer attention to the presence of all age classes, while always meeting the ecological requirements of the species (light levels according to developmental stage).

These models optimise cork production over the growing cycle, with production figures of 2,000 kg/ha of cork in low-quality stations and 4,000 kg/ha in high-quality stations. At present, the average production in Catalonia estimated by expert producers is 1,500 kg/ha, with certain exceptional plots of high station quality reaching 4,000 kg/ha.

One of the recommendations made as part of the Life+Suber project at landscape level, to overcome station quality limitation, is the **possibility of improving cork oak forest productivity by facilitating its advance towards areas of higher station quality for the species: productive hillsides or valley floors, which are traditionally reserved for more productive timber species** (*Pinus radiata, P. pinaster, Castanea*).

As regards adaptation of the forest to climate change, the ORGEST models provide:

- Flexibility in terms of the predict changes, by defining station quality according to parameters extrinsic to the forest (ecological variables, such as rainfall). Their possible change as a result of climate change would allow the control parameters to be adapted to the new situation.

- Improved forest vitality compared with conventional management (which applies low-intensity, almost sanitary, clearing), by encouraging capitalised structures with fewer trees, reducing individual competition. This is a key factor when facing less water availability. The impact of management on tree vitality has been assessed as part of the Life+Suber project (using the NDVI index) based on remote satellite sensing data from the Landsat and Sentinel missions (Figure 27). Similar cork oak forest management proposals in France and Turkey show a high degree of compatibility between this type of lower-density, although more capitalised, structures and increased water-use efficiency in trees (Khalfauri, 2018).

- Attention to regeneration, by proposing that cutting be carried out in small copses as a strategy to enhance the development of anticipated regeneration, present under the cover of cork oak and scrub, in forests with a shortage of young individuals allowing forest rejuvenation planting to be considered.

- Improved resistance and resilience to large forest fires, by creating structures with a vertical fuel discontinuity that is maintained over time and with young individuals

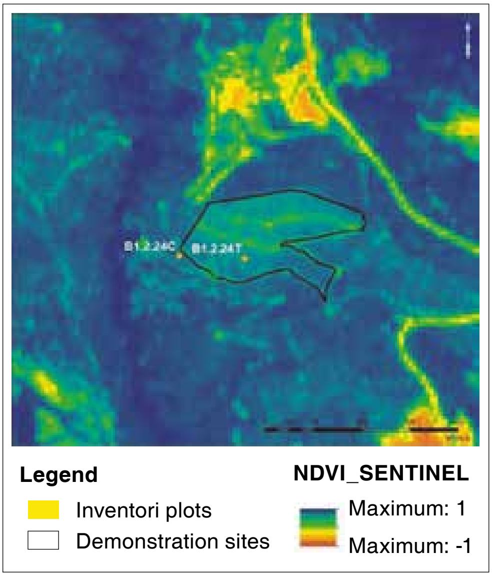


Figure 27. Example NDVI display with data from Sentinel in a demonstration stand for the Life+Suber project in Alt Empordà two years after the actions (Qs04 ORGEST models). This index allows tree vitality changes to be assessed in managed stands compared to unmanaged stands.

that are less vulnerable to fire (unstripped). The compatibility of production goals with the prevention of large fires in these models is developed in more detail in Section II of this guide.

- Encouraging species heterogeneity. Based on the ORGEST models for pure forests presented above, silviculture methods for the main mixed forests present in Catalonia have also been described. According to the dynamics of mixed forests and the specific productive criteria for each stand, various management options (Table 2), are recommended, which consider maintaining the two species at a stand level in varying proportions.

Although it is mathematically possible to optimise a management model that includes all the adaptation measures defined in the previous section, there will always be issues that will need to be applied at treatment level given that they relate to criteria for selecting the species and individuals to be cut, maintained, or enhanced at a microstation level. Some of these criteria are difficult to distinguish in silviculture models defined for forest parameters.

Table 2. Main mixed forests present in Catalonia, occupied surface area and management options considered in ORGEST (Vericat et a., 2013).

Mixed forests with cork oak	**Area (ha)**	**Maintain the mixed forest** (the 2 species with >20% BA)	**Progress towards cork oak dominance**	**Increase the proportion of the other species**
Cork oak and Aleppo pine	496	✓	✓	X
Cork oak and stone pine	16,631	✓	✓	✓
Cork oak and maritime pine	1,976	✓	✓	✓
Cork oak and holm oak	5,769	✓	✓	✓
Cork oak and oak	1,022	✓	✓	✓
Cork oak and strawberry tree	3,784	✓	✓	X
Cork oak and other broad-leaved trees	2,658	✓	✓	✓

Climate adaptation treatments proposed for cork oak forests

Silviculture treatments are defined according to forest parameters and fixed implementation criteria, which include adaptation criteria. Together these comprise the *silviculture standards* for the action. The standards are specific to each stand based on its characteristics and goals. Nonetheless, it is possible to define a series of general **climate change adaptation treatments for cork oak forest management** (Table 3):

Partial and selective scrub removal

Scrub is currently reduced by following cork-production-related criteria (ensuring worker safety, encouraging air circulation, and reducing the risk of cork oak trees being affected by the fungus *Diplodia corticola*), as well as criteria aimed at preventing large fires. Within a climate change context, the benefits offered by the presence of scrub are crucial and should be harnessed as far as possible while assessing the disadvantages of maintaining this in each stand.

- Weight: maintain part of the shrub cover at a variable percentage based on scrub removal needs or objectives. If the goal is to maintain a low vulnerability to crown fires and/or reduce competition for resources, scrub cover should be kept at no more than 30 or 40%. This criterion is compatible with the scrub removal logic for favouring access to the tree and may be a primary basic guideline for the person responsible for the work. Maintaining scrub in those areas with the least cork oak coverage should always be prioritised. In certain situations, the negative effect of the competition with scrub can be offset by its facilitator effect within a climate change context, which would advise against scrub removal. Examples of this include:

  - In coastal areas (the Montnegre and Les Gavarres ranges) or areas with regular mists, scrub (in particular *Erica*) can capture horizontal precipitation (mist) and thereby increase water availability (Botey, 2013). Maintaining this vegetation in stations less favourable for edaphic water retention should therefore be considered.

  - In areas exposed to strong and dry winds (Alt Empordà) where regeneration is the desired focus, scrub can act as a facilitator in the early stages of growth. For this reason, thickets should be maintained around saplings. If scrub is cleared, the scrub species that grow slowly or moderately fast, which perform this ancillary role of protecting, natural regeneration should be respected.

Table 3. Benefits and compatibilities of preventive management for large forest fires.

Adaptation measure	Consequences	Impact on the adaptive capacity to climatic change
1. Selection, cutting, with positive criteria and heterogeneity	• Reduced competition: more efficient water use and increased availability of water and other resources for the remaining individuals.	• Improved tree vitality, persistence (= resistance + resilience), and stand stability.
2. Capitalised stands (fewer, larger trees) and high cover	• Long-term control of the understorey maintaining vertical and horizontal fuel discontinuity and greater air circulation. • Greater extraction area, higher-calibre cork.	• Fire prevention. • Reduced risk of pests. • (Increased carbon fixation in the cork).
3. Attention to young specimens, which could grow from seed	• Presence of vital young specimens. • Forests can be renewed, more easily after disturbances (fires, drought, decay, etc.). • Greater genetic heterogeneity.	• Stand has increased persistence capacity. • Improved vitality.
4. Species and individuals of interest retaining during thinning (strawberry trees, English oaks, holm oaks, etc.)	• Heterogeneity of species and functional features. • Structure that favours greater biodiversity (e.g., living trees with microhabitats, dead trees still standing and on the ground).	• Improved habitat. • Improved stand biodiversity - greater pest-control capacity (e.g., presence of insectivorous birds). • Improved stand resilience.
5. Low-level selective thinning	• Reduced competition: more efficient water use and increased availability of water and other resources for the remaining individuals.	• Improved tree vitality and persistence and stand stability.
6. Pruning	• Smaller leaf area. Greater productivity and easier extraction - higher quality cork.	• Improved vitality.
7. Partial and selective conservation of the understorey (selective clearing)	• Partial presence: i) improved water availability (limited direct insolation, capture of horizontal precipitation); ii) greater potential diversity of faunal species able control pests. • Partial absence: i) better air circulation (fewer fungal attacks); ii) structure has horizontal discontinuity (hinders crown fires).	• Greated water availability at stand level. • Reduced attack of boring pests, e.g., the fungus *Diplodia corticola*. • Improved stand persistence and stability. • Fire resistance.
8. Chopping the remains from thinning and understorey removal, and distributing these in the stand	• Improved water availability in the stand.	• Improved the trees vitality.

- In very high-quality stands (for example, valley floors in dry areas), some managers maintain the competition from scrub in order to help achieve slower and more regular cork growth, improving its quality.

In stands where the problem is ladder fuel (such as high-quality stands where the dominant layer is taller than the high scrub), the removal of any scrub over 1.3 m tall can be applied as a guideline while always respecting a 30-40% scrub cover percentage and encouraging those species mentioned above as priorities.

- Criteris de selecció: priority should be placed on conserving clumps of resprouting vegetation (*Arbutus* and *Viburnum*), which should be thinned while maintaining the 1-3 most vigorous and vertical saplings per plant to encourage growth and increase the distance between the crown and the surface layer fuel. Priority should be placed on removing the species that grow fastest, the most pyrophitic germinators, and which are low-level (*Ulex* and *Cistus*), to remove both fuel from the surface and the most abundant species. Germinating species maintain an abundant seed bank in the soil. Efforts should be made to maintain individuals of fleshy-fruit-producing species, which attract various fauna that could potentially also predate *Coraebus*.

Selective mixed thinning based on improvement criteria (selection-cutting type)

The thinning goals should include: to reduce tree competition, matching stand structure with site quality; to guarantee the presence of young trees; and to promote heterogeneity.

- Weight: variable, but generally moderate (removing up to 20% of the initial basal area). Structures should be maintained with a CCF of at least 60% (low-quality stations) or 70% (medium- or high-quality stations) in order to avoid excessive scrub proliferation. Although cutting intensity should be adapted to the characteristics of each copse, a basal area of no more than about 20 m^2/ha should be left beneath the trees in high-quality stations and around 16 m^2/ha in low-quality stations.

- Selection criteria: remove the low-quality cork oaks in terms of cork production, maintaining dominant, healthy and vigorous trees that show a good rate of growth and productivity and are well shaped: straight and vertical, with a long trunk and balanced crown (Ø ≥1/3 h). Take the opportunity to encourage the most vigorous and productive cork oaks by removing their competition; **look for regeneration and encourage the presence of different age classes, concentrating the BA into the larger diameter classes (CD)** (>50% BA in trees with a

Figure 28. Left: total scrub removal. Right: partial and selective scrub removal with thinning of *Erica* plants.

diameter >35 cm). Maintain other tree species, mainly broad-leaved trees such as the strawberry tree (*Arbutus unedo*), English oaks and holm oaks (*Quercus* sp.), in a proportion that does not affect the development and production of the cork oak forest (maximum 20% of the BA), in pure forests. For mixed forests, follow the recommendations included in ORGEST (Vericat et al., 2013) for the different mixed forests. Identification and retention of key biodiversity elements in the stand (trees >CD45, trees home to microhabitats) and maintain or leave dead wood of DC>25 standing and on the ground.

Figure 29. Stand regenerated after cutting was carried out the year following a fire. Left: plant with non-differentiated regrowth. Right: differentiation of three dominant shoots.

Shoot selection (coppice)

Likewise thinning, selection of resprouts is necessari to reduce tree competition, and thus, to enhance the vitality of remaining trees.

- Weight: preferably leave one tree per stump, but if the regrowth is very young, abundant, and poorly differentiated, a maximum of three shoots per stump may be left.
- Selection criteria: it is preferable to leave the trees with the most vitality, greatest diameter and height, most vertical form, balanced crown (crown diameter larger than one third of the tree height), physical stability, strong ability to react to liberation (non-dominant shoots), and which are as far apart as possible if they are from the same stump.

Pruning

The goal is to encourage good quality future cork by raising the crown height, creating a branchless trunk of a height that enables easier cork harvesting.

- Weight: no pruning should take place above a height of 2/3 the total height of the tree. Efforts should be made to achieve the tallest branchless trunk possible. Branches to be removed should be cut before they reach 3 cm in diameter. In total, no more than 50% of the leaf surface area of the tree should be removed during pruning and trunk cleaning.

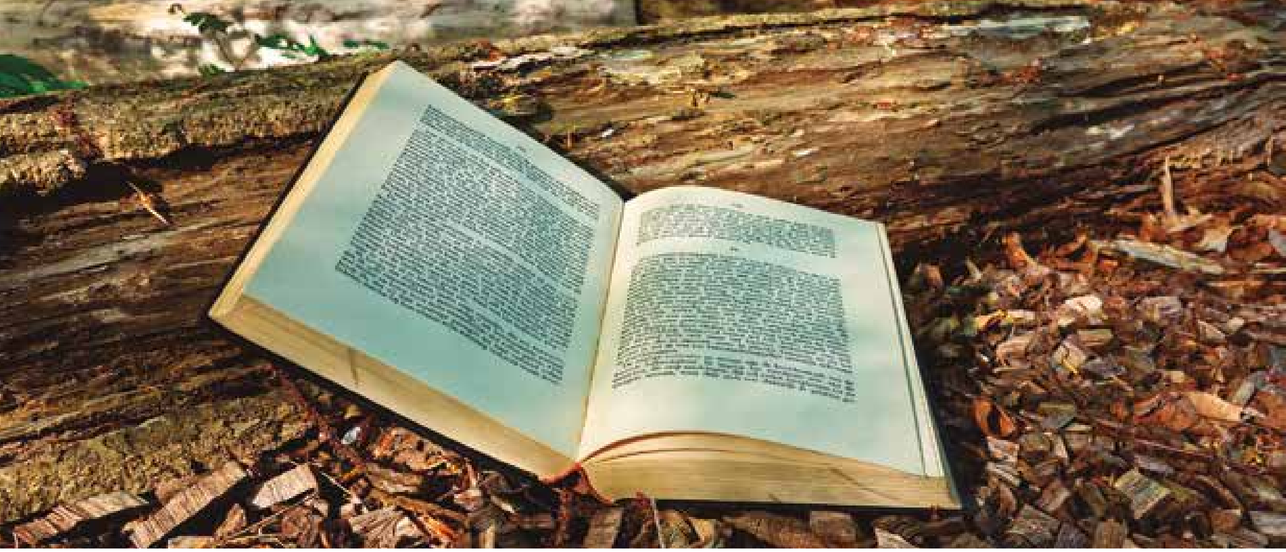
Figure 30. Cork stripping.

- Application criteria: in general, adult trees should not be pruned. This should only be carried out to respond to a clearly defined goal, such as the creation of vertical discontinuities to reduce the fire vulnerability of the crowns, or if the action is being taken achieve combined silvopastoral use. In these cases, maintenance pruning of adult cork trees should not affect more than one-third of the total crown biomass, nor branches with a diameter of more than 18 cm that modify the natural form.

Treatment of thinning remains

The main objective is to avoid fire risk. Generally speaking, *in situ* short crosscutting is performed to facilitate the rapid decomposition and absorption by the soil, or waste is removed or mechanically shredded in areas adjacent to paths. If the clearing is carried out by hand, the woody waste of over 5 cm in diameter is cut into pieces between 1 and 1.5 m in length and distributed evenly over the ground. If the clearing is mechanical, the waste should be shredded by the caterpillar brushcutter itself. In order to facilitate rapid decomposition and incorporation into the soil, *in situ* short crosscutting is recommended to ensure the waste is not more than 0.5 m above the ground and does not disrupt contour lines.

Figure 31. Stone pine cutting waste in a mixed cork oak-stone pine forest in Montnegre, cut into pieces and spread out.



References

Benito, M.; Alía, R.; Robson, T. M.; Zabala, M. A. 2011. *Intraspecific variability and plasticity influence potential tree species distributions under climate change*. Global Ecology and Biogeography, 20 (5), p.766-778.

Botey, J. 2013. *Bases para la creación de una selvicultura genuinamente mediterránea*. Actas del VI Congreso Forestal Espanyol. Vitòria-Gasteiz, p. 1-18.

Camprodon, J. 2013. *Ecologia i conservació dels ocells forestals. Un manual de gestió de la biodiversitat en boscos catalans*. Forest Science and Technology Centre of Catalonia - Ministry of Agriculture, Livestock, Fisheries and Food, Regional Government of Catalonia, Solsona. 225 p.

Emberger, C.; Larrieu, L.; Gonin, P. 2016. *Dix facteurs clés pour la diversité des espèces en forêt. Comprendre l'Indice de Biodiversité Potentielle (IBP)*. Technical document. Paris: Institut pour le développement forestier. 57 p.

González, JR.; Montero, G.; Ortega, C.1993. *Caracterización productiva de los alcornocales catalanes*. Investigaciones Agrarias. Sistemas y Recursos Forestales. Vol 2(1). Madrid, p. 55-69.

Khalfauri, M.; Siti, B.; Jebari, S.; Daly-Hassen, H. 2018. *Decision making support through spatially distributed valuation: Tunisian cork oak forest's ecosystem services*. INFORMED final meeting Minutes. Zagreb.

Liang, J., Crowther, T.W., Picard, N., Wiser, S., Zhou, Vayreda, J. 2016. *Positive biodiversity-productivity relationship predominant in global forests*. Science, 354 (6309), art. no. aaf8957.

Montero, G.; Torres, E.; Cañellas, I. 1994. *Regeneración de alcornocales*. Síntesis bibliográfica. Ecología (8). ICONA. Madrid, p. 271-283.

Piqué, M.; Vericat, P.; Cervera, T.; Baiges, T.; Farriol, R. 2014. *Tipologies forestals arbrades*. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST). The Forest Ownership Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia, Barcelona. 346 p.

Regato, P. 2008. *Adaptación al cambio global. Los bosques mediterráneos*. UICN Centre for Mediterranean Cooperation, Màlaga, Espanya. 254 p.

Serrada, R.; Aroca, M.J.; Roig, S.; Bravo, A.; Gómez, V. 2011. *Impactos, vulnerabilidad y adaptación al cambio climático en el sector forestal. Notas sobre gestión adaptativa de las masas forestales ante el cambio climático*. Ministry of the Environment, Rural and Marine Affairs, Madrid. 128 p.

Vericat, P.; Piqué, M.; Serrada, R. (eds.). 2012. *Gestión adaptativa al cambio global en masas de Quercus mediterráneos*. CTFC. Solsona. 171 p.

Vericat, P.; Beltrán, M.; Piqué, M.; Cervera, T. 2013. *Models de gestió per als boscos de surera* (Quercus suber *L.*)*: producció de suro i prevenció d'incendis forestals*. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST). The Forest Ownership Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia. 169 p.

Section II

Management for reducing the risk of large forest fires

Míriam Piqué
Eduard Busquets
Mario Beltrán

Large forest fires in Catalonia

Nowadays, forest fires are the main disruption affecting the Mediterranean region. The current landscape configuration and forest structure (with a large accumulation of fuel) gives rise to intense, fast-spreading fires that often surpass the capacity of fire extinguishing systems. These large forest fires, although rare compared with the total number of fires that affect Mediterranean areas, represent a serious environmental problem and pose a risk to human activity. They also jeopardise the continued existence of forest resources.

According to forest fire data from the Catalan Ministry of Agriculture, Livestock, Fisheries, and Food (excluding minor fires) for the period 1986 to 2017, an annual average of 12% of all fires in Catalonia exceeded 500 ha, accounting for 83% of the area burned each year. These annual averages fall when only considering the years from 1997 to 2017 (8% of fires were over 500 ha, accounting for 74% of the total area burned), or the most recent decade, from 2007 to 2017 (7% of fires were over 500 ha, accounting for 67% of the area burned).

Nonetheless, it should be noted that large fires are a complex phenomenon involving several different factors and the statistics from recent years may not reflect longer-term trends. For years now, work has been done on the «fire extinction paradox» concept (e.g., in Piñol et al., 2005), showing that greater effectiveness of small-scale fire extinction systems further encourages the accumulation of plant biomass, which could lead to more frequent large fires that surpass the capability of extinction systems.

The increased size and intensity of forest fires is usually presented as one of the main effects of climate change in the Mediterranean. Various factors contribute to this, but vegetation is one of the most important. Besides forests increasing in surface area and becoming denser, climate change aggravates the problem by facilitating the availability of vegetation as a fuel for these fires. The likelihood of a large forest fire increases with the increased frequency of extreme climate events (heatwaves, prolonged drought), in addition to rising temperatures and falling annual precipitation more concentrated into fewer rainfall episodes.

In order to discuss the prevention of large forest fires, we need to study the individual components of this risk: mainly the pattern, propagation, and behaviour of the fires with regard to the vegetation. There are two ways in which forest fires can spread, depending on the vegetation layer that fuels them: surface or crown. Usually, the former are low-medium intensity fires, while the latter are high-intensity fires. More specifically, they can be classified into (Figure 34):

- Surface fires. The flame spread via surface fuel and taller undergrowth.

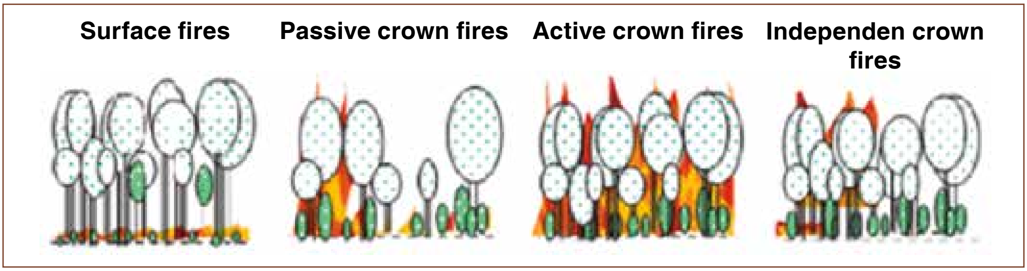


Figure 34. Types of forest fire based on the layer in which the fire spreads.

- Crown fires. The begin as a result of convective heat transfer from the surface fire to the tree crowns (Van Wagner, 1977). There are three sub-groups:
  - *Passive:* the crowns burn individually: convective heat transfer is insufficient to maintain inter-crown propagation.
  - *Active:* the fire spreads across the crowns and the surface in a continuous fashion but requires convectiva heat transfer to maintain inter-crown propagation.
  - *Independent:* the fire spreads between crowns independently of surface fire propagation. This type of fire is rare and develops under extraordinary meteorological conditions and on steep slopes.

Active crown fires represent the greatest threat to extinction systems because they generate high fire intensities, large-scale secondary outbreaks, tall flames, and propagation speeds that are twice those caused in a surface fire (Scott & Reinhardt, 2001).

To avoid such fires, it is very important that active forest management creates forest structures that hinder the spread of fires into the crown and facilitate fire extinction. It should also be taken into consideration that the weather often plays a more significant role in fire behaviour than the fuel itself. Generally speaking, Catalan cork oak forests are located in areas where the wind is usually a decisive factor in fire behaviour, especially in the Empordà region.

Broadly speaking, fires can be classified into three large groups according to the main factors defining their behaviour (Rothermel, 1972; Costa et al., 2011):

- Convection fires (standard or wind-driven). Widespread accumulation of forest fuel is the main cause of the fire intensity that develops.
- Wind fires (either over rough terrain or on the plains). Weather conditions are decisive in the behaviour of these fires, generally with high propagation speeds.

- Topographic fires. Complex orography and its interaction with convective wind caused bay the fire itself determine the behavious of these fires.

To define the fire regime for a given area, we use parameters of frequency (number of fires for a given period), recurrence period, burnt area, severity (affectation of organisms and functions of the system), intensity (physical magnitude of the energy liberated) and seasonality (Heinselman, 1981; Agee, 1993).

The Map of fire-type risk, produced by Piqué et al. (2001), allows to identify the areas with a higher probability to generate different typologies of big wildfires in relation to the characteristics of each area and its previous history of fire. Cork oak forests of Catalonia are mostly located in areas classified as of high or very high risk of fire (Figure 35).

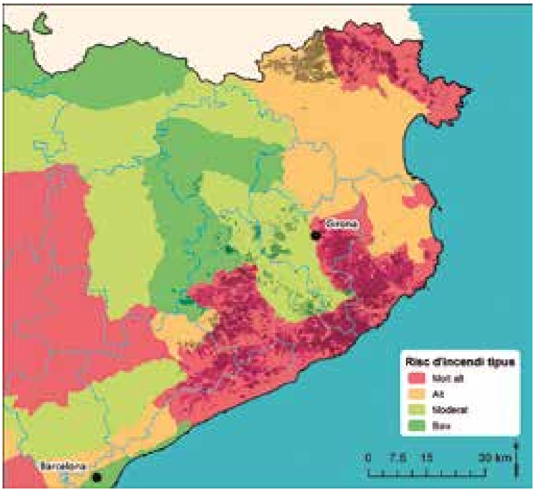


Figure 35. Detail of the Catalonia Fire Risk Map (Piqué et al., 2011) showing the distribution of Catalan cork oak forests (DGDRPF, 2016).

Fire behaviour in cork oak forest formations

In order to include the risk of large forest fires in forest management and planning for *Quercus suber* formations, we need tools that can help identify a forest's degree of fire vulnerability, and direct forest management towards forests that are more resistant and resilient to fire.

In this regard, it is important to consider the main factors that affect the behaviour and spread of a fire (topography, weather and fuel) (Rothermel, 1983) (Figure 36) and pay special attention to those that can be adjusted with forest management, like fuel (vegetation).

Forest typology, understood as the forest formation with a specific species composition and forestry characteristics relating to its structure and state of development (González-Olabarria et al., 2007), is essential for defining fire propagation and intensity (Dodge, 1972; Rothermel, 1991; Bilgili, 2003). Forest typologies with little fuel accumulation and forest structures with vertical discontinuity (in terms of vegetation layers) and horizontal discontinuity (in terms of crown and undergrowth cover) are more resistant to fire, hindering its spread and reducing its intensity.

Managed *Quercus suber* forests have structures that concentrate the fuel into the crowns, while presenting rather scarce undergrowth and a forest

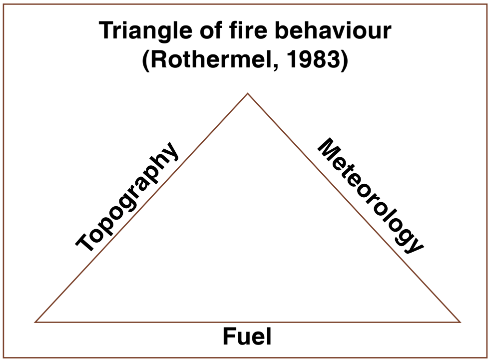


Figure 36. From a forest management and fire prevention perspective, it should be considered that fuel is the only factor that can be influenced when wishing to adjust fire behavious (Graham, et a., 2004).

structure with vertical discontinuity. This prevents fires spreading into the crown. Regrettably, however, there is increasingly less surface area with these characteristics. A lack of economic viability in the management of cork oak forests is leading to limitations on the maintenance work carried out, and the number of cork oak forest formations presenting dense undergrowth and fuel accumulation is on the rise. In extremely dry years, when the vegetation is very stressed, these forests present a high risk of large fires spreading through the crowns (Figure 37).

Resistance and resilience

Resilience is the ability of an ecosystem to absorb a disruption or alteration and recover systemic structures and processes similar to those that existed previously (Waltz et al., 2014). For example, in the case of cork oaks, the bark enables these trees to withstand high temperatures and survive a fire provided that the tissues with resprouting capacity are not affected. Nonetheless, changing fire patterns can potentially surpass the capacity of

Figure 37. High intensity wildfire in a cork oak forest, where fire has spread by the canopies.

Mediterranean forest systems to resist and recover following a disruption as intense as a LFF (Pausas, 2004).

Analysing the resilience of an ecosystem is complicated but, broadly speaking, requires a series of initial parameters to be defined. These can then be used to assess the resilience of a specific component to a particular disturbance (Waltz et al., 2014). In terms of the resilience of a Quercus suber forest to fire, including LFF, the main indicators are parameters related to forest structure (vulnerability to high-intensity fires) and, especially, the location of those structures. Other indicators may be related to forest vitality and water use efficiency under conditions of increasing aridity.

A cork oak forest with a structure less vulnerable to the outbreak and propagation of high-intensity crown fires, and which is also located at strategic points in terms of the behaviour of a LFF, is more resilient to forest fires. Furthermore, if the forest maintains good vitality, particularly the trees, for example, with low levels of competition for water resources, it is also more resilient to forest fires. Vitality leads to higher rates of growth, cork production, reserve storage, and seed production, meaning the forest can better resist periods of drought. This decreases the availability of dry fuel and enables more effective regeneration following a fire.

In Catalonia, various studies on forest adaptation to climate change (Lindner et al., 2010; Vayreda et al., 2012) have shown that forest management can play a major role in forest survival under more arid conditions by improving system vitality.

Traditional management for the prevention of forest fires

Silviculture proposals for forest fire prevention (e.g., Vélez, 2000; Serrada et al., 2008) focus on reducing the fuel load and creating large horizontal discontinuities, as well as a forest compartmentalisation strategy. However, their effectiveness is not guaranteed against certain types of fire, especially major wind-driven forest fires, one of the most devastating types. These activities are oriented strongly at fire defence, rather than preventing a fire from becoming a large forest fire. Hence, the likelihood of this not taking place in a firebreak area is limited when not combined with extinction efforts.

In addition, oak pasture structures that combine cork production and make a landscape more resistant and resilient to forest fires tend not to be used. However, considerable weight is still being given to extinction capacity, both in terms of speed and efficiency, as protection against forest fires.

Innovative practices and management recommendations for the prevention of large fires in cork oak forests

In addition, oak pasture structures that combine cork production and make a landscape more resistant and resilient to forest fires tend not to be used. However, considerable weight is still being given to extinction capacity, both in terms of speed and efficiency, as protection against forest fires.

One of the main innovations consists of approaching fire prevention by focusing on large forest fires at a landscape scale. Silviculture activities for prevention are prioritised in certain strategic areas for fire behaviour, with the aim of generating changes in the fires and creating extinction opportunities to avoid them becoming large forest fires (Figure 38).

One of the main innovations consists of approaching fire prevention by focusing on large forest fires at a landscape scale. Silviculture activities for prevention are prioritised in certain strategic areas for fire behaviour, with the aim of generating changes in the fires and creating extinction opportunities to avoid them becoming large forest fires.

Stand-scale measures

Within the current context of global change, the management of *Quercus suber* formations to prevent large

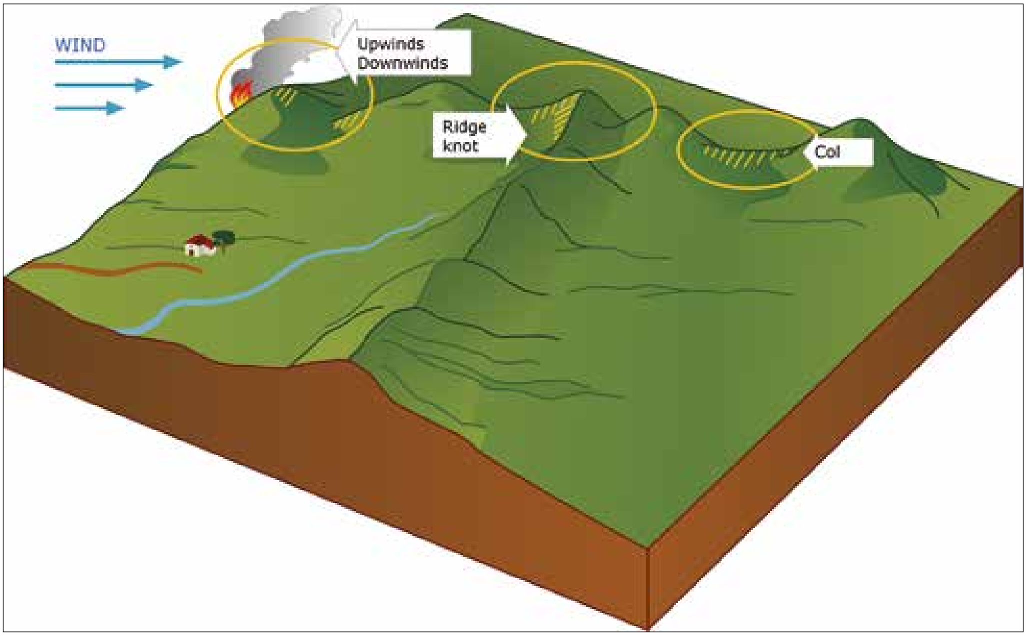


Figure 38. Example design for a firebreak area (linear) in riverbeds and flat areas (Vélez, 2000).

forest fires must include making these forests less vulnerable to generating fires that can spread through the crown and undertaking silviculture aimed at encouraging the intrinsic adaptability of these formations to fire.

In this regard, cork oaks (and quercines in general) have the advantage of already being adapted to fire, and therefore renewal disturbances, thanks to their ability to protect vital tissues and maintain reserves in their roots. This enables them to resprout following a fire, thereby enormously facilitating the adaptive management of these species and placing them among the species with the greatest resilience to fire.

For this reason, the goal for cork oak formations is to configure more fire-resistant forests that can even change the behaviour of a fire at certain strategic locations, thereby limiting the outbreak of high-intensity and widespread fires. This avoids traumatic ecological and economic losses, and we are sure that given a high intensity disturbance the system will have the capacity to renew itself. The main stand-scale management measures for adapting cork oak formations to climate change are:

- Fostering the natural resilience of these formations to fire, maintaining species vitality and heterogeneity (preferably broad-leaved trees).

- Creating formations that are less vulnerables (more resistant) to large forest fires by applying silviculture treatments and models for structuring the forest cover; basically thinning, clearing and scrub removal (Figure 39).

Figure 39. Stand included in the Life+Suber project where a forest structure that has low crown-fire vulnerability has been created by reducing shrub cover and increasing the vertical discontinuity with the crowns.

- Reducing the amount of fuel using silviculture treatments and waste management techniques, including the use of controlled fire in certain situations, although this must never directly affect the bark of cork oak trees to avoid decreasing cork quality.

- Encouraging the multifunctional use of cork oak forests by introducing grazing in those stands where it is important to maintain structures with less shrub-layer development, in other words, structures with low crown-fire vulnerability due to vertical and horizontal descontinuities in their vegetation layers.

Increased resistance and resilience

The prevention of large fires by increasing resistance is based on:

- Treatments to reduce forest fuel at strategic points for fire behaviour and for associated extinction activity, as part of a landscape-level prevention plan.

- Silviculture treatments where the new structures lead to significant changes in fire behaviour, mainly by reducing intensity and propagation speed.

- Actions that conseder natural dynamics and that are based on adaptive management, in order to find synergies with forest development that reduce implementation and maintenance costs. In general, the design of treatments should be based on minimal intervention and reduced cost, and their effect should last as long as possible.

Some of the main forest management actions that can be implemented to increase tree resistance to fire and, at the same time, facilitate the work of extinction teams, are increasing the distance between the ground and the base of the crowns, reducing the fuel load on the surface, and changing stand density.

Modifying or converting fuel models is mainly aimed at influencing fire behaviour. To do this, Agee & Skinner (2005) defined four basic principles for increasing the resistance of forest structures to fire (Table 6).

Similarly, in terms of increasing resilience, cork oak formations are already ideal due to their post-fire resprouting capacity. These formations are easily renewed following a fire, although it is important for fire-affected trees to be sufficiently developed and have enough vitality to ensure resprouting capacity. For this reason, encouraging the resilience of cork oak formations involves:

- Improving vitality. Some particularly interesting management models are those that lead to structures of low crown-fire vulnerability, especially regularised structures. It is also possible to create and maintain irregular structures that are low

Table 6. Basic forest management principles for reducing crown vulnerability to fire

Principle	Effect	Benefit	Comments
Reducing surface fuel load	Reduces flame height	Easy control, less crowning	This can be achieved with various types of action to reduce shrub cover and plant waste
Raising crown base height	Fire does not spread to the crowns	Less crowning	Surface wind speeds may increase
Reducing apparent density of the crowns	The spread of fire between crowns is reduced	Reduced potential of crown fire	Surface wind speeds may increase and surface fuel may contain less moisture
Leaving large trees	The crowns are located at a greater height	Increased survival	Cork oak forest regeneration should be ensured in certain situations

vulnerability, although their long-term maintenance may require greater management intensity. Selective pruning and scrub removal usually form part of these management models.

When dealing with a recently burned cork oak forest, it is necessary to ensure vigorous resprouting. This enables the original vegetation density to recover as naturally and quickly as possible, avoiding a profusion of low viability epicormic shoots that will compete against stump or root shoots. Thinning is usually needed for the youngest burned trees.

- Maintaining a certain degree of tree diversity. Despite the cork oak's ability to respond to fire, other tree species should be maintained that have varying responses to disturbances. This will maintain a certain degree of strategy diversity for forest recovery following a disturbance. In addition, in forests dominated by other species where the cork oak is an accompanying or occasional species, it may be of interest to encourage and maintain the presence of this species due to its differentiating role in the response to disturbances.

Treatment of plant waste following silviculture operations

When undertaking action on the trees or scrub that generates a significant amount of waste, this should be treated to avoid the accumulation of surface fuel, prevent interference with forest regeneration, and facilitate the rapid incorporation of this organic matter into the soil.

The most common techniques for treating such waste that should be taken into consideration for cork oak forests are:

- Cutting the largest woody remains into small pieces (1 m maximum) so that they lie as flatly as possible on the ground.

- Piling up and cordoning off the waste. This may be particularly necessary for regeneration cutting where the new shoots and seedlings need as much soil and light as possible. For selection cutting in irregular forests or regeneration cutting in regular forests, attempts should be made not to cover any cut stump in order to allow successful resprouting. However, this may be a costly process and may also encourage the growth of brambles in some areas.

- Piling up and burning the waste, in order to ensure total elimination of the dead fuel that remains on the ground. Another option is to carry out extensive burning (controlled burning) of the waste, although such action requires significant technical resources and knowledge, and it is particularly important to avoid the fire touching the surface of the cork surface so its value is not decreased.

- Chipping or shredding *in situ* a mobile chipper or shredder, having previously cordoned off the waste, or at the same time as scrub removal. Woodchips help control scrub response and maintain a certain level of moisture in the soil, into which it is incorporated fairly quickly. This is a high-cost option and limited by accessibility and the mobility of the machinery.

- Pathside chipping or shredding, removing the waste manually, with a winch or *skidder*. This is a high-cost option that should be used in certain situations where various management objectives converge.

Forest-and landscape-scale measures

Based on the study of the various types of fire and historical fire records (behaviour patterns), for specific areas it is possible to identify the strategic points where fire prevention measures should be concentrated. Landscape-level measures allow “fire-smart” landscapes to be created, with forest structures and spatial distribution patterns that help hinder crown fire propagation and facilitate the extinction of forest fires (Costa et al., 2011).

Three types of actions or measures can be differentiated for cork oak forests:

- Specific timely actions to defend against fire associated with extinction efforts. These are determined according to the characteristics and propagation patterns of the various types of fire that may occur in a certain area, especially the most dangerous ones. These actions relate to strategic management points (SMP), low fuel load zones, and ancillary strips adjacent to paths.

- Actuacions per la formació d'una matriu de coberta forestal amb una estructura que dificulti el desenvolupament i propagació dels GIF, i que també contribueixi indirectament a incrementar les oportunitats i capacitats d'extinció.

- Actions for encouraging heterogeneity at a landscape level, mainly in structures.

Catalan Guidelines for Sustainable Forest Management (ORGEST)

ORGEST constitutes a series of technical tools for supporting decision-making processes in forest management and planning. These have been developed from an adaptive and multifunctional point of view, and also incorporate climate change.

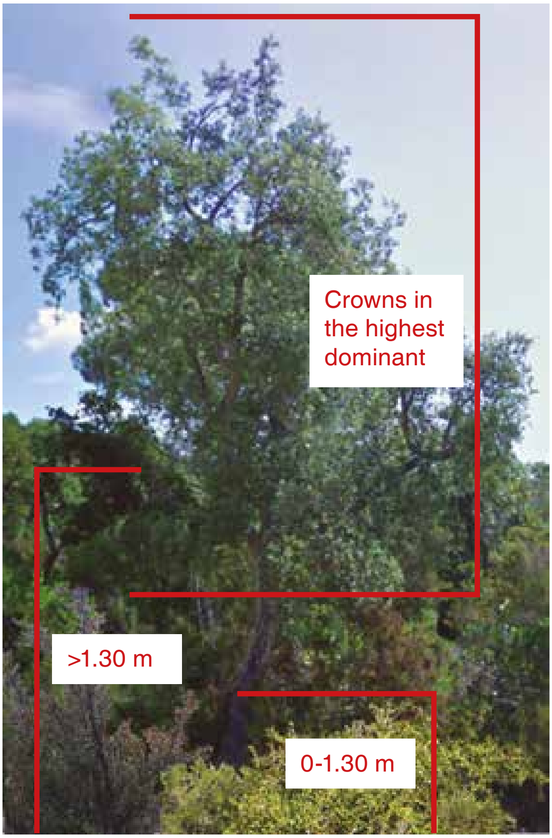
The ORGEST management models for cork oak forests (Vericat et al., 2013) present a series of silviculture models adapted to various management scenarios based on forest station quality and priority goals. To prevent large fires, there are a series of specific management models for creating and maintaining structures that have a low vulnerability to crown fires, which are particularly recommended for implementing at strategic locations.

The control parameters for these management models refer primarily to the forest structure, which is analysed according to the vegetation stratification shown in Figure 40. The main variables are the heights and cover of the various layers and the vertical distances between them:

- High vulnerability (A). Forest structures with silviculture characteristics (e.g., vertical and horizontal continuity of the various layers, and canopy cover fraction) that mean fire rises into the crowns and continues to burn. Structures characterised by active crown fire, the surface fire generates sufficient convection heat to consistently maintain fire propagation into the crowns. The structures affected by this kind of fire usually involve high mortality rates.

- Moderate vulnerability (B). Forest structures with silviculture characteristics (e.g., vertical and horizontal continuity of the various layers, and canopy cover fraction) that limit fires rising into the crowns more than A structures. Structures that generate crowning and secondary outbreaks which burn passively in crowns, groups of small trees catch fire, but inter-crown propagation is not consistently maintained. The structures affected by this kind of fire usually suffer less severe effects than the previous category. The existence of a mixture of entirely burned trees and others with a high percentage of singed crown are characteristic of these stands. Some also have a green crown.

- Low vulnerability (C). Forest structures with silviculture



AERIAL FUEL: Formed by the crowns of the trees in the highest dominant or co-dominant layers.

LADDER FUEL: Aerial fuel at heights of above 1.3 m that is not part of the dominant or co-dominant layer. This includes small trees, shrubs, lianas, and fallen trees.

SURFACE FUEL: Fuel at heights of below 1.3 m. This can be scrub, herbaceous vegetation, fallen branches and trunks, and silviculture waste.

Figure 40. Fuel stratification for defining structure vulnerability.

characteristics (e.g., vertical and horizontal continuity of the various layers, and canopy cover fraction) that limit both fire in the crowns and the sustainability of this. The fire propagates below the aerial fuel. The surface and ladder fuel, if present, is consumed but the vertical discontinuity with the aerial fuel means that the fire does not spread into the crowns and remains at ground level. The structures affected by this kind of fire usually involve low mortality rates. An occasional tree may die. This category includes regenerated forests because the fires they generate are, from an extinction point of view, similar to those of a surface fire although, in the majority of cases, tree mortality is absolute.

Benefits and compatibilities of management for reducing the risk of large forest fires

Management for reducing the risk of large forest fires (Figure 41) based on ORGEST is part of Sustainable Forest Management, understood as the stewardship and use of forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems (Helsinki Ministerial Conference, 1993). Table 7 contains a series of benefits and compatibilities that may be generated through management for reducing the risk of large forest fires.

Figure 41. One of the ORGEST objectives for preventing large forest fires is to reduce the capacity of cork oak forest structures to generate high-intensity fires (Photo: Fire Service of the Regional Government of Catalonia).

Practical cases of cork oak forest management for the prevention of large forest fire

Measures implemented in the Life+Suber project

Actions to prevent large forest fires have been undertaken in eight stands, with a total area of 33 ha. These involve one stand of high forest station quality and another of low quality in each area (Alt Empordà, Gavarres, Montseny-Guilleries, and Montnegre-Corredor).

Objectives and definition of the measures

The objective is to prevent forest fires by creating and maintaining forest structures of low crown-fire vulnerability in locations identified as strategic at landscape level in relation to the

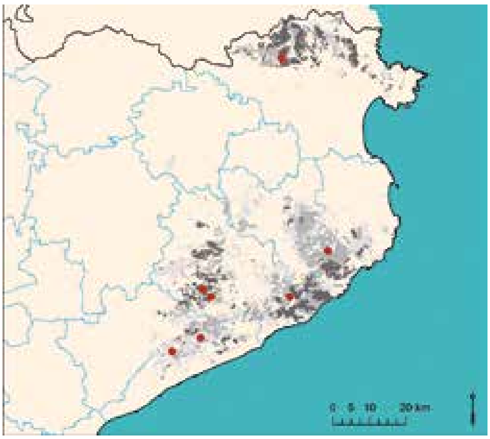


Figure 42. Localization of the 8 stands where silviculture activities have been implemented to prevent large forest fires.

Table 7. Benefits and compatibilities of LFF preventive management

Measure of adaptation	Consequences	Impact on the capacity to adapt to climate change
Use of silviculture that maintains a low CCF (cration of forest pastures) with larger existing trees at strategic locations	• Creation of horizontal discontinuity at crown level. • Creation of safety areas for extinguishing fires. • Increased stripping intensity. • Opportunity or grazing use.	• Prevention of fires. • Increased carbon capture by existing trees. • Increased blue water in the system (groundwater recharging).
Elimination of scrub cover (selective scrub removal)	• Creation of horizontal and vertical discontinuity at ground level. • Reduced intra-species competition. • Reduced management costs (strategic points).	• Prevention of fires. • Increased blue water in the system (groundwater recharging).
Silvopastoral management for controlling scrub	• Creation of horizontal and vertical discontinuities at ground level. • Reduced intra-species competition. • Development of the local economy.	• Prevention of fires. • Protection of the carbon stock.
Products from preventive treatments used as biomass (firewood)	• Creation of horizontal discontinuity at crown level. • More profitable treatment. • Development of the local economy.	• Prevention of fires. • Zero CO_2 balance and encouragement of renewable energies.
Encouragement of cork oak in forests dominated by other species	• Increased cork production.	• Increased resilience to forest fires.
Creation of a forest cover matrix	• Hindered development and propagation of LFF. • Increased fire-extinguishing opportunities and capabilities. • Landscape repurposing.	• Prevention of fires.

behaviour of large forest fires (Figure 43). Pasture structures are generally proposed with the aim of generating strong fuel discontinuity, which may be useful for developing specific extinction measures in the event of a fire with the potential to become a LFF. Likewise, the pasture structure enables stripping intensity to be increased and fire prevention to be made compatible with cork production and grazing use.

The objective structure is a regularised forest with a CCF of approximately 40%, with the greatest vertical discontinuity possible between the crowns and lower vegetation layers, which, in turn, should have sparse cover. The reduced density allows cork production to be increased because inter-tree competition is limited.

High-quality stations are preferentially located in mosaic areas with crops where a sizeable low-vulnerability area was created, as well as on valley floors. Low-quality station qualities are

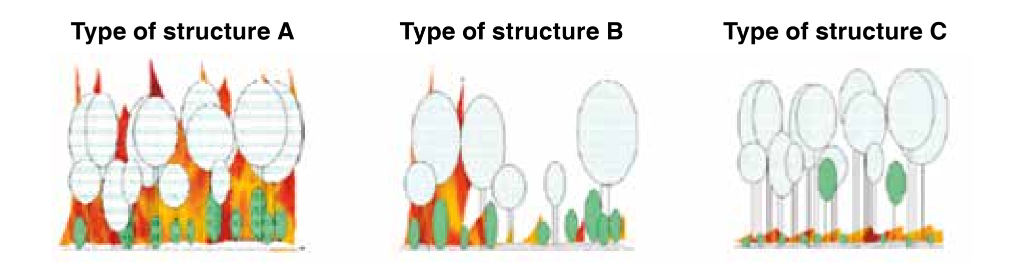


Figure 43. Diagram of the forest structure based on the three vulnerability categories defined by Piqué et al. (2011) (Structure type A), (Structure type B), (Structure type C).

preferentially located on crests and in dividing areas. The actions include intensive clearing and selective scrub removal. Clearing reduces the initial basal area to 10 m^2/ha beneath the trees, achieving a CCF of close to 40%. The selective removal eliminates part of the scrub, principally maintaining species like *Arbutus unedo* and eliminating other more flammable species, reducing the scrub layer to effectively reduce the propagation of fire into the crowns.

The silviculture work is a combination of selective scrub removal (with a variable weight of shrub cover removed from 90-100% to 40-60%), selection cutting, to a varying extent but generally intense (>40% of the initial BA), and the treatment of plant waste (generally, in situ short crosscutting to facilitate rapid decomposition and incorporation into the soil).

Main results

The actions designed for each of the eight stands were implemented successfully between January and April 2016. At the same time, forest dasymetric parameters were tracked in order to monitor the actions and compare the results before and two years later. Figure 44 shows the change in appearance of a stand where action was carried out.

Figure 44. Appearance prior to action, afterwards and two years later at the stand in Mas Genís, Empordà.

The main result of the actions was reduced structure vulnerability. Analysing the data from all the stands as a whole, Figure 45 shows the evolution of vulnerability according to the abundance of the various structure types defined by Piqué et al. (2011). The structures most vulnerable to fire are category «A», while the least vulnerable are category «C». The actions generate structures that are less vulnerable to fire and this improvement is generally maintained over the subsequent two years, although some high-vulnerability structures can already be seen.

The largest reduction in the fire vulnerability of the crowns is apparent immediately after the actions, when all the crowns in all the stands show low vulnerability to fire. Two years after the treatments, 25% of the structures continue to show low vulnerability, 50% show moderate vulnerability, and 35% show high vulnerability. These cases refer to structures where the main trees are relatively short and the crowns do not have sufficient vertical discontinuity from the ladder and surface layers, which also have a significant capacity to resist intervention. As tree height and cover develops, further limiting scrub development, the low-vulnerability structures generated by future actions will have increased durability.

Figure 46 shows the evolution of diametric distribution. It can be seen that density per DC has been displaced towards the larger categories two years after the treatment, reflecting tree growth. The density of DC5 and DC10 has fallen considerably from 88 and 100 trees/ha to 45 and 38 trees/ha, respectively. DC20 is the diametric category showing the greatest increase following the treatments, returning to initial levels.

As a result, cork oak forests are moving towards more regularised, low density structures, but with larger trees.

Furthermore, the actions also served to regulate the specific composition (Table 8), limiting the presence of conifers. The basal area of other broad-leaved trees has been reduced, but this is basically due to the elimination of a large number of arborescent trees of species like the strawberry tree and heather. These were competing against or limiting the

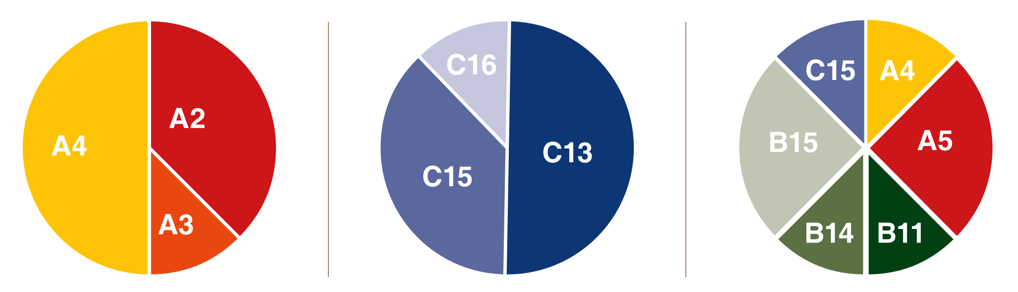


Figure 45. Evolution of forest structure vulnerability in the stands for actions aimed at preventing large forest fires in strategic locations. Left: before the actions. Centre: immediately afterwards. Right: two years later.

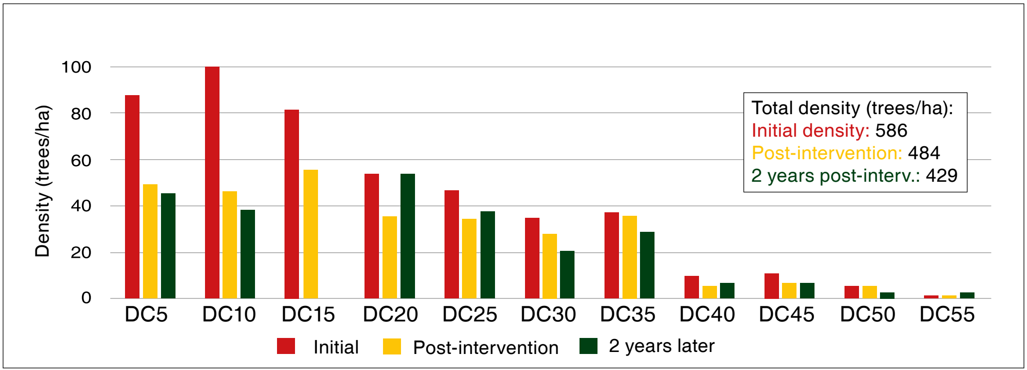


Figure 46. Diametric distribution of cork oaks in the stands for action aimed at preventing forest fires in strategic locations; prior to the actions, immediately afterwards, and two years later.

Table 8. Average basal area percentage based on specific composition in the stands for actions aimed at preventing fires in strategic locations

	Quercus suber	Conifers	Other leafy vegetations
Prior to the action	75%	2%	23%
Afterwards	88%	0%	12%
Two years later	87%	0%	13%

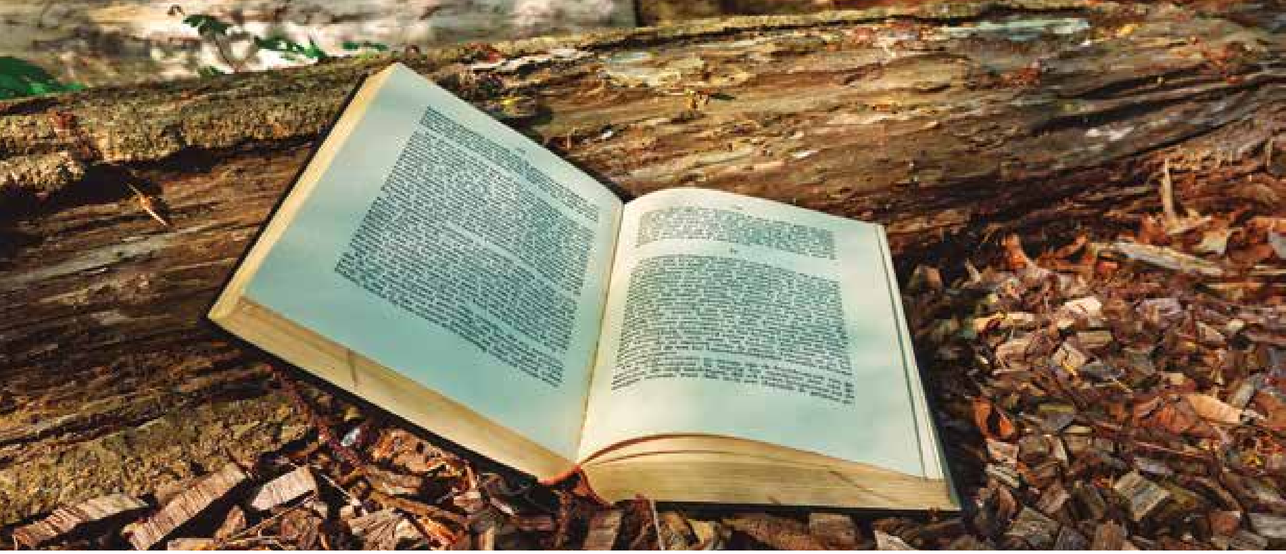
development of cork oaks and generating high levels of ladder fuel cover.

Finally, Table 9 shows the evolution of CCF in order to see the effect of the treatments on crown structure. It can be seen that there was a reduction of approximately 20% following the treatment, although the cover had risen slightly two years later due to crown development.

Table 9. Evolution of average canopy cover fraction (CCF) calculated from hemispherical photographs in the stands for actions aimed at preventing fires in strategic locations

	CCF
Prior to the action	81%
Afterwards	62%
Two years later	68%

Figure 47. The structures created by the actions in the Life+Suber project are perfectly compatible with grazing use.



References

Agee, J. K. 1993. *Fire Ecology of Pacific Northwest Forests*. Island Press, Washington DC. 505 p.

Agee, J. K.; Skinner, C. N. 2005. «Basic principles of forest fuel reduction treatments». Forest Ecology and Management, 211 (1-2): 83-96.

Bilgili, E. 2003. «Stand development and fire behavior». *Forest Ecology and Management*, 179 (1-3): 333-339.

Cooper, C. F. 1960. «Changes in vegetation, structure, and growth of south-western pine forests since white settlement». *Ecological Monographs*, 30 (2): 130-164.

Costa, P.; Castellnou, M.; Larrañaga, A.; Miralles, M.; Kraus, D. 2011. *La prevención de los grandes incendios forestales adaptada al incendio tipo.* GRAF-Technical Unit, Ministry of Home Affairs, Regional Government of Catalonia, Barcelona. 87 p.

DGDRPF. 2016. *Mapa forestal de España. Scale 1:25.000. Catalonia*. Directorate-General of Rural Development and Forestry Policy. Ministry of Agriculture, Food and Environmental Affairs, Madrid.

Dodge, M. 1972. «Forest fuel accumulation-a growing problem». *Science*, 177 (4044): 139-142.

González-Olabarria, J. R.; Kolehmainen, O.; Pukkala, T. 2007. «Using expert knowledge to model forest stand vulnerability to fire». *Computers and Electronics in Agriculture*, 55 (2): 107-114.

Graham, R. T.; McCaffrey, S.; Jain, T. B. 2004. «Science basis for changing forest structure to modify wildfire behavior and severity». *General Technical Report* (RMRS-120). USDA Forest Service, Fort Collins, CO. 43 p.

Heinselman, M. L. 1981. «Fire intensity and frequency as factors in the distribution and structure of northen ecosystems». En: Mooney, H. A.; Bonniksen, J. M.; Christensen, N. L.; Lotan, J. E.; Reiners, W. A. (eds.). *Fire regimes and ecosystem properties*. USDA Forest Service. Washington DC, p. 7-57. (GTR-WO-26).

Lindner, M.; Maroschek, M.; Netherer, S.; Kremer, A.; Barbati, A.; Garcia-Gonzalo, J.; Seidl, R.; Delzon, S.; Corona, P.; Kolström, M.; Lexer, M. J.; Marchetti, M. 2010. «Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems». *Forest Ecology and Management*, 259 (4): 698-709.

Pausas, J. G. 2004. «Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin)». *Climatic Change*, 63 (3): 337-350.

Piñol, J.; Beven, K.; Viegas, D. 2005. «Modelling the effect of fire-exclusion and prescribed fire on wildfire size in Mediterranean ecosystems». *Ecological Modelling*, 183 (4): 397-409.

Piqué, M.; Castellnou, M.; Valor, T.; Pagés, J.; Larrañaga, A.; Miralles, M.; Cervera, T. 2011. *Integració del risc de grans incendis forestals (GIF) en la gestió forestal: Incendis tipus i vulnerabilitat de les estructures forestals al foc de capçades. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST)*. The Ownership Forest Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia, Barcelona. 122 p.

Rothermel, R. C. 1972. «A mathematical model for predicting fire spread in wildland fuels». *Research* *paper (INT-115)*. USDA Forest Service, Ogden, UT. 40 p.

Rothermel, R. C. 1983. «How to predict the spread and intensity of forest and range fires». *General Technical Report* (INT-143). USDA Forest Service, Odgen, UT. 161 p.

Rothermel, R. C. 1991. «Predicting behavior and size of crown fires in the Northern Rocky Mountains». *Research Paper (INT-438)*. USDA Forest Service, Ogden, UT. 46 p.

Scott, J. H.; Reinhardt, E. D. 2001. «Assessing crown fire potential by linking models of surface and crown fire behavior». *Research paper (RMRS-29)*. USDA Forest Service, Fort Collins, CO. 59 p.

Serrada, R.; Aroca, M. J.; Roig, S. 2008. «Selvicultura preventiva de incendios». En: Serrada, R.; Montero, G.; Reque, J. A. (eds.). *Compendio de selvicultura aplicada en España*. National Institute for Agricultural and Food Research and Technology, Ministry of Education and Science. Madrid, p. 949-980.

Van Wagner, C. E. 1977. «Conditions for the start and spread of crown fire». *Canadian Journal of Forest Research*, 7 (1): 23-34.

Vayreda, J.; Martinez-Vilalta, J.; Gracia, M.; Retana, J. 2012. «Recent climate changes interact with stand structure and management to determine changes in tree carbon stocks in Spanish forests». *Global Change Biology*, 18 (3): 1028-1041.

Vélez, R. 2000. *La defensa contra incendios forestales. Fundamentos y experiencias*. Mc Graw Hill, Madrid.

Vericat, P.; Beltrán, M.; Piqué, M.; Cervera, T. 2013. *Models de gestió per als boscos de surera* (Quercus suber *L.): producció de suro i prevenció d'incendis forestals. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST)*. The Ownership Forest Centre. Ministry of Agriculture, Livestock, Fisheries and Food. Regional Government of Catalonia. 169 p.

Waltz, A. E. M.; Stoddard, M. T.; Kalies, E. L.; Springer, J. D.; Huffman, D. W.; Meador, A. S. 2014. «Effectiveness of fuel reduction treatments: Assessing metrics of forest resiliency and wildfire severity after the Wallow Fire, AZ». *Forest Ecology and Management*, 334: 43-52.

Section III

Restoration of Degraded Cork Oak Forests

Roser Mundet
Josep M. Tusell
Joan Abel

Description of Degraded Cork Oak Forests

A cork oak forest is considered to be affected by degradation when it presents low vitality. Forest vitality refers to a vegetative condition that enables a forest to withstand alterations or unfavourable events vhile also facilitating potential regeneration (Vericat et al., 2012). In other words, a degraded or low vitality cork oak forest performs far below its potencial in terms of productivity and ecosystem service provision.

50% of cork oak forests in Catalonia have been abandoned and a large number of them are degraded to a certain degree. The main symptoms of degradation, some of which are interrelated, are:

- Advanced senescence, ageing forest masses with little vigous.
- Insufficient or non-existent regeneration.
- Cork growth and productivity far below forest station potencial.
- Deficient density, with abundant open spaces usually occupied by scrub and herbaceous vegetation.
- Excessive density, with the forest mass stagnating and a highly simplified structure.
- Abundant presence of tree-like scrub, with heights, densities, and high cover that compete with the cork oaks for light, water and nutrients.

Main Causes of the Degradation

The main causes of cork oak forest degradation, which are closely interrelated, are:

- Fire. The cork oak is a typically Mediterranean species and cork oak forests are periodically affected by forest fires. In Catalonia, over 80% of the surface area is in a zone with a very high fire risk and over 95% has a high to very high fire risk (Nebot et al., 2013).

  The survival rate for cork oaks following a fire can be as high as 70% due to the protection afforded by the bark and their strong regrowth capacity. This percentage increases in younger trees, such as virgin (never stripped) specimens, or when the cork layer is at least 20 mm thick, which is sufficient to provide the tree with adequate protection against fire (data obtained from experimental plots in the SUBERNOVA Project).

  In any case, even where defence mechanisms exist (cork layer and regrowth capacity), the combination of fires with other biotic and abiotic agents can threaten the viability of these forests. Furthermore, the effect of a fire on a recently stripped forest can seriously compromise future productivity.

- Damage caused by other abiotic agents. The main abiotic agents that directly or indirectly damage cork oak forests and whose impact is expected to be aggravated by climate change in the Mediterranean region (Vericat et al., 2012) are:

  - Drought: in the same way as fire, this phenomenon is intrinsic in the Mediterranean and occurs every year. The cork oak has defence mechanisms against drought, but the intensity and duration of the drought may mean these become ineffective.

  - Snowfall: heavy snowfall is a rare phenomenon in areas where cork oaks grow and may only occur at intervals several decades apart. When it does occur, however, it can cause severe damage (mainly broken branches) because this species is nor very well adapted to this phenomenon.

  - Extreme temperatures and wind, storms: although these phenomena do not usually have a major impact on cork oak trees, they can weaken forests or increase their susceptibility to other threats. For example, the impact caused by northerly winds can limit cork oak development and productivity (Montero & López, 2008).

- Damage caused by biotic agents. Acorns and young saplings are eaten by both domestic and wild fauna (particularly wild boar), which can significantly hinder forest

Figure 48. Cork oak affected by heavy snowfall in Les Gavarres area, 2010.

regeneration. Two diseases that cause serious damage are *Diplodia corticola*, which leads to «bot canker», and *Biscogniauxia mediterranea*, which leads to «charcoal canker». One of the most significant pests that affects cork and jeopardises its commercial viability is the flathead oak borer (*Coraebus undatus*), a buprestid beetle that bores galleries into the cork during its larval stage (described in more detail in Section IV). The incidence of this pest seems to be associated with low tree vigour and water stress. Other cork borers that can cause damage are the ants *Lasius brunneus* and *Crematogaster scutellaris*. Finally, other pests that weaken these forests include defoliating lepidopterans (*Lymantria dispar*, *Tortix viridana*, *Catocala nymphagoga* and *Malacosoma neustria*) and the true weevil (*Curculio elephas*), which bores into acorns during its larval stage, affecting their viability. In an indirect way, soil compaction from overgrazing can also significantly limit natural regeneration.

- Poor management practices. Inadequate management contributes to the degradation of cork oak forests. The main problems are related to overexploitation and improper tree management: stripping too early, too often, or too high, stripping on rainy days or in dry wind, damage to the mother layer caused by poor cork extraction (Figure 49) or excessive pruning for firewood. Other poor practices include overgrazing, focusing management exclusively on cork operations without paying attention to forest regeneration, repeated land burning to maintain it for pasturing, land clearing that disturbs the soil in areas with moderate or severe gradients, and repeated tilling, especially when this takes place beneath the tree crown, in areas used for grazing (SUBERNOVA, 2005). A number of these practices, particularly those affecting soil quality, represent a serious impediment to either natural or artificial regeneration of cork oak masses because they affect the area to such an extent they make it unviable for new cork oaks (Montero & López, 2008).

- Abandonment. Cork oak forests are located in areas that have been heavily used by humans for millennia, meaning that present day forests are the result of a lengthy interaction with human beings. Abandonment usually leads to a steady over-densification of the forests and a series of negative consequences: there is greater vulnerability to forest fires, a loss of vitality and capacity for sexual reproduction, and it becomes increasingly difficult to profitably reactivate management. In the case of open forests or those used for grazing, abandonment leads to the excessive proliferation of scrub. This then competes with the cork oaks, preventing natural regeneration, increasing vulnerability of the forest to fire and hindering future exploitation (Figure 50).

Figure 49. Damage to the mother layer caused by poor cork extraction.

Figure 51 shows the relationships between the main causes of cork oak forest degradation. In exceptional cases, degraded cork oaks may exist due, to significant forest station limitations, such as the upper altitude limit, or the shallow and stony soil frequently associated with steep gradients, leading to much shorter or thinner trees. In these situations, no improvement action is required as the height and thickness will not be affected by thinning (Vericat et al., 2012).

Figure 50. Cork oak forest where there has been management for many years. This is a stand in the Life+Suber project prior to the degraded cork forest recovery action.

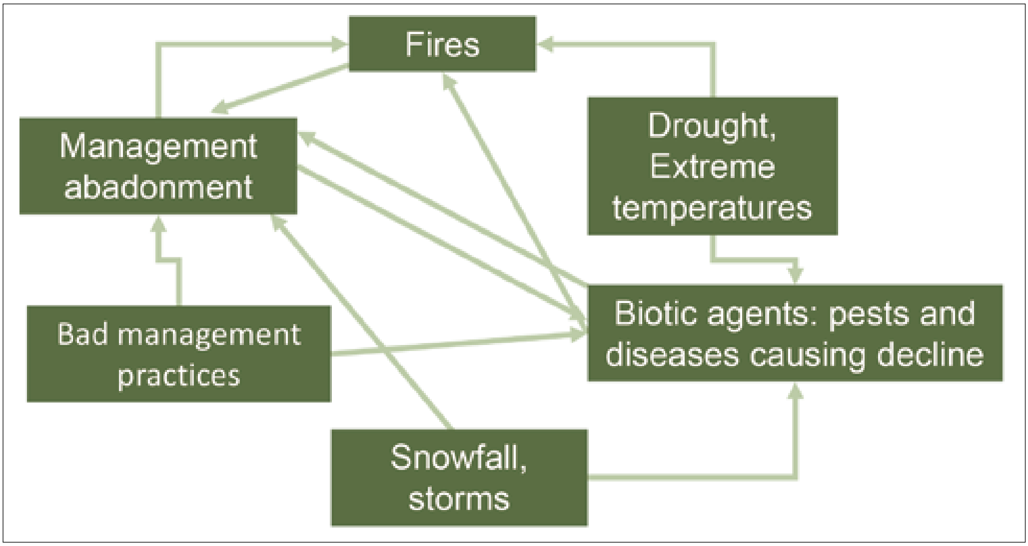


Figure 51. Diagram of relationships between the main causes of cork forest degradation.

Degraded Cork Oak Forest Restoration Practices

The restoration of cork oak forests seeks to correct the degradation indicators, regardless of their cause, and recover forest vitality. The main actions proposed for the restoration of degraded cork oak forests are described below, based on published studies and the experience gained from the cork oak forest restoration work carried out between 2014 and 2018 as part of the Life+Suber project.

It should be noted that these actions are fundamentally based on high forest station quality, as this is where long-term success can be best guaranteed.

- Measures for reducing competition: scrub removal, coppicing, clearing, and thinning enable improved cork oak forest vigour and fruiting by reducing competition for water. These measures also allow the forest structure to be improved from the perspective of vulnerability to forest fires. The criteria to be followed are those for managing the adaptation of cork oak forests to climate change (Section I of this guide).

- Actions specific to cork oak forest restoration:

  - Regeneration felling: eliminating trees that are sick or have poor vigour, as well as those affected by fire that have lost their viability or show weak regrowth limited to the crown (Vericat et al., 2012). In these cases, thinning should take place 2-3 years after felling.

  - Forest rejuvenation: encouraging fruiting and sexual regeneration by acting on the forest structure to facilitate recuitment.

- Densification planting or seeding: artificially installing new saplings, preferably from identified and selected stands in the local area. This is characterised by high plantation costs and mainly low success rates limited by predation in the case of seeding. The success of planting and seeding greatly depends on the installation of protective systems to combat the damage caused by wildlife. In the case of severe edaphic degradation and active erosion, the introduction of more frugal species may be considered, such as the Aleppo pine or stone pine (Linares & Fariña, 2001). Further information is given on this activity in a specific section.

- Stripping of burnt trees:the first stripping after a fire should take place no earlier than three years later to avoid stressing the tree further. Stripping is essential for removing the burnt cork and encouraging the production of new defect-free cork (Figure 52).

  It is recommended to wait until at least 75% of the crown volume has been recovered and until the cork is thick enough to enable safe stripping (at least 20 mm). To properly organise a cork harvest, the trees should be stripped at the start of the season (Berdón et al., 2015).

Figure 52. Stripping of burnt trees five years after the 2012 fire in Alt Empordà.

Densification of *Quercus suber* Forests

Despite the conviction that natural regeneration is the most effective process and necessary in forestry management, some cork oak forests are degraded, natural regeneration is scarce, and this may threaten the forest as a whole.

Artificial reforestation processes, such as seeding or planting, are needed in these cases to cause new, more vigorous, more functional, and more resilient forest to emerge.

In the case of burnt cork oak forests, after clearing the fire-affected vegetation, supporting reforestation can be undertaken to increase the forest density in certain areas. However, before deciding to do this, it is necessary to observe how the forest develops, as in some cases there can be very abundant regeneration. This happened in many of the cork oak forests burnt during the 2012 fire in Alt Empordà (Figures 53 & 54).

Choosing the Forest Reproductive Material (FRM)

When repopulation is considered necessary, we need to take into account the type of FRM to be used. In repopulations where the main objective is protection, the chosen FRM should guarantee that the plant will be able to adapt to the conditions in the environment where it will live. This adaptation is achieved by carefully

Figure 53. Stand from the Life+Suber project located in Alt Empordà and affected by the 2012 fire, where abundant natural regeneration can be observed three years later.

Figure 54. Detail of regenerated material following a fire.

selecting the source region of the material. If the FRM is also required to provide additional characteristics, such as a certain degree of vigour, specific timber properties, or trunk or crown shape, material with greater genetic gain should be sought (Pemán & Navarro, 1998) and sourced from selected forests or stands, a seed orchard, or tested clones.

The commercialisation and certification of **FRM in Spain is regulated by Spanish Royal Decree 289/2003, of 7 March,** on the commercialisation of forestry reproductive material (Official State Gazette Nº 58, of 8 March 2003) and its amendments in Spanish Royal Decree 1220/2011, of 5 September. These regulations set out compulsory FRM certification and commercialisation guidelines for producers and suppliers. The goal is to certify sustainable management as well as the conservation and improvement of genetic forestry resources in order to ensure that any FRM used is high quality and suited to the environmental conditions in which it is utilised.

FRM is defined as the fruits and seeds, parts of plants, and whole plants that are used to multiply forestry species and their artificial hybrids. These are subdivided into four groups based on their genetic category: **identified, selected, qualified, and cotrolled**, the latter being those that must meet the strictest requirements and those that present the greatest selection and least variability..

FRM is obtained from basic material (BM). The following types of basic materials are currently approved: seed sources, seed orchards, clones, selected stands, parents of families, and clonal mixtures.

The Spanish National Catalogue of Basic Materials *[Catálogo nacional de materiales de base]* can be consulted on the website of the Spanish Ministry of Agriculture, Fisheries and Food.

Sowing cork oak acorns

Sowing is a traditional forestry restoration technique that dropped out of favour during the second half of the 20th century as container plants became the dominant format (Reque & Martín, 2015). Nonetheless, sowing has been regaining popularity in temperate areas in recent years.

The advantages of sowing acorns

The main advantages of restoring cork oak forests by sowing acorns instead of planting trees are the following:

- Considerably lower cost: the price of acquiring, transporting, storing and planting seeds is significantly lower than that for plants. The savings achieved from sowing rather than planting can be around 30-40% (King & Keeland, 1999) and even more than 65% (Bullard et al., 1992) or 75% (Madsen & Löf, 2005).

- Less intensive land preparation: forest restoration can be undertaken in areas that cannot be accessed by regular or adapted machinery, and in soil vulnerable to erosion.

- Phytosanitary and genetic contamination factors: less likelihood of transporting disease and exogenous fungi to restored areas (Sánchez et al., 2005).

- Similar to the natural regeneration process (which favours natural selection and greater environmental adaptation).

- Strong natural development of the root system: autumn sowing allows development of the taproot at depth during the wettest months so that, when the dry season arrives, the seedling has access to the wettest parts of the soil. It should be taken into consideration that, during initial plant stages, cork oak trees allocate 90% of their resources to developing a root system and only 10% to above-ground development. In contrast, container plants cannot develop a taproot (due to the stunting effect of the container) and those grown bare rooted lose a large part of the taproot when transplanted. As a result, the root system of a nusery plant is more superficial than that of those grown in natural conditions, meaning they are more susceptible to water deficits because they cannot access deep soil layers.

- High survival rate of sown plants: plants grown from acorns present survival rates during the early vegetative stages in excess of 50% and often close to 100% (Mendoza et al., 2009; Matías et al., 2009).

The disadvantages of sowing acorns

Although the advantages are clear, sowing is still not yet an important technique in forest restoration due to the disadvantages described below:

- Greater uncertainty about the availability of seeds (especially in the case of masting species or recalcitrant seeds, which cannot be stored for prolonged periods of time), and the germinative potential of the seed, which is more difficult to assess than plant quality.

- Seed predation: acorns are especially sought after by rodents (mice, moles, squirrels, and rabbits) and wild boar, due to their high nutritional value. There are other potential, locally-relevant threats, such as deer, birds or insects, especially the chestnut weevil (*Curculio elephas*), a coleopteran whose larvae bore into acorns for food. Although there are various ways to protect seeds against predation, they are not widely known. A number of these systems are presented in this guide.

- Competition from established vegetation, especially herbaceous vegetation. Greater need for cultural maintenance in the first year.

- Mortality caused by late frosts or summer droughts and therefore increased vulnerability of the seedlings during the early stages of development following germination.

The balance between the advantages and disadvantages of sowing and planting is therefore highly dependent on the particular conditions of each restoration method. It can, however, be concluded that sowing could be a highly effective way of undertaking cork oak forest restoration, especially in areas where the use of machinery for preparing the land is limited due to accessibility (scattered small stands), trafficability limitations (presence of adult trees or steep gradients), or other environmental or technical restrictions, provided that predation can be controlled effectively and affordably.

Recommendations for sowing cork oak acorns

The main aspects to be considered when sowing acorns are explained below, based on the published literature and contributions from the Life+Suber Committee of Experts.

- Acorn size is a very important factor, as this has a direct impact on root length and vigour. It is important for the acorns to be as heavy as possible.

- If the acorns are not pre-germinated, they should be well hydrated by immersing them in water for 48 hours (Gómez et al., 2016). The acorns should also be submerged in water so that any which float can be discarded, as this indicates they are not viable.

- Sowing depth should be 5-7 cm.

- To facilitate the sowing process, Grupo Sylvestris has developed a manual sowing device that makes sowing at a depth of 5-7 cm much easier. Although these devices are not available on the market, they can be made using the design provided by Grupo Sylvestris (Figure 55).

- The number of acorns per sowing point is another important factor. Considering the low cost of purchasing acorns, it is generally recommended that two acorns are placed at each sowing point in order to increase the likelihood of success and minimise the impact of potential germination-failure problems.

- To guarantee maximum acorn viability, the acorns should be sown immediately after they are collected. The difficulties of preserving acorns in cold storage and chestnut weevil attacks mean that they should not be sown any later than January. Another factor underpinning this recommendation is the short time the plant would have to develop a strong root system and cope with water stress in the summer.

- In large burnt areas and where natural regeneration is not expected, acorns should be sown as soon as possible. The more time that passes between the fire and sowing, the greater the competition from herbaceous vegetation and other plants. The presence of predators will also be greater.

- In the event that two shoots emerge during germination, it is best to wait for the second sap before removing the less vigorous one.

- According to an experience recorded by University of Huelva, the survival percentage on plots with partial shade conditions (CCF (canopy cover fraction) between 40-80%) over three years is greater than on shady plots (CCF > 80%) or in sunny areas (CCF 0%), although sunny conditions may favour taller plant growth.

- Use of anti-predation strategies.

Techniques for preventing acorn predation

To prevent or mitigate predation, various forest seed-protection systems can be used. These tend to be grouped together as follows:

a) Individual physical protection (or for 2-3 acorns sown together)

In recent years, two types of physical protection have been developed. Both have been used in the Life+Suber project.

Seed Shelter

Patented by the University of Granada and licenced by Grupo Sylvestris

Figure 55. The Sylvestris sowing device.

SL, this consists of a 0.8 mm-thick truncated octahedron made from polypropylene that is assembled during the sowing process (using two pre-cut sheets with slots and tabs that can be put together in just a few seconds). The interior of the device is filled with soil from the hole itself (or, depending on the texture, preferably with peat) and two acorns are positioned horizontally in the centre of the shelter (Figure 56). The device is buried with its top at a depth of 2 cm. The lower and upper holes allow the taproot and stem to emerge, respectively (Figure 57) (Castro et al., 2015).

According to the experience of Grupo Sylvestris, this type of protector is highly effective against rodents but not in the presence of a high density of wild boar and a small reforestation area. This was also found to be the case during trials carried out as part of the Life+Suber project.

In these situations, another much more robust type of protector is appropriate (metal mesh with 3-4 stakes), although these are much more expensive. The Seed Shelter can also be installed inside these metal protectors to protect the acorns from rodents.

Figure 58 compares acorn predation in the following situations: with and without fencing, and with and without the Seed Shelter. It can be seen that use of the Seed Shelter prevented acorn predation by small rodents (squirrel and rats), regardless of whether the area was fenced or not. In contrast, in unfenced areas there was acorn predation by wild boar and almost no difference was seen whether the Seed Shelter was used or not.

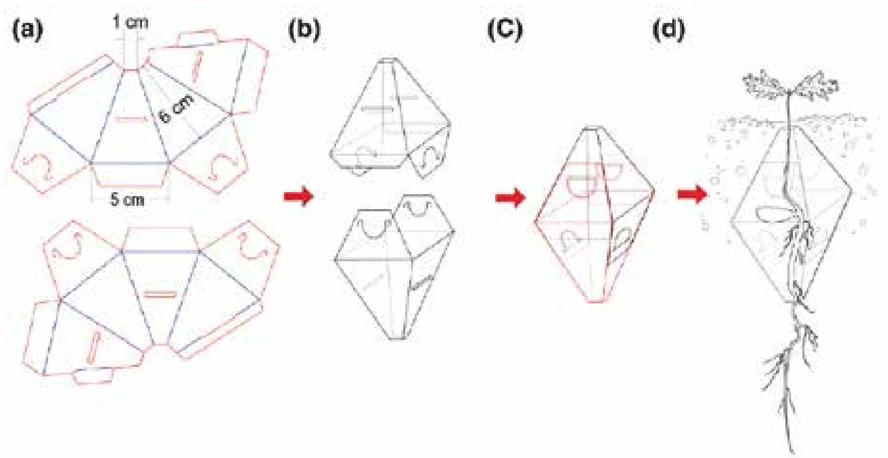


Figure 56. Assembly and installation diagram for the Seed Shelter (Castro et al., 2015).

Figure 57. Seed Shelter already assembled with the acorns and soil inside.

Mesh Protector

Patented by University of Valladolid (Reque & Martín, 2015), this protector consists of a very fine cylinder of metal mesh (1mm thick, 35 cm tall, 6 cm in diameter and with a mesh size of 6 mm) that is medium-term degradable. The base is conical and allows the root system to emerge. This model includes a series of defences against various mammals. The conical base of the mesh is connected to the cylinder with a kind of crown that prevents rodents from accessing the acorn from below the protector; to avoid access from above, there is a sphere (a gall or ping-pong ball), supported by three threads, which the plant will gradually push out of the protector as it grows (Figure 59).

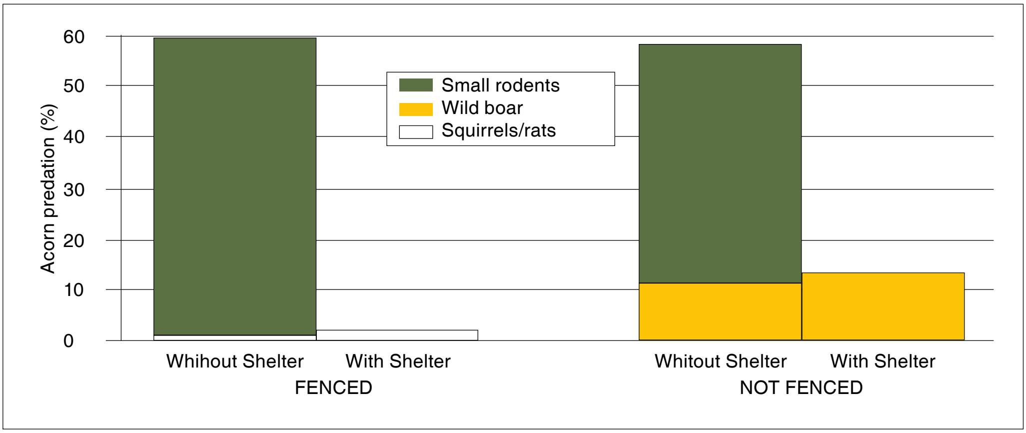


Figure 58. Acorn predation percentages by the various predator types according to the installation of fencing and use of the Sedd Shelter (Castro et al., 2015).

This more complex and heavier device protects both the seed and the seedling. The main disadvantage is the highly laborious manual assembly required; these are not sold pre-assembled nor manufactured on an industrial scale (Figure 60).

A wild boar is capable of pulling up the cylinder but its flexibility prevents the animal from extracting the acorn. It eventually gives up if the reforested area is very large. In smaller areas, the protector should be covered with cutting waste to hinder wild boar trafficability, although this will not affect rodents (Leverkus et al., 2013).

According to the experience of the Life+Suber project, each protector can be assembled in approximately 10 minutes, meaning that the preparation and assembly cost is higher than that of the Seed Shelters.

b) Chemical and physiochemical protection

Coating the acorn or surrounding soil with a product that changes its taste or smell (bitter or irritant/spicy), making it unpleasant for the possible predator. Although there is a wide range of substances, both commercial and homemade, none have shown any great success because they are either ineffective or because they damage the seed. The challenge for repellents is, therefore, to effectively prevent predation without negatively affecting the seed's germination capacity.

Some of the products shown to be ineffective according to the published literature are camphor, dry manure, kerosene, turpentine, denatonium benzoate, and various plant and animal extracts.

c) Collective protection

This involves installing a fence, electrified or not, around the perimeter of a large sown area to prevent access by wild boar. It should be noted that this is a very expensive system and cannot be applied in many forest stations.

Another alternative for ensuring success is very high-density sowing (four times the expected density), although this is not always an effective solution. If possible this should be done in a good harvest year because, if there are a lot of acorns available, wild animals will forage for them much less in repopulation areas.

Finally, excessive land preparation should be avoided because wild boar are attracted by the disturbed soil.

Planting

Planting is the process whereby the plants produced at a nursery are planted on site so they develop to form a future productive and stable forest.

Generally speaking, the seedlings are either bare rooted or in a container. Bare-rooted plants are those cultivated at a nursery directly in the soil and

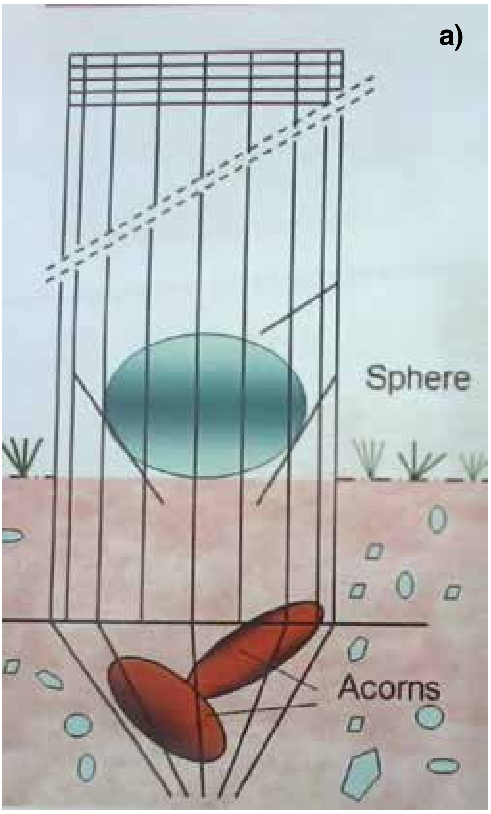


Figure 59. Diagram and image of the «University of Walladolid protector».

a) Side view of the protector. b) Partially buried protector with roots emerging in February (Reque & Martín, 2015).

Figure 60. Sowing with the mesh protector in Can Iglesias, a stand in the Life+Suber project.

then taken to the site without a root ball covering the root system. These plants have a very short planting period; in other words, planting depends on the time of year. This option is rather uncommon in the case of the cork oak due to the low availability of plants grown using this system and the fact they must be planted immediately after being lifted.

Container plants are produced in special containers filled with an appropriate substrate, and have a root ball around the root system. It should be taken into consideration that one-year cultivated seedlings usually come in forest trays. The cavities in these trays are shallow and limit taproot growth (Gómez et al., 2016), which is essential for cork oaks that depend on early development of the main root to survive droughts (Figure 61).

Figure 61. Cork oak plant in container.

- Plant handling

The way the plant is handled between its departure from the nursery and arrival at the repopulation site is very important.

It is extremely important to protect the plant to avoid desiccation or overheating, which could lead to fermentation. If an open vehicle is used to transport the plants, they should be protected with some sort of packaging. Covered vehicles should be used for long journeys (Bernal & Ojeda, 2010). The soil should be continuously checked to ensure sufficient moisture and avoid desiccation. Once the plant is at the site, it should be kept in an area that is protected from the cold, strong winds, heat, and predators.

- Planting methods

Depending on the resources available and terrain morphology, manual methods can be used for planting. This involves digging a pit (the larger the better), which should be at least 40 x 40 x 40 cm (De María et al., 2003) using a narrow-blade hoe or similar tool.

Besides manual planting with a hoe, another option would be to create the furrows using a backhoe. This ensures the furrow is the correct size.

A good method for harnessing rainwater and helping plant survival is to dig a little around the plant and create a ridge that retains water and protects the plant against drought.

- Protection against damage caused by animals

Wherever animals have been shown to be present in sufficient numbers as to pose a risk to repopulation, repopulated plants will require protection. There are basically two systems for this: enclosures or individual protectors.

An enclosure consists of closing off the entire repopulation area. It is an effective system but expensive in terms of construction and maintenance (Pemán & Navarro, 1998).

Given the cost and the impossibility of enclosing the entire area, the use of individual protectors is often considered. Low-cost commercial protector designs are available on the market, with labour (installation and maintenance) representing the most significant cost. The greater the protection afforded, the higher the financial outlay.

Generally speaking, these protectors are plastic or metal tubes up to two metres tall that are partially buried in the ground and supported by a stake to prevent livestock or wildlife from damaging the plant (Figure 62).

Figure 62. Cord oak tree plantation with protectors in Montnegre-Corredor.

Practical Cases of Management for the Restoration of Degraded Cork Oak Forests

Measures taken in the Life+Suber project

Degraded cork oak forest restoration has been undertaken in four stands, one in each area with cork oak forests in Catalonia (Alt Empordà, Gavarres, Montseny-Guilleries and Montnegre-Corredor). Each stand measures three hectares and is located in an area of high station quality.

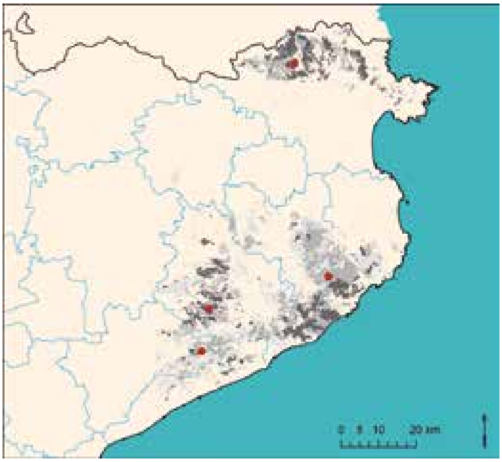


Figure 63. Location of the 4 demonstration sites where treatments have been applied in degraded cork oak forests.

Objectives and definition of the measures

The aim is to recover degraded cork oak forests, either because they have suffered a fire or because no forest management activities or exploitation has been carried out there for years. Specifically, the project consists of work on three stands affected by fire (Alt Empordà in 2012, Les Gavarres in 2003, and Montseny in 1994, none with any kind of subsequent intervention), in addition to a stand in Montnegre-Corredor where no kind of forest management activity has been undertaken since 1960-65.

The goal is to recover the productive potential of these forests, making them more vital, resilient, and resistant to the numerous threats that could affect their persistence and productive capacity. In general, uneven forest structures are proposed with a canopy cover fraction of between 60-70% in order to avoid excessive proliferation of scrub and thereby help improve the forest structure from the point of view of vulnerability to fire.

The forestry management consists of selective scrub removal (with a variable quantity of brush cover to be removed ranging from 90-100% to 40-60%), selective clearing to remove trees with reduced productive capacity, and pruning of post-fire regrowth to encourage future cork quality by creating a branchless trunk of a height that facilitates cork exploitation, thinning in stands of cork or holm oads with abundant regrowth, and the treatment of plant waste to reduce fire risk (generally, short corsscutting *in situ* to facilitate rapid decomposition and absorption by the soil).

Densification sowing also took place at the stand in Montseny because a clearing was found with a very low tree density. To reduce predation risk, the two types of seed protector described above were used (Seed Shelters and mesh protectors).

Main results

All the actions designed for each of the four stands were implemented during the dormancy period of 2015/2016, avoiding the breeding season for the main species of wildlife present. At the same time, forest dasymetric parameters were tracked in order to monitor the actions and compare the results before they were implemented and two years afterwards. Figure 64 shows the change in appearance of a stand where action was carried out.

By analysing the evolution of the diametric distribution (Figure 65), it can be seen that by DC (diameter class), this has remained almost unchanged after two years, although there has been a reduction in total density. Increased density was recorded in DC20 and DC25.

As regards the specific composition (Table 10), there have been significant changes in *Quercus suber*, which has increased to over 80%. The treatments have led to a considerable reduction in the number of conifers. Finally, there has also been a reduction in other leafy vegetation, although this still accounts for more than 10%. The forest is now considered a pure cork oak formation.

Figure 64. Appearance of the stand in Can Mainouet, Montnegre-Corredor prior to action, afterwards and two years later.

Finally, by analysing the evolution of CCF (Table 11) to see the effect of the treatments on crown structure, it can be seen that a reduction of approximately 20% has occurred following the treatment. This variable increases slightly after two years from the treatment, possibly due to the removal of competition meaning that the remaining trees have been able to further develop their crowns.

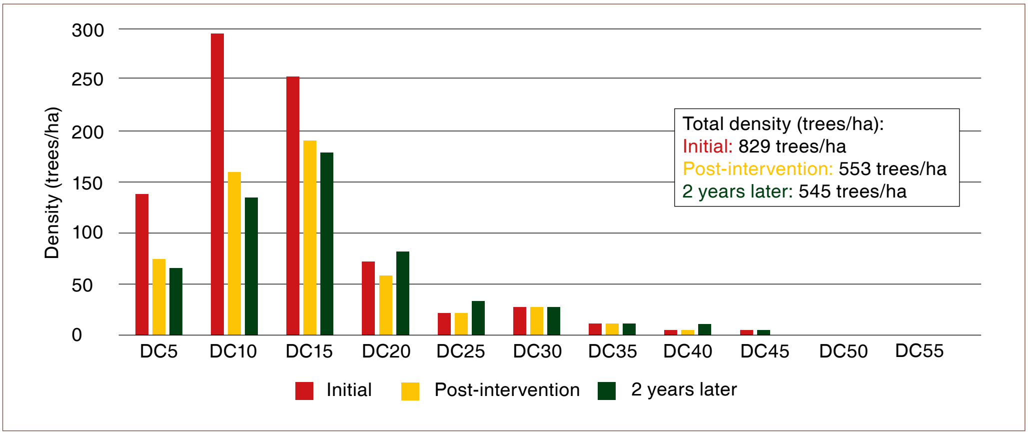


Figure 65. Average diametric distribution of cork oak trees in the stands for productive potential recovery, prior to the action, afterwards, and two years later.

Table 11. Evolution of average canopy cover franction (CCF) calculated from hemispherical photographs in the stands subject to the recovery of cork oak productive potencial

	CCF
Prior to the action	79%
Afterwards	60%
Two years later	66%

Table 10. Average basal area percentage according to the specific composition of the stands for cork oak productive potencial recovery

	Quercus suber	**Conifer**	**Other leafy vegetation**
Prior to the action	76%	7%	17%
Afterwards	84%	3%	13%
Two years later	83%	3%	14%

References

Berdón, J.; Bernal, C.; Cardillo, E.; Encinas, M. 2015. *Restauración de Alcornocales Incendiados*. CICYTEX – Instituto del Corcho, la Madera y el Carbón, Mérida. 37 p.

Bernal, N.; Ojeda, J.P. 2010. *Manual de buenas prácticas sobre la regeneración del monte alcornocal*. AGRESTA. Madrid. 116 p.

Bullard, S.H.; Hodges, J.D.; Johnson, R. L.; Straka, T. J. 1992. *Economics of direct seeding and planting for establishing oak stands on old-field sites in the South*. South J Appl For 16:35-40.

Castro, J.; Leverkus, A.; Fuster, F. 2015. *A new device to foster oak forest restoration via seed sowing*. New Forests, 46 (5): 919-929.

De María, A.; Touriño, L.; Manzano, I.; Domínguez, M. 2003. *Técnicas de Gestión Forestal Sostenible en la Repoblación Forestal*. SILVANUS Galicia. Santiago de Compostela. 173 p.

Gómez, P.J.; Jiménez, M.N.; Navarro, F.B.; Fernández, P.; Carbonero, M.D.; Muñoz, M.L.; Caño, A.B. 2016. *La regeneración del arbolado en la dehesa. IFAPA*. Institute of Agricultural and Fisheries Research and Training. 90 p.

King, S. L.; Keeland, B. D. 1999. *Evaluation of reforestation in the lower Mississippi River Alluvial Valley.* Restoration Ecology. p. 7: 348-359.

Leverkus, A.B.; Castro, J.; Puerta-Piñero, C.; Rey Benayas J.M. 2013. *Suitability of the management of habitat complexity, acorn burial depth, and a chemical repellent for post-fire reforestation of oaks*. Ecol Eng 53:15-22.

Linares, L.; Fariña, J. 2001. *Estado actual y propuestas de gestión del alcornocal en montes del PN Los Alcornocales (Cádiz)*. In: III Spanish Forest Conference. Spanish Society of Forest Sciences. Granada.

Madsen, P.; Löf, M. 2005. *Reforestation in southern Scandinavia using direct seeding of oak (*Quercus robur *L.)*. Forestry 78:55-64.

Matías, L.; Mendoza, I.; Zamora, R. 2009. *Consistent pattern of habitat and species selection by post-dispersal seed predators in a Mediterranean mosaic landscape*. Plant Ecol. 203, 137-147.

Mendoza, I.; Zamora, R.; Castro, J. 2009. *A seeding experiment for testing tree community recruitment under variable environments: implications for forest regeneration and conservation in Mediterranean habitats*. Biol. Conserv. 142, 1491-1499.

Montero, G.; López, E. 2008. *Selvicultura de Quercus suber L*. En: Serrada, R.; Montero, G.; Reque, J. A. (eds.). *Compendio de selvicultura aplicada en España.* National Institute for Agricultural and Food Research and Technology. Ministry of Education and Science. Madrid, p. 778-825.

Nebot, E.; Piqué, M.; Villar, M.; Frigola, P.; Laporta, X. 2013. *Integració del règim i tipus d'incendis en la gestió de les suredes a l'Alt Empordà: quin model de gestió seguir?*. In: Tusell, J. M.; Vericat, P. (eds.). XXX Jornades Tècniques Silvícoles Emili Garolera. Consorci Forestal de Catalunya. Santa Coloma de Farners, p. 59-68.

Pemán, J.; Navarro, R. 1998. *Repoblaciones forestales*. Publications Service, University of Lleida. Lleida. 400.

Reque, J. A.; Martin, E. (2015). *Designing acorn protection for direct seeding of Quercus species in high predation areas*. Forest Systems 24(1): e018.

Sánchez, M.E.; Andicoberry, S.; Trapero, A. 2005. *Pathogenicity of three Phytophthora spp. causing late seedling rot of Quercus ilex* ssp. *ballota*. For Pathol 35:115-125.

SUBERNOVA. 2005. *Código Internacional de Prácticas Suberícolas*. Proyecto SUBERNOVA, Évora y Mérida, p. 13.

Vericat, P.; Piqué, M.; Serrada, R. (eds.). 2012. *Gestión adaptativa al cambio global en masas de Quercus mediterráneos*. Forest Science and Technology Centre of Catalonia, Solsona. 172 p.

Section IV

Integrated Pest Management in Cork Oak Trees

Antonio Torrell
Josep Maria Riba

Cork Oak Forest Pathologies

These affect cork oak trees to varying degrees and can be divided into two categories: diseases and pests. Many of them weaken the trees, some negatively affect cork quality, and others can be lethal. Integrated pest management (IPM) is recommended for preventing and controlling these problems, with the aim of maintaining pathogen population levels below the thresholds that cause significant damage.

Whenever possible, biological, biotechnical, cultural, and physical methods should be prioritised over chemical methods when applying IPM.

If chemical products must be used, the active substances should always be as compatible as possible with organisms that are not the target of the control, as well as posing the least threat to humans and livestock. In short, they should produce the least environmental impact possible.

Both the pheromones and phytosanitary products used in the treatments should be authorised for their specific use in the Register of Phytosanitary Products of the Spanish Ministry of Agriculture, Fisheries and Food.

Diseases

Bot canker *(Diplodia corticola)*
Charcoal canker *(Biscogniauxia mediterranea)*
Root rot associated with *Phytophthora cinnamomi*

Bot canker *(Diplodia corticola)*

És una malaltia caracteritzada per provocar uns xancres que es formen sobre la superfície destapada de l'alzina surera. La dispersió de les espores es produeix mitjançant la pluja, el vent o les eines de poda o lleva infectades; és per això que les lesions generalment venen associades a ferides de lleva.

The fungus causes the death of conducting vessels in large areas of the trunk as well as in the regenerative cork tissues. The lesions are accompanied by withering, a gradual loss of leaves, and the death of branches. The wounds themselves do not usually compromise the vitality of the tree, but they do seriously affect the production of good quality cork; if the attack is very serious, the tree may eventualy die. This is why fungicidal treatments are recommended after cork stripping, especially in humid weather.

Prevention Measures

- Avoid bark wounds on trunks and branches, especially in the rainy season.
- Disinfect tools.
- Reduce the intensity and frequency of pruning.
- Maintain vigorous trees and avoid tree stress in order to hinder the progress of the disease.
- Apply fungicidal products immediately after stripping or pruning.

Figure 66. Cork oak trees affected by *D. corticola.*

Charcoal Canker *(Biscogniauxia mediterranea)*

This disease can affect various leafy plants, with *Q. suber* and *Q. ilex* being the most susceptible. It is an opportunistic pathogen associated with tree decline that takes advantage of weakness caused by drought or root infections to spread, and cause death.

Typical symptoms include the presence of carbonaceous stroma in the longitudinal cracks in the bark. The effect usually begins on branch terminations, subsequently spreading to lower parts, even reaching the trunk.

Prevention measures

- Disinfect pruning tools.
- Reduce pruning frequency.
- Remove or prune the trees or branches affected by the canker and destroy them, preferably by burning them.
- Clear the forest.
- Avoid water stress.
- Implement appropriate cultural practices to increase tree vigour.

Figure 67. *Biscogniauxia mediterranea* stroma in cracks

Root rot associated with *Phytophthora cinnamomi*

This is a highly virulent pathogen that does not need a tree to be weakened in order to cause disease. It leads to the slow death of absorbing roots, preventing the cork oak from obtaining water and nutrients from the soil. The development of this disease leads to the death of the tree.

It has been seen that *P. cinnamomi* plays a significant role in "drying" processes.

Prevention measures

- Avoid temporary or permanent waterlogging.
- Limit earthworks to a minimum.
- Disinfect tools.
- Avoid tilling beneath the tree crown to avoid damaging the roots.
- Keep trees in a good condition.
- Envourage bacteria and fungal flora.

Figure 68. Sudden death caused by *Phytophthora cinnamomi.*

Pests Caused by Insects or Mites

Picadors-xucladors

Gal·lícoles

Defoliadors, mastegadors i minadors

Piercing-sucking Pests

Principally insects, like aphids and woodlice, but also some mites, feed on internal plant liquids and sap. During significant attacks, these pests physiologically weaken the trees making them susceptible to colonisation by boring insects. Some examples include: *Asterodiaspis ilicicola, Parthenolecanium, Kermes ilicis* and *Acera ilicis*.

Figure 69. *Asterodiaspis ilicicola.*

Figure 70. *Aceria Ilicis.*

Kermes vermilio should be highlighted because, since 1997, significant infestations have been recorded in both natural and ornamental holm oaks in Catalonia. The trees most affected are those growing in isolation or along the edges of crop fields.

Figure 71. *Kermes ilicis.*

K. vermilio is a sucking woodlouse that attaches itself to small branches to feed on the sap, leading to the gradual withering and desiccation of the leaves. This reduces the photosynthetic capacity of the tree. It attacks most often in warm and dry climates.

Prevention and combat measures

- Keep the trees in a good condition.
- Chemical treatments are only recommended during heavy attacks in consecutive years, because the woodlouse's natural enemies (predators, parasites, and entomopathogenic fungi are usually capable of keeping the population at such low levels that it is not considered a pest. Treatment should take place between the end of June and the start of August given that new-born nymphs are mobile at this time and have not yet formed the protective wax covering that prevents the treatment being effective.

Figure 72. Crown affected by *Kermes vermilio.*

Figure 73. *Kermes vermilio* females.

Gall-making Pests

These insects cause abnormal leaf or twig tissue development, leading to galls, or *cecidia*. These malformations are characteristic to each species. In most cases, they do not compromise tree vitality.

Some examples include: *Dryomyia lichtensteini, Andricus hispanicus, and Plagiotrochus quercusilicis.*

Figure 74. *Andricus hispanicus* galls.

Figure 75. *Dryomyia lichtensteini* galls on the underside of *Quercus ilex* spp. *ballota*. Author: Luís Fernández García. Source: Wikimedia.org

Defoliating, Chewing, and Mining Pests

The caterpillars of these lepidopterans cause damage by feeding entirely or partially on the young leaves and buds of healthy trees. They cause cycles of heavy defoliation and are sometimes associated with a number of other species; together these cause the damage.

Generally speaking, the life of the tree is not compromised but heavy defoliation affects tree growth and makes it more susceptible to attack from other harmful agents.

In the case of the cork oak, heavy attacks can eventually hinder and even prevent cork stripping due to the effects caused both during the current year and in previous years. In periods between stripping, these attacks reduce the quality of the cork.

The species that cause the most damae to cork oak trees in Catalonia are:

Lymantria dispar

This is a highly polyphagous and voracious lepidopteran. The adult females are 45-65 mm long and have very bulky abdomens. This prevents flight and forces them to travel on foot. In contrast, the male is a good flyer. Females pass through six larval stages before pupating, while the males pass through only five. In the first three stages, the caterpillars have a black head and simple markings on the body. In the final stages, the caterpillars reach a length of 45-75 mm and are characterised by the presence of two lines of tubercles on the upper body, four blue pairs and seven red pairs.

Figure 76. Sixth-stage *Lymantria dispar* caterpillar.

The population dynamics of this insect are characterised by alternating periods of several low-impact years followed by other shorter periods with a demographic explosion and major defoliation.

The pest is dispersed by the wind, which transports the caterpillars during their early stages thanks to the numerous hairs that cover their body.

Tortrix viridana

This is a light green butterfly with a 2 cm wingspan. When in caterpillar form, it builds easy-to-spot shelters from leaves or catkins joined together with its silk.

The caterpillars hang from branches by silky threads, using the wind for dispersal.

Both these shelters and the silky threads are easy to see and give al clue to this kind os attack.

Figure 77. Eruga *Tortrix. viridana* en el 5è estadi.

Figure 78. Damage caused by *Tortrix viridana.*

Figure 79. Early-stage *Tortrix viridana* caterpillar.

Catocala nymphaea and *Catocala nymphagoga*

These two species of lepidopterans look very similar. The front wings are greyish in colour and imitate tree bark or dry leaves, while the back wings are yellow or orange with black stripes. The caterpillars of these species present pronounced polymorphism.

At the beginning of summer it is very easy to see these butterflies flying around, as it is throughout the season. Clouds of these butterflies can form in forest environments, and even at night in nearby towns as they are attracted by the light.

The following species are also in this group but they are less important as they cause little damage:

- Lepidopterans including: *Malacosoma neustria, Euproctis chrysorrhoea, Dryobota labecula, Dryobotodes eremita, Erannis defoliaria, Phalera bucephala, Archips xylosteanus* and *Aleimma loefingiana.*
- Coleopterans including: *Altica quercetorum, Attelabus, Rhynchites* and *Lachnaia*.
- Hymenopterans including: *Periclista andrei*.

Figures 80. Various morphologies of *Catocala* sp. caterpillars.

Figure 81. *Catocala nimphaea.*

Prevention and combat measures

- Install nest boxes to encourage insectivorous birds and bats.
- Preserve trunk cavities to facilitate the installation of insectivorous birds and bats.
- Increase the heterogeneity of the forest by interspersing other tree species between the *Quercus* to hinder the spread of the pest.
- Install traps containing specific pheromones durint the flight season of the adults of each species.
- Generally speaking, the populations of these insects should be controlled naturally, as any treatment would harm the beneficial entomofauna. One of the predators that helps maintain the populations of these insects is the coleopteran *Calosoma sycophanta*.

Figure 82. *Calosoma sycophanta.*

Phytosanitary treatments can be undertaken when significant losses are forecast due to cork or acorn damage. Various products are authorised for this, but priority should be given to the use of biotechnical products over chemical products containing chitin-synthesis inhibitors or contact insecticides.

For the treatment to be effective, it is very important to understand the cycle of the insect in question, as this determines when the treatment should be applied. Action should always be taken against the caterpillars and not the adults.

Boring Pests

These are insects that can affect different parts of the tree: the trunk *(Cerambyx cerdo, Platypus cylindrus* and *Xyleborus* sp.*)*; the branches *(Coraebus florentinus)*; the cork *(Crematogaster scutellaris)*; the acorns *(curculiónidos);* or the cambium *(Coraebus undatus)*. The life of the cork oak is not compromised in any of these cases, but the ants and flathead oak borer cause damage that directly effects the production and quality of the cork, rendering it useless for industry or considerably devaluing its price.

Curculio elephas

This is the member of the *Curculionidae* family responsible for most of the damage caused by these boring coleopterans. Early acorn fall and the presence of circular exit orifices on fallen acorns are signs of their attack.

<u>Prevention and combat measures</u>

Surface soil ploughing beneath the trees (between 15-20 cm deep) in winter to interrupt the insect life cycle.

Coraebus florentinus

This is a small metallic bronze green coleopteran (16-18 mm long and 5 mm across) with two zig-zag stripes on the distal portion of the elytra. The larvae (yellowish and around 30 mm long) bore longitudinal and annular galleries that eventually form a ring around the branch and desiccate it. This affects the small (3-5 cm), outermost branches that receive the most sunlight. In mid-spring, these go yellowish-brown and eventually desiccate, leading to the appearance of the typical colour patches that dot tree crowns. Branch loss leads to a reduction in crown volume, thereby reducing vegetative tree growth and directly affecting the production of acorns, wood, and cork.

Figure 83. Acorns affected by *Curculio elephas.*

Figure 84. Tree crown with affected branches.

Prevention and combat measures

- Maintain the cork oak forest in good conditions, and undertake proper stripping, pruning, and improvement clearing.

- Remove the affected branches before the imagoes emerge (June). The branck cutting point can be identified just below the pupation position as this is whee tender shoots appear.

Figure 85. Affected branch.

Figure 86. Adult *Coraebus florentinus*.

Crematogaster scutellaris

This is an unmistakable ant due to its reddish head and black thorax and abdomen. It forms colonies that build their nests in both living and dead wood, as well as throughout almost the entire cork layer on cork oaks, into which they bore galleries and chambers that hinder cork exploitation.

They are also highly bothersome to cork strippers as they are aggressive and give painful bites. They also attack cork piles, occasionally causing significant damage if they are left on site for a long time.

Figure 87. Damage to a cork sheet caused by *Crematogaster scutellaris*.

Figure 88. Aphid colony with *Crematogaster scutellaris.*

Cerambyx cerdo

A large, dark brown (almost black) xylophage coleopteran (35-62 mm long) with reddish colouring in the distal portion of the elytra, where its body thins. It has long antennae that are longer than the body in males. The larvae are cylindrical, yellowish in colour and even larger than the adult insect.

Figure 89. Trunk section showing galleries created by this longhorn beetle..

It bores large galleries in the wood, compromising the structural capacity of the tree and occasionally causing it to break.

It usually attacks decrepit or run-down trees, however, abusive and poorly performed pruning can encourage this longhorn beetle to colonise «healthy» trees.

C. cerdo has been included in Annex IV of Directive 92/43/EEC of the Council, on the conservation of natural habitats and of wild fauna and flora as a species of community interest that requires strict protection. For this reason, phytosanitary treatments against this insect are not generally permitted. If occasionally the damage they cause becomes severe and phytosanitary treatment is necessary, authorisation for this must be requested from the Fauna and Flora Service of the Territory and Sustainability Department of the Regional Government of Catalonia.

Figure 90. Adult *Cerambyx Cerdo.*

Figure 91. Serious damage (orifices and galleries) caused by *Cerambyx* on a holm oak trunk.

Platypus cylindrus

A small (5 mm long), dark chestnut-coloured burrowing coleopteran that causes serious damage to cork oak trees due to the reduced sap flow caused by the numerous entry orifices and the pathogenic action of the fungus these beetles carry, which is deposited along the length of the galleries they create. The presence of fine sawdust around the entry orifices, or even at ghe base of the tree, is a sign of their presence.

In molst cases, this beetle acts as a secondary agent because it affects trees previously weakened by other causes. Nonetheless, heavy attacks occasionally lead to tree death.

Prevention and combat measures

- Maintain goo tree vigour.
- Identify attacks as soon as possible, paying special attention in the stripping year and the immediately subsequent years.
- Remove trees that are heavily damaged, by cutting them at ground level and taking the timber away from the area.

Figure 92. Entry orifices created by *Platypus cylindrus.*

The case of *Coraebus undatus*

The Case of *Coraebus undatus*

Description

This is a coleopteran from the family of jewel beetles that in Catalonia only affects the cork oak. There is no sexual dimorphism, so sex can only be determined by examining the genitalia of imagoes. Its sex ratio is 1:2; in other words, populations consist of one male to every two females.

Figure 93. *Coraebus undatus* larva.

Figure 94. Adult *Coraebus undatus.*

The adults are approximately 15 mm long and 5 mm across. They are elongated and elliptical in shape. The head and anterior portion of the elytra are light metallic green, with darker tones and white transversal zig-zag stripes across the posterior half. The larvae are apodous, yellowish in colour and can be as much as 50 mm long and 5 mm across.

Biology

They have a biannual cycle; in other words, they require two years to develop completely. The adults emerge between June and September and live for only a few weeks, during which time they reproduce and lay individual eggs inside cracks on the bark of the trunk, below the upper cork stripping limit. New-born larvae penetrate the cork-generating layer, which they feed on together with the new layer of cork, producing sinuous galleries that can be over 1.5 m long. In spring and summer, they create a pupation chamber insider the cork sheet (Figure 95).

The males emerge a few days before the females (Figures 96 and 98).

The population dynamics of this insect are characterised by alternating periods of several low-impact years followed by other occasional periods of demographic explosion (Figure 99).

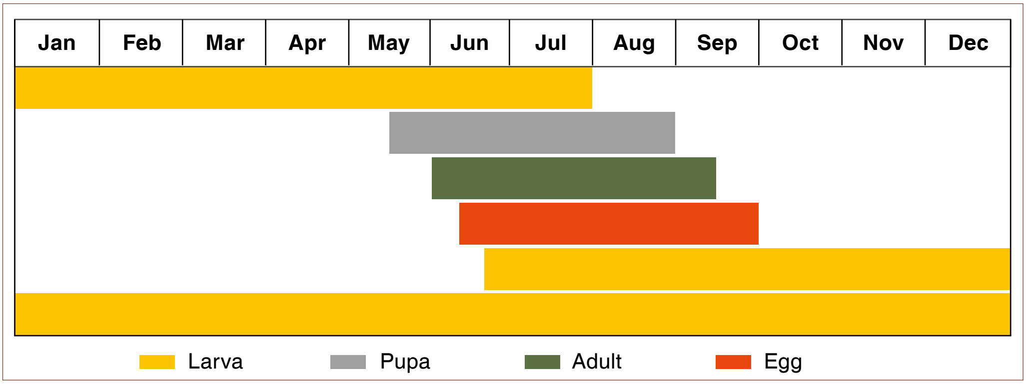


Figure 95. Biological cycle of *Coraebus undatus.*

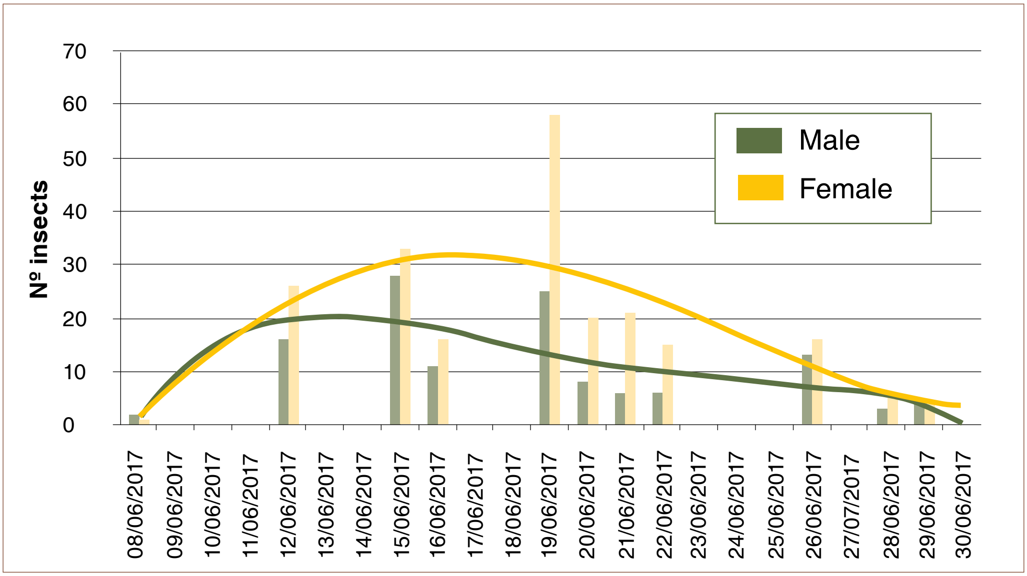


Figure 96. Emergence curve for male and female *Coraebus undatus*.

Figure 97. Adult *Coraebus undatus* captured in prism traps.

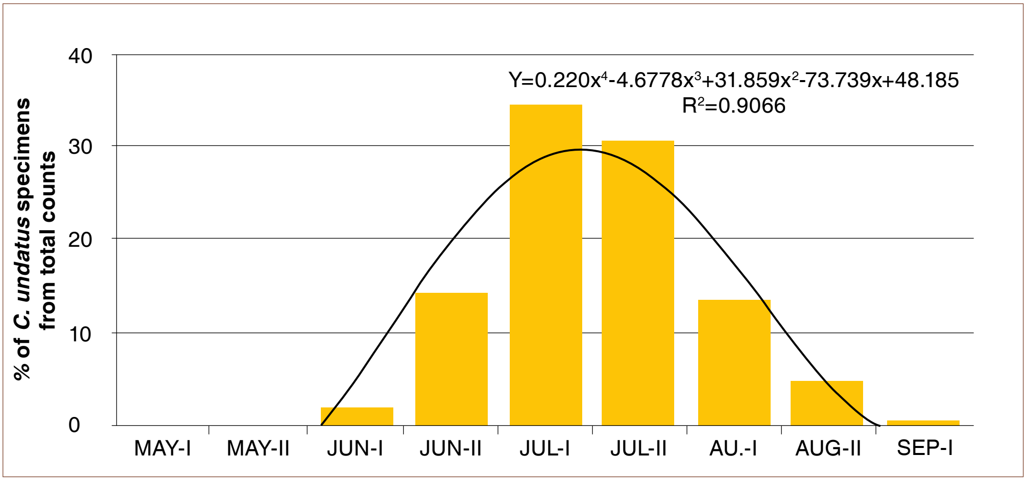


FigurE 98. Flight curve based on the capture 1,772 adults between 2003 and 2018.

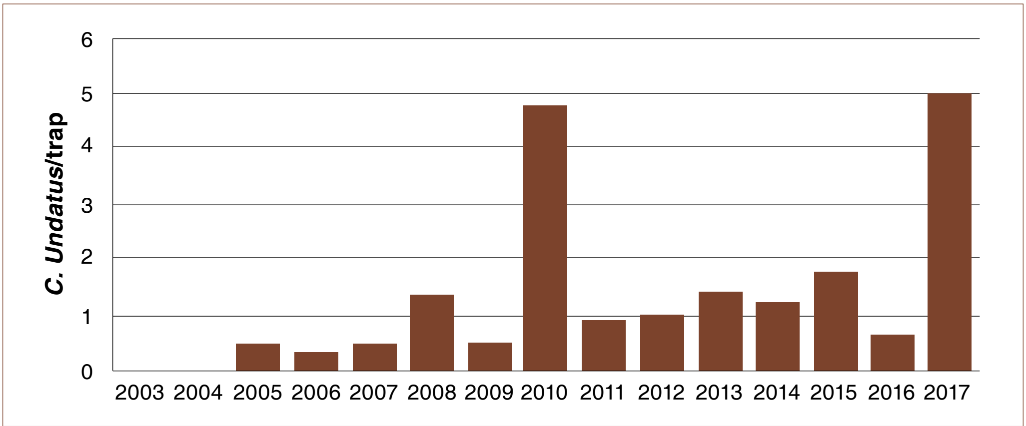


Figure 99. *Coraebus undatus* captured in traps in each year durint which samples were collected in Catalonia.

Symptoms and damage

The most apparent symptom is sap extravasation (colourfully known in Spanish as «kite droppings») which is easy to see on the bark, especially in stripped areas, where it is black at first, turning yellow and finally white. This is caused by the assault of the *C. undatus* larvae when creating galleries, and the subsequent infection.

The larvae are responsible for the main damage, because as they feed they create galleries that lower the quality of the cork and reduce its commercial value. Three different gallery types can be distinguished:

- News: short (30-50 cm), narrow and light in colour as the excrement is

Figure 100. Recent extravasation.

relatively recent. These galleries still contain live larvae.

- Old: long length (>1.5 m), wide (6-8 mm) and very dark in colour due to excretion degradation. The galleries

Figure 101. New gallery.

are caused by the development of larvae born between 3 and 5 years earlier; no larvae are now present in these.

- White: their age is unknown but they may be more than ten years old. These galleries contain no

Figure 102. Old extravasation.

Figure 103. Old gallery.

excrement but are clearly visible due to their sinuous traces that leave an impression on both the mother layer (dark) and the cork sheet (white).

Furthermore, these galleries hinder and even prevent stripping as they lead to the formation of wounds and creacks in the cork-generating layer that prevent the new cork growth and leave the xylem exposed, allowing boring pests

Figure 104. White gallery.

to enter and attack, including *Platypus cylindrus* and *Xyleborus* sp., as well as fungit like *Diplodia corticola.*

Prevention and combat methods

The trees should be kept in a good condition as a preventive measure, and stripping, pruning, and selection thinning work should be performed properly.

Despite the fact that the work and studies conducted to date fail to guarantee that the use of attractant-baited traps can significantly reduce

Figure 105. *Coraebus undatus* damage to the cork sheet.

flathead oak borer populations, studies continue to be conducted to improve this trapping and possible control system.

At present, large-scale trapping campaigns are carried out using purple triangular prism traps with dispensers loaded with five volatile compounds and covered with Tangle Trap® (a colourless and odourless long-lasting glue).

This type of trap has two attraction effects on adult *C. undatus*: one due to the purple colour; and another due to the incorporation of a dispenser containing the attractants. The trap has various openings on the side that

Figure 107. Damage caused when stripping due to the presence of galleries.

help diffusion and it is also open at the top and bottom.

It should be noted that all the *C. undatus* caught using this system are female. This is why the traps are effective at reducing flathead oak borer populations and, by extension, the damage they cause.

Figure 106. Prism trap with dispenser.

Large-scale trapping consists of installing eight traps per hectare and should be carried out between June and September. As far as possible, the weeks with the greatest presence of adults in the area should be covered.

In Catalonia, this period runs from the second fortnight of June to the first fortnight of August.

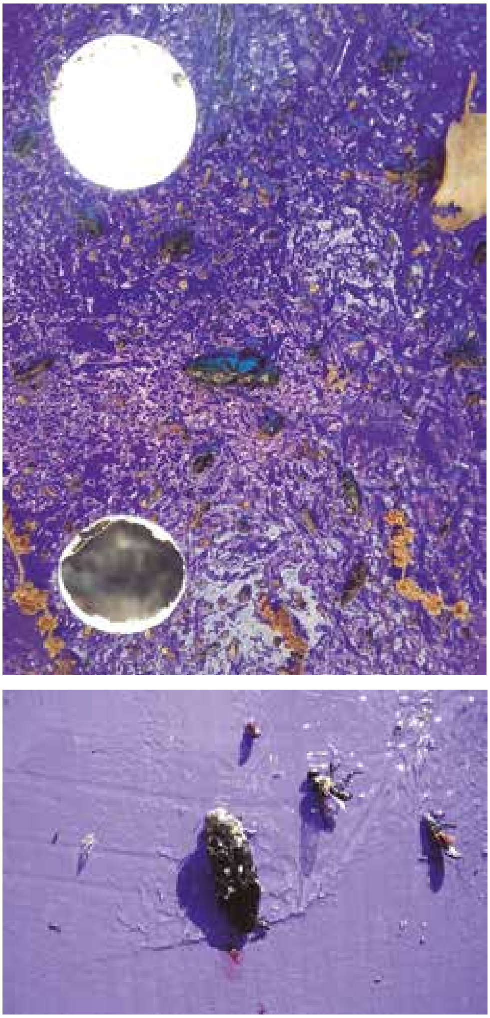


Figure 108. Adult *Coraebus undatus* on a prism trap.

In Catalonia, this period runs from the second fornight of June to the first fortnight of August.

Given that one of the attraction components of the trap is colour-based, the traps should be installed at a height of approximately 170 cm and 25 m^2 of land should be cleared around each trap to make it easier for the adults to detect.

Figure 109. An installed prism trap.

The traps should be checked several times over the course of the trapping period in order to clean the surface, as falling leaves can cover it, considerably reducing the capture area.

Figure 110. A trap that is partially covered with leaves.

Figure 111. A trap after being checked.

45 days after installation, the attractant dispensers should be replaced. The dispensers are placed inside tha trap, with the product diffusing side facing inwards.

Figure 112. Close-up of the dispenser inside a trap.

The use of phytosanitary treatments is not asvised given that these do not effectively control this pest. The larvae are protected from these treatments beneath the cork sheet.

The most predators of *C. undatus* are insectivorous birds; the European green woodpecker (*Picus viridis*) and Eurasian nuthatch (*Sitta europaea*) can feed on the larvae but to do this they bore through the cork and leave it useless. The woodchat shrike (*Lanius senator*) and species of the genus *Parus* feed on the adults.

Figure 113. The Eurasian nuthatch (*Sitta europaea*) is an insectivorous bird that can feed on flathead oak borer larvae (Photo: Eudald Solà).

Figure 114. *Coraebus undatus* gallery inside the opening created by a woodpecker.

Figure 115. Cord damage caused by woodpechers.

References

Alford, D.V. 2000. *Pest and Disease Management Handbook*. Wiley-Blackwell. 624 pp.

Carrero, J.M. 1996. *Lucha integrada contra las plagas agrícolas y forestales*. Mundi-Prensa. 256 pp.

Fürstenau, B.; Quero, C.; Riba, J.M.; Rosell, G.; Guerrero, A. *Field trapping of the flathead oak borer* Coraebus undatus *(Coleoptera: Buprestidae) with different traps and volatile lures*. Insect Science (2015) 22, 139-149.

Llácer, G.; López, M.M.; Trapero, A.; Bello, A. 1996. *Patología vegetal*. Ed. Mundi-Prensa. 1165 pp (2 vol.).

Muñoz, C.; Pérez, V.; Cobos, P.; Hernández, R.; Sánchez, G. (2003). *Sanidad forestal. Guía en imágenes de plagas, enfermedades y otros agentes presentes en los montes*. Madrid: Ediciones Mundi-Presa. 575 pp.

Romanyk, N.; Cadahía, D. 2003. *Plagas de Insectos en las masas forestales españolas*. Spanish Society of Forest Sciences. Ed. Mundi-Prensa. Madrid. 336 pp.

Soria, F.J.; Villagrán, M.; Del Río, R.; Ocete, M. E. *Estudios prospectivos de los principales perforadores del alcornoque en la Sierra Norte de Sevilla*. Bol. San. Veg. «Plagas», 20: 643-651, 1994.

Torrell, A.; Beltrán, M.; Porras, D.; Mundet, R. 2017. *Informe de Evaluación Técnica de las acciones de trampeo masivo de* Coraebus undatus*. Resultados intermedios*. Life+Suber project (LIFE13 ENV/ES/000255).

Torrell, A.; Beltrán, M.; Porras, D.; Mundet, R. 2018. *Informe final de Evaluación Técnica de las acciones de trampeo masivo de* Coraebus undatus. Life+Suber project (LIFE13 ENV/ES/000255).

Torres, J. 1998. *Patología Forestal*. Ed. Mundi-Prensa. 270 pp.

Van Halder, I. 2002. *Guía de Plagas-Enfermedades forestales del sur de Europa*. IEFC. Cestas. 164 pp.

Webografy

http://www.mapama.gob.es/es/agricultura/temas/sanidad-vegetal/productos-fitosanitarios/guias-gestion-plagas - Guía de gestión integrada de plagas, *Quercus*. (2016) Madrid: Ministry of Agriculture, Food and Environmental Affairs.

http://www.magrama.gob.es/es/agricultura/temas/sanidad-vegetal/productos-fitosanitarios/fitos.asp- Register of Phytosanitary Products. Ministry of Agriculture, Food and Environmental Affairs.

http://agricultura.gencat.cat/ca/ambits/medi-natural/gestio-forestal/sanitat-forestal/plagues-malures-forestals/fitxes-plagues-forestals- Fitxes patologies. Departament d'Agricultura, Ramaderia, Pesca i Alimentació. Generalitat de Catalunya.

http://www.juntadeandalucia.es/medioambiente Pathology data sheets. Department of Environmental Affairs and Land use Planning. Regional Government of Andalusia.

This book has been produced within the framework of the Life+Suber project, *Integrative management for an improved adaptation of cork oak forests to climate change.* LIFE13 ENV/ES/000255. lifesuber.eu

PARTNERS

Consorci Forestal de Catalunya

CTFC

Generalitat de Catalunya
Forestal Catalana, SA

AMORIM

Generalitat de Catalunya
Departament d'Agricultura, Ramaderia, Pesca i Alimentació

Centre de la Propietat Forestal

CO-FINANCERS

Diputació Barcelona

Institut Català del Suro

AMORIM FLORESTAL MEDITERRANEO, SL