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THE VITALITY OF CORK AND HOLM OAK STANDS AND FORESTS

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I. Invited speakers

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1. Introduction

Cork (*Quercus suber*) and holm oak (*Q.rotundifolia and Q. ilex*) woodlands or the derived silvopastoral systems (the Portuguese *montados*, the Spanish *dehesas* or Italian *pascolo arbolato*) are of high conservation and socioeconomic value within their areas of geographic distribution around the Mediterranean basin: Iberia Peninsula, southern France, Sardignia, Algeria, Morocco and Tunisia. These systems support a rich variety of species (e.g. the Iberian Lynx *Lynx pardina* or the Imperial Eagle *Aquila adalberti* in Spain) also providing sources of income and ways of living (e.g. cork production, wood for fuel, animal fodder).

Large areas of cork and holm oak tree mortality have been observed in recent years. These raised concerns on the sustainability of such systems. Decline is not restricted to holm and cork oak species as mortality of the genus *Quercus* spp. has been observed in such different countries as the United States of America or Poland. Oak decline extends beyond of the Mediterranean Basin and is of global nature.

The Évora conference aimed to gather technicians and researchers for an update on the state of the art of the oak mortality issue, suggesting possible ways to mitigate the problem. There were invited participants from the North and South Mediterranean countries, particularly those having institutional organizations addressing cork oak and holm oak issues (e.g. Institut Mediterranéen du Liege in France, Stazione Sperimentale del Sughero in Italy or Instituto del Corcho, Madera y Carbon Vegetal in Spain) as well as representatives of other countries where oak decline seems to be occurring.

This report summarizes the presentations that were made during the conference and is divided in two main sections: a first section aiming to characterize present situation (distribution, health status) of areas of cork and holm oak and a second section addressing possible causes of decline and suggesting mitigation measures.

2. The status of cork and holm oak stands and forests

A first division must be stated, related to the status of cork and holm oak stands in North (Portugal, Spain, Italy, France) or South Mediterranean (Morocco, Tunisia, Algeria). In European countries cork and holm oak are mainly private property, have been strongly affected by Common Agricultural Policies from the European Union and, frequently, problems arising relate to land abandonment, increase of vegetation fuel and risk of fire. In Northern African countries cork and holm oak occurs exclusively in public land where local populations over utilize the land for grazing, gathering of wood for fuel or even acorn collection. In these countries over-use is risking the sustainability of the stands.

2.1. European countries

2.1.1. Portugal

For characterizing cork and holm oak stands in Portugal three main sources of data (National Forest Inventory, ICP and an INTERREG project) were used employing both aerial photography and field work validation at the plot level. These allowed characterization of present distribution and health status of stands and were: 1) area covered by holm and cork oak; 2) level of defoliation of holm and cork oak trees; 3) level of defoliation of trees at the plot level; 4) proportion of dead trees in plots and 5) number of trees per hectare.

Data based on area covered by species suggest an increase of cork and holm oak *montados* between 1902 and 1956, from approximately 800.000 ha to 1.200.000 ha, respectively, following a relatively stable period from 1956 to 2006 where both species together occupied, approximately, 1.200.000 ha (cork areas being slightly larger than holm oak). No clear patterns of increase or decrease of area of distribution could be observed using aerial photography data (Figure 1).

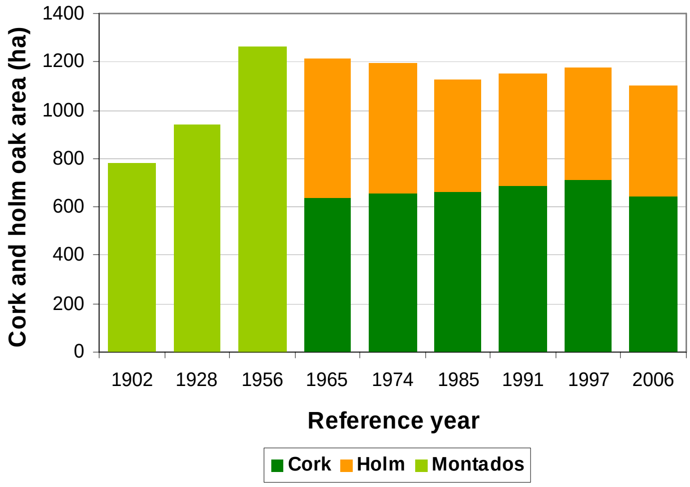

Figure 1. Area covered (x10^3 ha) by cork and holm oak in Portugal between 1902 and 2006. First three year classes consider both species aggregated as the silvopastoral system *Montado*.

Although distribution measured by area of occurrence seems stable, it is nevertheless necessary to assess health condition of stands. This was made using an index of individual tree canopy defoliation and considering four levels of defoliation: bad (more than 60% of canopy damaged), medium (26% to 59% of canopy damaged), good (11% to 25%) and excellent (0% to 10%). Defoliation data used came from two different sources: the Portuguese National Forest Inventory and a project funded by the European Union program INTERREG. Although results between the 2 data sources were not full consistent, a higher proportion of trees classified as "excellent" and "good", as compared to "medium" or "bad", were found (Figure 2). The same general results were found using still another source of data (ICP project) (not shown).

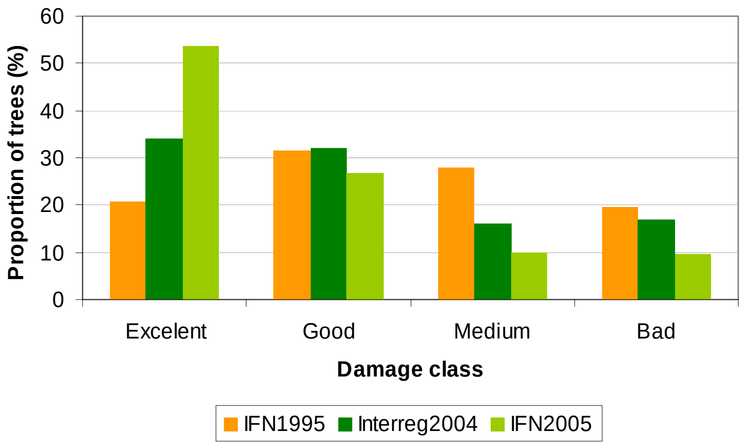

Figure 2. Proportion of trees classified according to level of canopy defoliation using data from the National Forest Inventory (IFN) in 1995 and 2005 and an INTERREG project (2004).

For results at the plot level the proportion of trees with their canopy affected were considered using two different criteria. A first criteria classified plots as “Good” if less than 50% of trees had levels of defoliation above 60%; “Medium” if 25% to 50% of trees had levels of defoliation above 60%; and “Bad” if more than 50% of trees had levels of defoliation above 60%. According this classification there was a steady increase of “Bad” plots between 1995 and 2005, which reached 90%of the visited plots in 2005.

An alternative criteria considered plots as “Excelent” if more than 50% of trees had levels of defoliation below 10%; “Medium” if 25% to 50% of trees had levels of defoliation below 10% or “Bad” if less than 25% of trees had levels of defoliation below 10%. Using data from the Portuguese National Forest Inventory for 1995 and 2005, approximately 15%, 20% and 65% of the plots were classified, in 1995, as “Excellent”, “Medium” and “Bad”, respectively. Conversely, in 2005, approximately 60%, 20% and 18% were classified as “Excellent”, “Medium” and “Bad”, respectively

As expected, different criteria for classifying the plots, led to different results. For instance in 2005 criteria 1 suggests that a high proportion (60%) of plots were in “Excellent” condition whilst criteria 2 classified as “Good” only 20% of the plots. This enhances the need of standardized, systematic protocols for monitoring health condition of stands.

Using data from the Portuguese National Inventory on the number of dead trees found in the different plots, it was found that, in 2005, mortality was over 25% only in 5% of the plots and below 10% in 10% of the plots. Using data on the number of trees per hectare, from the same data source, showed that numbers were steady between 1995 and 2005 with the majority of stands (approximately 35% of plots) having tree densities varying between 40 to 80 trees/ha. There was variation among years with densities of trees ranging from 0 to 40 trees/ha in 20% of the plots in 1995 but, the same class of density, increasing to 30% in 2005. Results suggest that number of trees per ha may have decreased between 1995 and 2005.

It would be crucial to implement standard and systematic monitoring schemes, across different projects addressing cork and holm oak distribution and health status, in order to make best use of data available from the different sources. The different parameters analysed for characterizing the situation in Portugal suggest that area and tree densities are in relatively fair condition but health status, namely levels of defoliation at the plot level, suggest that a high proportion of plots may be in “Bad” condition.

2.1.2. Spain

Data from the Spanish National Forest Inventory indicate that areas occupied by holm oak are of 4.8×10^6 ha extending from the temperate north until the xeric southeast and 0.5×10^6 ha are occupied by cork oak particularly in the regions of Extremadura, Andaluzia and Catalonia.

There is evidence of holm and cork oak decline in Spain with trees showing symptoms of mortality ranging from 1) progressive signs of defoliation with partial or total dead branches; 2) quick death of trees in a short period of time after leaves getting red (sudden oak death) and 3) surviving of trees during a large period of time in apparently very bad health condition. Mortality occurs in pocket areas with no apparent geographic patterns.

Different biotic and abiotic factors may be interacting and contributing to decline. Among pests, leaf eaters (e.g. *Lymantria dispar*, *Tortix viridiana*), miners (e.g. *Dryomia lichensteini*, *Kermes* spp.) or species that attach the trunk (e.g. *Cerambyx* spp. *Platypus cilindrus*) are frequently associated with areas of decline. Diseases such as *Phytophtora cinnamomi* or *Armilaria* spp. were shown to occur in areas of decline. In addition, pests and diseases may be interacting with climatic factors such as increasing periods of water stress. Lack of proper management namely inadequate silviculture and land abandonment may also be interacting with pests and diseases and triggering mortality. No clear relations were found between tree mortality and soil type, topography or microclimatic conditions. A high temporal syncrony in mortality, however, tends to occur, particularly after drought years (e.g. 1990, 1992, 1994 2004 and 2005 were particularly critical years).

Monitoring schemes were systematically implemented since 1987 with 181 plots of holm oak (total of 3200 trees) and 34 plots of cork oak (397 trees) assessed every summer for their status and health condition. Results of monitoring have shown, for example, occurrence of high defoliation levels in 1995 with 70% of cork and 30% of holm trees severely defoliated. Mortality, however, seems to be higher in holm than cork oak, occurring mainly in mature and homogeneous stands. Young trees are mostly affected by sudden oak death, particularly in autumn, and following wet springs and dry summers. In contrast, adult and old trees tend to suffer progressive decay, particularly at lower areas ("water beds") where spores of the fungi *P. cinnamomi* were shown to occur at high levels in soil samples.

Mitigation of oak decline includes measures related to good management practices including: grazing (e.g. deferred grazing, avoidance of grazing in the end of summer and beginning of autumn); implementation of conservative techniques of cork extraction (e.g. avoiding harvesting in years of drought or of high pest incidence); use of uninfected tools in pruning or wood collection; shrub clearance (e.g. not ploughing in slopes above 20% or under canopies, for not destroying regeneration, preferentially use of manual or light machinery); pruning (e.g. possible not exceed 1/3 of canopy volume and avoid affecting main branches of trees). In case of root disease incidence, it is advisable that dead roots are extracted in place and dead trees burned or treated in site to avoid spreading of the infection.

Advisement on best management practices as those stated above are conducted mainly by IPROCOR – a public institute dealing with cork and holm oak issues. The institute has also identified other others factors involved in oak decline such as a need for younger age classes of trees in most stands and development of clones resistant to *Phytophtora cinnamomi*, a topic of strong research in Spain. At the policy level (e.g. incentives for good management) there is also scope for action, as neither abandonment nor overuse is compatible with sustainability of Spanish cork and holm oak stands

2.1.3. France

France has an area of cork oak of approximately $90x10^3$ ha from which $40x10^3$ ha are currently exploited for cork. Area of distribution includes the regions of Aquitaine in SW France, Pyrenees Orientales in South, Var in SE and most of the east (and part of the west) coast of Corse. The stands are generally characterised by a high number of trees per ha (approximately 100 trees/ha).

Previously, main land use on such area was silvopastoral. However, since the 1960´s, silvopastoral use decreased. Lack of use led to strong development of maquis vegetation where other *Quercus* species (e.g. *Q.ilex*, *Q.pubescens*) are becoming dominant and outcompeting cork oak. Accumulation of vegetation fuel also led to a dramatic increase of risk of fire (e.g. 34% of the productive cork oak stands have burned between 1974 and 2004).

Cork harvesting occurs in different stands (in areas where cork has good quality there is a tendency for overexploitation, whilst in areas of poor quality of cork land abandonment occurs frequently) but extraction is frequently inadequately conducted partly due to lack of regulations. Other non-timber products exploited in cork oak areas include mushrooms and hunting, while leisure activities are an important use in such areas.

There is perception of cork oak decline. Besides the most important factor related to risk of fire, different pests and diseases were identified in areas of decline (e.g. *Platypus cilindrus*, *Lymantria dispar*, *Bicogniauxia mediterranea*, *Diplodia mutil* or *Coroebus undatus*).

Holm oak stands are mainly exploited for coppicing with cuts traditionally occurring in each 40 year period. A decline in holm oak has been recognised since 1993. Stands are affected by pests as *Coroebus bifasciatus* or *Lymantria dispar* and suffering competition from *Q.pubescens* which is outcompeting holm oak in different regions. Conversely, because it is a species well adapted to dry regions, holm oak is expanding in West and South West of France.

Mitigation of decline of cork and holm oak require extensive advise on prevention (e.g. burnt of dead trees, use of uninfected tools). Additionally, and in particularly for cork oak, different stakeholders were identified (e.g. Forest Services, Institute of Cork, Forest Owner Associations, Public Institutions related to forest management) and engaged in common projects across the area of distribution of the species in order to revert decline in France.

2.1.4. Italy

Current area of cork oak in Italy is, approximately, of $152x10^3$ha distributed across Toscania (12 $x10^3$ha), Lazio (1.1 $x10^3$ha), Calabria (2.3 $x10^3$ha), Sicilia (16.5 $x10^3$ha) and Sardegna (120 $x10^3$ha). More than 80% of cork production in Italy ($15x10^3$t) is concentrated in Sardegna.

In Italy, cork oak stands are of three main types. Those used mainly for cork production, those where animal production occurs and those not managed and having conservation purposes only.

The stands used for cork production are subjected to a silvilculture oriented to cork extraction, can be single or multi-species systems, usually form areas of same age class of trees and normally have adequate levels of regeneration. These stands can sometimes be grazed (but at very low animal densities) and seldom have problems of decline.

In stands used for animal production, grazing by sheep is main activity and the cork is considered as a secondary product. These are usually even age stands, with a very low number of trees/ha where shrub clearance and implementation of pasture are common management practices. These stands are characterised by very low oak regeneration, and considered critical stands with high decline problems.

Non-exploited cork oak stands are mainly conservation oriented. These stands are characterised by a well developed shrub cover with considerably lack of regeneration, possibly due to competition of oak seedlings with shrub species. These stands are considered to have medium problems of decline.

Cork oak decline has been perceived in Italy since the 1990´s. Main symptoms include areas of dead canopy as well as death of twigs and branches or even main trunk. High levels of canopy defoliation and lack of regeneration are frequently associated with areas of decline. These areas tend to occur as “pocket” locations and form well localized phenomena.

Perceived factors of decline in Italy, possible act in synergy and include inadequate management practices, pests and diseases and fire. These factors are probably enhanced by climatic events such as drought. In stands oriented mainly for cork extraction, silviculture techniques put low emphasis on enhancement of proper regeneration and adequate management of shrub cover (high of shrub cover in many stands are increasing risk of fire: fire is presently the main problem of oak stands in Sardegna with more than 50 $x10^3$ ha of cork oak stands burned between 1998 and 2005). Inadequate cork harvesting techniques are also leading to weakening of trees and, ultimately, mortality. Stands directed to animal production usually have problems of overgrazing, animal trampling, deep ploughing and intensive shrub clearance which induce mortality of young and adult trees. Indeed the system of "pascolo arbolato" (pasture with trees) is considered by some authors as a degraded form of cork oak stands.

Pests such as *Lymantria dispar*, *Malacosoma neustria*, *Platypus cilindrus*, *Tortix viridiana*, *Coroebus* spp. are frequently associated with areas of cork oak decline. Drought years may enhance some of the negative effects of inadequate managements and occurrence of pests and diseases.

A monitoring network of 43 plots was established in Sardegna in 2002. This network aims to quantify cork oak decline, identify causes of tree mortality leading to establishment of mitigation measures. Development and implementation of certification schemes (e.g. official recognition of good management practices) in cork oak stands is presently being conducted in Italy, jointly by the Forest Stewardship Council (FSC), World Wide Fund for Nature (WWF) and the Stazione Experimentale del Sughero. This may significantly contribute for implementing good management practices in cork oak stands and contribute to reduce decline.

2.2. Northern African Countries

2.2.1. Morocco

In Morocco, cork oak has a surface area of approximately $350x10^3$ha distributed across the regions of Maâmora, Plateau Central and the Rif. There is general perception of degradation of cork oak stands. The Maâmora forest, for instance, is an alarming case where cork oak surface decreased from 133 $x10^3$ha to 60 $x10^3$ha between 1955 and

2000, a rate of lost of approximately 1600ha/year. Main reasons for such sharp decrease are particularly related to severe over-use of forest resources by local populations (e.g. wood for cooking, overgrazing, acorn collection) which, associated with drought periods and pests and diseases, is aggravating the degradation problem.

Pests associated with degraded areas include defoliators (e.g. *Lymantria dispar*), wood borers (e.g. *Platypus cilindrus* and *Cerambyx cerdo)* and species affecting roots of young trees (e.g. *Phyllognathus excavatus*, *Sphodroxia maroccana*). Among diseases, fungi affecting cork quality (e.g. *Hypoxylon mediterraneum*), twigs and branches of trees (e.g. *Diplodia mutila*, *Stuartella formosa, Dothiorella spp., Coryneum spp., Cytospora spp*) or attacking roots (e.g. *Armellaria mellea*) have been identified in association with degraded areas.

The Forest Services and the Services for the Protection of Cultures of Morocco have developed a national plan to fight pests and diseases affecting cork oak stands. These programs include both chemical (e.g. *Diflubenzuron*) as well as integrated fighting (e.g. *Bacillus thuringiensis*) which have been relatively successful and contributed for recovery of previously highly degraded areas.

Holm oak covers approximately $1400x10^3$ ha in regions such as the Rif, the East Mountains, the mid- Great- and the Anti-Atlas as well as the Saharian Atlas. Morocco has lost approximately 15800 ha of holm oak between 2000 and 2005. Main causes of holm oak mortality relate to increase of frequency of droughts which increases susceptibility of trees to attack of defoliator insects (e.g. *Tortix viridiana*, *Malocosoma neustria*, *Catocalla spp*.) that has been recorded in the generality of the stands.

2.2.2. Tunisia

In Tunisia, $1.2x10^6$ ha are covered with forest stands from which approximately 13% are of cork oak, the main forest resource of the country. Cork oak occur either as single or mixed species stands (e.g. with *Pinus pinea*, *P.pinaster*, *P.halepensis*, *Eucalyptus* spp and other *Quercus* spp.). Approximately, 80 $x10^3$ha of cork oak stands are considered as degraded.

Main cause of degradation is related to overuse of forest resources by local populations. People live within cork oak forests with an average density of 100 habitants/km^2. Many of the cork oak stands are also exploited for cork and have management plans which started to be implemented in 1965 by government authorities. Besides stands used for cork extraction there are conservation-oriented cork oak forests. This is the case, for example, of the mountains of Kroumirie, a cork oak dominated region characterised by the occurrence of the critically endangered Barbary deer (*Cervus elaphus barbarus*).

Different projects running in Tunisia involve national institutions as the Forest Services and National or International Non-Governmental Organizations, which are addressing aspects of management (e.g. silviculture, grazing, regeneration) and of the socio-economy of the systems. The Tunisian government "Strategy for the Forests" has a section specifically addressing cork oak stands.

Holm oak stands are not particular considered in forest management although they are important as conservation objectives.

2.2.3. Algeria

In Algeria, area of cork oak stands is nowadays of $150x10^3$ ha comparing to $440x10^3$ ha in 1930´s. Over this period cork production in Algeria decreased from $40x10^3$ tones to $9x10^3$ tones.

Main factor of degradation of cork oak stands in Algeria relate to bad management and excessive use of forest resources by local populations. Fire is also of importance and is mainly related with reclamation of land for grazing. More than $3x10^6$ ha of forest area was lost to fire in the last one hundred years (an average of $36x10^3$ ha burned every year).

A National Forest Plan, approved by the government in 1999, suggests forestation of $1250x10^6$ ha among which $100x10^3$ ha would be with cork oak.

It is suggested that a creation of a cork oak network for the North African countries, enabling technical and scientific changes would be of most interest for the promotion of adequate management techniques and conservation of such forests. In particular it is considered as crucial that local populations perceive and get real benefits from cork oak stands in areas surrounding the places where they live.

2.3. Opportunities for Conservation

An important way to reverse prospects of decline of oak forests is through proper evaluation of direct and indirect services provided by such multifunctional forests. Payment for environmental services (biodiversity, soil protection, hydrological cycle) provided by such forests is a mechanism that needs further research and proper implementation in the future. In many cases landowner are providing services, by maintaining their oak stands, without proper compensation that could contribute to avoid conversion to other uses. Essential is also to address mechanisms related to *forest management* (capacity building of landowners and managers, implementation of long-term management plans, systematic monitoring of activities), *policy issues* (proper consideration of oak forest in rural development policy, enhance public profile of rural issues, socio-economic aspects related to oak forests) and *market issues* (adequate consideration of competition by cork substitutes, existence of informal products markets such as mushrooms, occurrence of non-marketable benefits). For assuring conservation of cork and holm oak forests it is thus crucial to maintain the multifunctionality of the system and the create markets for different products, beyond cork, originated by the systems. Payment for environmental services, certification of good management schemes and, in some cases, restoration of degraded areas, are mechanisms that must be considered as challenges for the conservation of cork and holm oak stands.

2.4. Synthesis

Although not clearly quantified, there is a general perception of decline of cork and holm oak, both in Europe and North Africa. Biotic factors, particularly pests and diseases, are common factors for all regions that area associated with areas of decline. Oak decline tends to occur in “pocket” and well localized areas (e.g. Spain and Italy). Inadequate management (including inadequate techniques for harvesting cork) is referred in all situations as a predisposing factor of decline. Main contrast relates to use of forest resources in European countries and North African countries: Whilst in Europe land abandonment is an important factor of decline (e.g. Portugal, Spain, France) in North Africa there is over-utilization of resources by local populations. Fire is associated with land abandonment and increase of fuel vegetation in all European countries but, paradoxically, suggested as an important factor of decline in Argelia particularly due to reclamation of land for grazing (land use conflict). Non timber forest products (e.g. hunting, mushrooms) and use for conservation or leisure are indicated as potentially contributing to valuation of cork and holm oak stands.

Common biotic (pests and diseases) and abiotic factors (fire, management) acting in oak decline in different countries give wide scope for common action of countries where forest and stands of cork and holm oak occur.

3. Causes of mortality

It is generally accepted that oak decline is related to different factors possibly acting in synergy. These include factors pests and diseases, inadequate management or fire. Some of these factors and their implications are summarized below.

3.1 Soil degradation due to mismanagement

Soil degradation may be an important factor of cork oak decline. Cork oak trees are generally adapted to soils free of calcium carbonate, with a PH ranging from slightly too strongly acid, sufficiently drained, with well preserved organic horizons and few limitations for root penetration. Factors changing such characteristics may make soils inadequate for supporting healthy populations of cork oak trees. *Physical processes* such as soil compaction and erosion may be caused by overgrazing or deep ploughing, whilst *chemical processes* such as losses of soil organic matter can be a consequence of severe fires. Physical and chemical processes interact and lead to changes in soil biological processes (e.g. changes in flora and fauna activity).

Overgrazing, deep ploughing or fire, are factors that may change properties of soil and ultimately contribute to oak decline. Overgrazing strongly reduces plant cover and tree regeneration and leads to compaction of soil (trough animal trampling) which reduces water infiltration capacity and increases runoff and the possibility of soil erosion.

Deep ploughing eliminates shrub cover which may change soil inputs of organic matter. Also, if plant cover is strongly reduced, there may be higher risks of soil erosion after strong rainfall. Ploughing may reduce regeneration ability of trees by affecting microenvironment characteristics. Additionally deep ploughing may damage roots of trees.

Severe fire may completely destroy vegetation cover and the soil organic horizons. Lack of soil organic matter will reduce capacity of soil for water retention, water infiltration rates and permeability of soil, increasing risk of erosion, particularly at high slopes. Chemical changes in soil properties may also be induced by fire with some of the nutrients being volatized and lost, although other mineral elements my return to soil.

In generally, there is a good understanding on the causes and processes of soil degradation and its effects on the vitality of cork oak trees. Less is known on the characteristics of soil and its effects on cork production and quality, an area in need of further research.

3.2. Pests, diseases and mismanagement

In North Africa, cork and holm oak stands and forests are inhabited by people using local resources. Grazing is one of the main sources of income of local populations. Consequently, overgrazing of cork oak and holm oak stands commonly occur and is an important cause of oak decline. For instance, in Kroumiri, in Tunisia, grazing pressure may exceed 3 to 5 times herbage production. This leads to high rates of browsing and utilization of tree foliage, as well as acorns, which severely constrains regeneration. Lack of regeneration and a high proportion of even age, old stands, is one of the main constraints on the sustainability of cork and holm oak forests of Northern Africa.

Besides processes related to overgrazing and excessive ploughing, inadequate techniques of cork harvesting were identified as important factors weakening trees and increasing their susceptibility to pests and diseases. Additionally, bad oriented pruning or excessive clearance of shrubs may also lead to tree weakness, mortality, and, ultimately, oak decline. For instance, excessive clearance of shrubs may induce changes in microclimate conditions, such as temperature, shade or soil moisture that may be unfavourable tree regeneration.

3.3. Pests, drought and mismanagement

Pests are affecting cork production in different countries of North Africa and Algeria in particular. In Algeria, for instance, it has been observed that decline may occur at concentrated areas within the stands affecting small groups of trees (2 to 10) or virtually in the whole of the stand, causing extensive mortality. Decline is progressing relatively slowly in Algeria and may be related to both climatic and management factors acting in synergy.

Drought years tend to occur in 3 to 5 years cycles which may weaken trees and making them susceptible to pests. Inadequate management aggravates the situation. Excessively old stands with lack of adequate regeneration, frequently competing with other tree species (in particular pines such as *Pinus pinaster*, *Pinus halepensis*) accentuate trees susceptibility. Inadequate management allows strong development of shrub or tree vegetation (e.g. invasion by pine species) debilitating trees through competition and creating conditions for fire hazard. Additionally inadequate techniques of cork extraction also affect negatively health status of trees.

Debilitated trees are prone to attacks by defoliators such as *Lymantria dispar*, which tend to act in localized areas. Other less important pests include *Euproctis chrysorrhoea* or *Totrix viridiana*. There are also a number of wood borers (e.g. *C. cerdo*, *H. cinereus*, *P. unicolor*, *P. cylindrus*) that may attack weaken trees and contribute to their mortality. It is necessary to ameliorate management conditions and the stand level and implement adequate cork extraction techniques to mitigate the effects of pests on trees.

3.4. Oak diseases: diagnostic tools

Pests such as *Phytophtora* spp. occur in all *Quercus* spp. and may be an important factor of cork and holm oak decline. These fungi are mainly spread though nurseries and along streamlines carrying their spores. More than 90 species of *Phytophtora* spp., with different degrees of pathogenic activity, have now been identified recurring to DNA techniques by examination of rizhosphere soil samples.

Molecular diagnosis will be increasingly used to identify and detect pathogenic species and to assure Healthy Plant schemes (i.e. no occurrence of symptons in nurseries). Expedite techniques recurring to PCR arrays will enable quick detection of *Phytophtora* spp. in samples of plants, soil or water. Using such techniques, well developed for other oak species, in cork and holm oak will contribute to diagnosis and mitigation of mortality induced by *Phytophtora* spp.

3.5. Oak endophytic fungi

Endophytic fungi can affect physiology of their hosts. Some will develop comensal or mutualistic relationships but others can act as pathogenes to theirs hosts. This last group may have an important role on oak decline. In Sardegna, Italy, for instance, surveys conducted in cork oak forests have shown high variability in the composition of endophytic fungal communities, both in trees with and without symptoms.

Among pathogenic species, *Biscogniauxia mediterranea*, *Botryosphaeria corticola* and *Apiognomonia quercina* were the most frequent that were identified. *B. mediterranea* can survive as an endophyte in all of the aerial organs of the plants. Its infection causes the drying up of the woody organs and the appearance of lesions commonly called “charcoal cankers”. *B. corticola* cause symptoms similar to those of a vascular disease. On the upper part of the tree canopy, the branches dieback, starting from the external ones; on branches and trunk necrotic spots may appear, with production of exudates and development of cankers. In the infected organs, internal tissues are discoloured and the vascular ones are invaded by fungal hyphae. If numerous centers of infection occur, even the strongest plants are destined to die. In particular, lethal fungal attacks can be seen in adult plants in dry years immediately after cork extraction. *A. quercina* is the causal agent of anthracnose ant twig blight of several oak species. It may affect all the aerial organs, but mainly the leaves, causing severe defoliation and consequent reduction of the photosynthetic activity and alteration of host metabolic processes.

Among the antagonistic species the three species of *Trichoderma*, and specially *T. citrinoviride*, express high activity against *B. corticola*, limiting its *in vitro* development, and its *in planta* infections. Recently, secondary metabolites with high antifungal activity were isolated from stationary culture of these species of *Trichoderma*. These results encourage further studies on the fungal endophytes of oaks as a new source of bio-control agents against the forest pathogens. The use of bio-pesticides in alternative to chemicals could be very useful in declining cork oak forests in order to prevent the pathogen infections after the cork extraction.

For reducing potential inoculum pathogens and prevent infections it is considered to be priority the removal and burning of dead or infected trees, to use nursery pathogen-free plants in reforestations and possibly using chemical treatments in infected areas. Biological control has strong potential and can be an alternative to chemical treatments. These measures of control will only be effective if associated to adequate management and silvicultural practices.

3.6. Climatic change

Predicted and observed scenarios of climatic changes include an increase of the variability of precipitation, an increase in the frequency of droughts and a tendency for temperatures to increase. All these factors may affect vegetation cover and structure. In Spain, and Andaluzia in particular, the effects of such factors on the distribution of cork were investigated. Progressive decay of cork oak areas has been observed in Andaluzia and considered related to drought effects. Phytoclimatic and Regression models were used to investigate actual and potential plant communities associated with cork oak stands under different climatic scenarios. Main hypothesis considered scenarios based on an increase of the average annual temperatures (approximately $2^{o}C$) as well as different ranges of annual precipitation. All hypothesis showed that the actual distribution of cork oak will be affected with possible fragmentation of actual areas of distribution, total reduction in area size, and possible migration of the species to areas where it does not occur nowdays. Climatic change scenarios are an important issue to consider when thinking approaches to the conservation of cork oak stands.

3.7. Cork oak responses to fire

Fire occurs frequently in cork oak forests. In Portugal, for instance, more than $100x10^3$ ha of cork oak stands have burned between 1984 and 2004. Unmanaged cork oak stands, in particular, with high shrub accumulation are particularly prone to fire. Cork oak trees are well adapted to fire mainly due to its good insulating bark - the cork. There are site and tree factors affecting the probability of cork oak trees to survive fire injuries.

A descriptive study in Algarve, South Portugal, has shown that, 1.5 years after fire occurrence, cork oak trees that were not harvested for cork had slightly higher surviving probability (89%) than harvested trees (82%). Besides survival, the factors affecting survival of barked or debarked trees to fire were different. In the case of unharvested trees, height was the main factor affecting survival, with taller trees having higher probability of surviving to fire. In the case of harvested trees, cork thickness (cork growth since last extraction) was main factor affecting survival, with trees with thicker bark having higher rates of survival than trees with thinner bark.

Site factors, such as topographical factors, also determine survival of cork oak trees to fire, but they affect differently harvested or not harvested trees. For instance, mortality of harvested trees was higher in steep slopes and southeast expositions but slope had no effect on the mortality of trees that were not harvested for cork. In general, older trees (with larger diameter at breast height) in southern exposures, with thin bark and dense understorey shrub cover seem to be particularly susceptible to fire. Shrub cover is a strong determinant of fire occurrence and tree mortality. Shrublands are the land-use more prone to fire in Portugal. This is particularly aggravated in cork oak forests which, if non-managed or properly restored, tend to be replaced by shrubland areas after fire occurrence, creating a feedback loop ultimately leading to higher risk of fire in such areas.

Factors affecting fire induced mortality of trees may be the same affecting incidence of stress or pests and diseases. Fire may be adding to other factors of mortality (e.g. climate change, fungi, wounds, bad management practices) and probably facilitating the action of these factors. These interactions remain to be investigated.

3.8. The role of water in oak decline

There are a large number of oak trees dying every year. For instance, in Portugal, the National Forest Service permits to cut dead oak trees are on average of $150x10^3$ per year. High oak mortalities occur not only in Iberia but also in regions such as California, in USA.

The symptoms of declining oak trees (e.g. slow growth and dead branches, few leaves per stem, low tissue water potential or increase of apical dominance) suggest that they are experiencing chronic water stress. In most cases death occurs when the tree looses its capability to transport water from the soil, through roots to the leaves. This can happen if the xylem (wood) becomes embolised, i.e., when it looses conductivity with increasing water stress. Xylem embolism hinders normal fluid transport which may ultimately lead to the death of tree.

Oaks are, in general, adapted to a long dry season. Cork and holm oak trees, for instance, avoid dehydration trough stomatal closure and rely heavily on water supply from large root systems to compensate water losses from transpiration. In the case of cork oak, xylem embolism has intermediate values between those of deciduous oaks or the more drought tolerant holm oak. For instance, the leaf water potential of cork oak is on average -3MPa as compared to -5Mpa of Gum cistus *Cistus ladanifer*, a semi-deciduous species. Hydraulic lift is another mechanism contributing to avoid water stress that has been shown to occur in cork oak (using stable isotope analyses such as $\delta^{18}O$).

All factors inducing xylem embolism may thus contribute to increase susceptibility of trees to water stress. For instance, infection of roots by *Phytophtora cinnamomi* is one of such factors, as it may increase levels of water stress independently of the values of xylem vulnerability to embolism. Chronic root infection may progress slowly, increase susceptibility of tree to other factors of stress acting in synergy (e.g. drought periods, eroded soils, pests) and cause death of tree only after several years or be relatively rapid, particularly in young trees. Death of tree will come sooner or later according to individual tree characteristics and weather conditions. Droughts may bring about severe mortality.

In order to test if drought is a direct factor of mortality, the number of permits of the Portuguese National Forest to cut dead oak trees was compared to an index of severity of drought. No relationships were found between mortality of oak and drought severity, even allowing for time-lag comparisons (e.g. comparing mortality against index calculated for previous year or two and three previous years). It is thus unclear if it is drought that increases susceptibility of trees to pests and diseases or if it is the infection by root pathogens which increases susceptibility to drought.

Research is needed to provide an unbiased description of spatial patterns at landscape level, better understanding of the pathogen-host relationships and of the tree water relationships. The role of soils on tree genetics is another important field potentially contributing to clarifying some of the previous relationships.

3.9. Modelling oak decline in the United States of America

Oak decline has been occurring in the United States and it has been related to *predisposing factors* such as tree physiology, climatic trends, competition with other species or soil types; *inciting factors* such as defoliation, drought, frost, stand disturbance; as well as *contributing factors* such as root pathogens (e.g. *Armilaria* spp), Canker pathogens (e.g. *Hypoxilon* spp.) or bark boring insects (e.g. Red oak borer).

Oak decline inventory data has been systematically collected since 20 years ago in the United States with measurements made at the site (e.g. exposition, slope, productivity, elevation) and the stand level (e.g. stand density, stand age, stand composition, oak decline incidence). Such data has been used to model oak mortality and identify areas of high risk of mortality. Modelling includes using of decision tree methods applied at the landscape level as well regression analyses used particularly at the site level.

Applying modelling exercises have generated different results to different regions of USA. Factors such as clay content of soils, slope gradients and soil depth, have contributed to explain high variation of mortality at site level. Additionally, oak basal area of stand, age of stand and number of oaks in stand relatively to other tree species were major variables explaining mortality at the stand level.

Modelling tools, providing that they are fed with reliable data collected in a systematic and standardized way, have strong potential to be applied to questions related to cork and holm oak decline in their geographical areas of distribution in North and South Mediterranean.

3.10. Oak decline and the carbon balance of forests.

In order to face oak decline it is crucial to understand the mechanisms involved in oak mortality. Relevant questions include those related to understanding physiological mechanisms involved in oak mortality and quantifying environmental factors inducing mortality such as: thresholds of rainfall, precipitation patterns or interactions between water deficit and increasing temperatures. Of particular interest is to quantify balance of carbon in oak forests and relate it with environmental factors that may ultimately lead to death of trees. This can be effectively conducted using modelling techniques combined with collection of field data. Such approach was used to investigate the carbon balance of an holm oak forest, Prades, in Catalonia, Spain.

Holm oak stands are characterised by very low rates of increase partly due to a high stem density and high root to shoot ratios (over 1.2). As a consequence, and in the majority of cases, the carbon balance is at the limit, with respiration losses equalling primary productivity. To understand the carbon balance of the holm oak Prades Forest the Gotwilda model was used. This model is based in understanding five compartments and their interactions: climate, forest structure, ecophysiology, management and soil.

Field data used in the model consisted on the quantification of carbon measured in natural conditions at the leaf, stem and soil level. With such data was possible to estimate, for instance, the maintenance costs of leaves (e.g. total cost is 1033gC·m^{-2} ground·year^{-1} corresponding to 189 gC·m^{-2} ground·year^{-1}for leaf formation and 844 gC·m^{-2} ground·year^{-1}for leaf maintenance). This approach also allowed the conclusion that fine roots (often neglected in similar exercises due to their low proportion relatively to the whole plant biomass), require as much carbon as the tree whole canopy because they have very high rates of turnover.

enses of starch stored in the root system. Environmental factors affecting mobilization of carbohydrates are thus of relevance to understand oak mortality. For instance, in Mediterranean climatic such that of the Prades forest, soil dries during summer months and net primary production of holm oak becomes negative. As a consequence, tree respiration must be compensated by use of the reserve of mobile carbohydrates. Thus, in years of low rainfall, the mobile carbon stored in the trees decreases to compensate the cost of maintenance of respiration of living tissues which affects the carbon balance. Results of modelling were confirmed with field data. Experiments manipulating water in soil as well as management through thinning have shown higher stem diameter and higher rates of increase of holm oak diameter under the treatments of thinning and no water exclusion. Modelling also suggested that thinned plots need 15 to 25 years to rebuild starch stores - the same period that was empirically used by rural people between thinning periods to produce charcoal and maintain the stand productive. Such results suggest that decay of mobile carbohydrates in oaks may be used as *"markers"* of die-back has below certain thresholds oaks would be unable to resprout.

Climatic change may interact with management (particularly thinning) and affect holm oak carbohydrate pools. Modelling suggests that the carbon balance of Mediterranean forests may be at their limit and that the cost of formation of living tissues (1/3) and maintenance (2/3) may require rainfall values of the magnitude of the 200 and 400 mm, respectively. Management practices that reduce losses to respiration, such as restrain the number of resprouts (or tree) density of the stands may indeed be useful to mitigate adverse effects of predicted scenarios of climate change in Mediterranean Forests such as those predicting an increase of frequency of droughts.

Modelling based on accurate field information can be used to understand physiological responses of trees, particularly carbohydrate dynamics and carbon balance, and anticipate the effects of climate change on Mediterranean Forests.

4. The way forward

Information related to the present status of cork and holm oak stands and forests within their geographical areas of occurrence, suggests the need for implementation of standardized protocols for monitoring distribution and health status of stands. This could be enabled through the establishment of cork and holm oak networks in countries where the species occur. Techniques such as remote sensing, applied along with confirmatory field data (e.g. age of stands, regenerative status, mortality level, land use) could possibly be used in order to obtain a clear picture of present situation and contribute to understand spatial and temporal patterns of oak mortality. Good molecular tools are presently available to identify the occurrence of diseases such as *Phytophtora* spp. in quick and reliable ways in soil, plant or water samples. These techniques could be used in monitoring schemes and contribute to understand relevance and dynamics of the disease in oak decline.

Additionally, research should be directed for understanding physiological mechanisms of tree mortality. More than descriptive studies, manipulative experiments together with modelling are required, both at the tree and stand level. A synergy of factors may be interacting and inducing mortality of trees. There is a good comprehension of processes occurring at the soil level, particularly those related with effects of management (e.g. grazing, ploughing, fire) and affecting soil properties (e.g. organic horizon, availability of nutrients) as well as good descriptive work on main pests and diseases involved in mortality. It is now essential to use mechanistic approaches which, combined with modelling, will contribute to understand physiological basis of mortality and decline. It is of crucial importance to understand tree water relationships and its effects on physiology and health of tree. For instance, the ability of oaks to resprout and survive after disturbance is dependent on their physiological capacity to store and mobilize carbohydrates. There are open questions that should be addressed by an integrated research project:

- How does drought and patterns of rainfall affect capacity of trees to store and mobilize carbohydrates? How does this affect tree death or resprout ability?

- How does management (e.g. thinning, cork harvesting, shrub clearance, browsing by herbivores) relate to physiology of tree and health status?
- Are there reliable, and expedite to measure, indicators of physiology that could be monitored in inventory schemes for anticipating mortality levels?
- How does physiology of tree (e.g. water status) relate to probability of infection by diseases such as *Phytophtora* spp. or pest attacks?
- Are pests and diseases causing likelihood of tree to water stress or is water stress increasing the susceptibility of trees to pests and diseases?
- Is oak decline related to inadequate management and regeneration of stands which are now of old age? Or is decline as important in young stands?
- How are all previous questions affected by socio-economic background (e.g. land abandonment, over-utilization of resources)?

5. Conclusions

Although the socio-economic background in European and North African countries is distinct, there is ground for common action among countries in order to better characterize and understand dynamics of cork and holm oak decline. Implementation of a thematic network promoting regular meetings and establishing platforms for standard monitoring schemes and research cooperation would be essential to reverse oak decline. That seems to be possible under international funding schemes (e.g. European Union, Food Association Organization) actually available. Research cooperation and integrated action may contribute to reverse the decline of cork and holm oak forests and stands across their geographical areas of distribution.