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Forest fires in cork oak (*Quercus suber* L.) stands in Portugal

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Fire and cork can be considered both the most serious problem and the most valuable resource of Portuguese forests. The existence of important areas of burned cork oak stands resulting from severe fire seasons in recent years is an environmental problem which deserves special attention. This paper makes a multidisciplinary survey of the problem of burned cork oak stands focusing on: the dimensions of the problem in Portugal, the remarkable resistance of cork oak to fire, the post-fire management of cork oak stands, and the economic and ecological effects of fire in cork oak stands. Particular emphasis is given to knowledge gaps in this context.

Keywords: Cork oak; Fire; Portugal

1. Introduction

One of the most remarkable characteristics of the Portuguese forest is the fact that it includes the highest surface of cork oak stands (*Quercus suber* L.) in the world. In fact, the Portuguese territory includes around one-third of the world's cork oak surface and is the origin of more than half of the world's cork production (table 1). This has long been considered an important advantage, because of the outstanding qualities of cork for industrial use. Therefore, cork oak forests are a very important source of income and a sector which is responsible for thousands of jobs in the different stages of the production chain. On the other hand, cork oak stands are associated with a remarkable biodiversity and constitute unique ecosystems which are recognized for their ecological value [1]. This ecological importance was taken into account in the classification of cork oak stands as protected habitats in the framework of the Natura 2000 Network, established by the European Union (Directive no. 92/43/CEE) since 1993. This is the case of Habitat 6310 – *Montado*s of evergreen *Quercus* spp. and Habitat 9330 – *Quercus suber* forests.

Another particular characteristic of Portuguese forests is the existence of the highest incidence of forest fires in the whole of Europe (relative to the forest surface) and probably one of the highest in the world [2]. This problem has been increasing in importance, reaching levels of catastrophe never previously known since the existence of official statistics on this

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Table 1. World statistics of cork oak surface and cork production

Country	Area[a] (1000 ha)	Area[a] %	Production[b] (1000 ton/year)	Production[b] %
Portugal	730	32.2	185	54.4
Spain	500	22.0	88	25.9
Algeria	410	18.1	20	5.9
Morocco	340	15.0	15	4.4
France	100	4.4	5	1.5
Tunisia	99	4.4	9	2.6
Italy	90	4.0	18	5.3
Total	2269	100	340	100.00

[a]Source: DGF year 2002.
[b]Source: APCOR year 2002.

subject (1980). In particular, the fire seasons of 2003 and 2005 were the worst ever registered, accounting for almost 15% of burned forests (DGRF). Among the burned areas there was an important surface of cork oak stands which was affected. Despite the remarkable resistance of cork oak to fire, there are important ecological and economic consequences to consider. Although many trees manage to survive, the burned cork is often unsuitable for most industrial uses and it takes some time (variable, depending on different matters) until the ecosystem recovers. On the other hand, cork oak trees present a considerable advantage compared to other tree species, since much less effort is normally needed to rehabilitate the burned area. This is a great advantage which should be taken into consideration in reforestation policies. Therefore, the burning of cork oak stands in Portugal is an environmental problem which deserves special attention, because of the proportions of the destruction, the strategic importance of these stands and the particularities of cork oak trees.

This paper surveys the relationship between fire and cork oak stands in Portugal, taking into account the different aspects of the problem. The authors have drawn the data from the available literature and from their continuing studies.

2. Fire and cork oak statistics

2.1. Fire

Contrary to the case with other Southern European countries, forest fires have increased in importance along the last two decades in Portugal. The years of 2003 and 2005 were the worst ever recorded with an overall of more than 750,000 ha of burned surface in a country of 8,879, 862 ha, with a forest surface of more than 3 million ha [3,4]. Comparing the average relationship between total burned area and forest surface (1995–2004) in the different Southern European Union countries, Portugal leads the statistics [5]. This percentage is seven times higher than in Spain, 24 times higher than in France, five times higher than in Italy and six times higher than in Greece. The statistics, in terms of the number of fires per unit surface, are even less favourable to Portugal. Although the meaning of ‘forest fire statistics’ is not always the same for all countries, there is undoubtedly a much more serious situation in Portugal than in the rest of Europe. Further, the situation has worsened in recent years, as can be confirmed by the trends (adjustment of a second order polynomial) shown in figure 1.

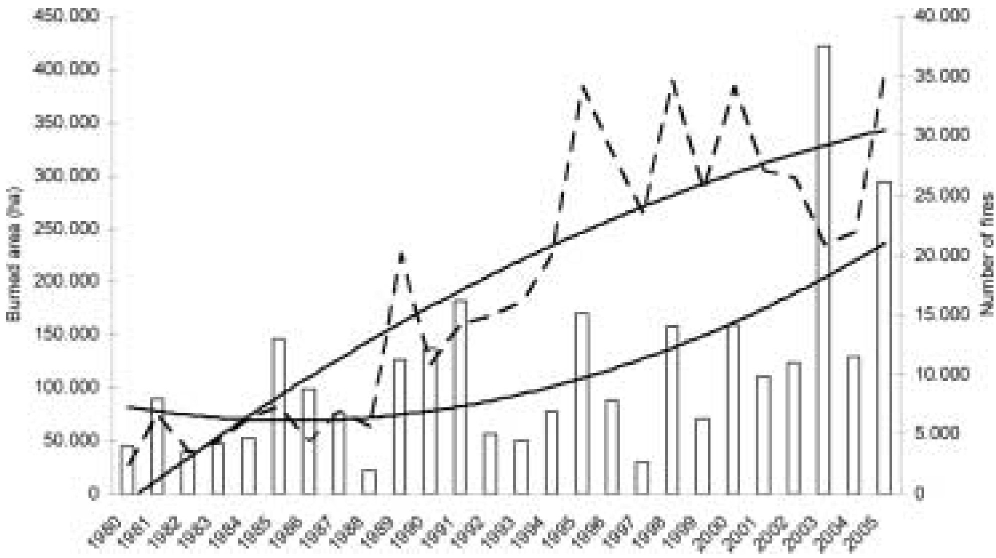

Figure 1. Number of fires and burned area in Portugal between 1980 and 2005 (provisional data for 2005). Solid lines represent main trends given by a second order polynomial adjusted to the data (source: DGRF).

In terms of the distribution within the different Portuguese regions, forest fires are mostly concentrated in the northern half of the country. The Tagus river roughly separates the open woodlands of the flat south from the timber forests of the mountainous north. In terms of burned areas, the larger fires tend to happen in the interior part of the country, whereas the regions closer to the sea tend to have smaller fires. This is explained by the type of landscape, more continuous in the interior and more fragmented close to the sea, but also by demographic reasons. It can be shown that the number of fires in a certain district is related to the population density (figure 2).

One issue which arouses public opinion and which recurs in the mass media is the cause of fires. A very large percentage of Portuguese citizens are convinced that the main origin of

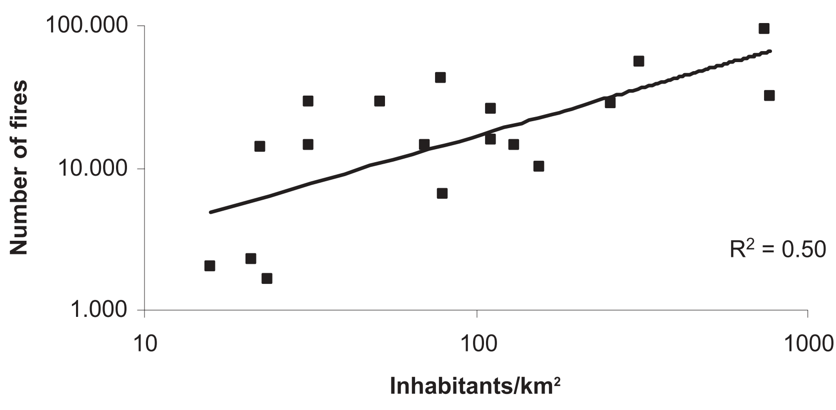

Figure 2. Relationship between population density and the number of forest fires in Portugal (log-transformed scales) according to statistics from the 18 Portuguese districts.

forest fires is arson. Yet the results of the investigations on fire causes show that most fires occur through negligence. Taking the results from the periods 1994–96 and 2001–03 (source: DGRF), only 5% of all fires were natural, 35% were classified as negligence, 32% were classified as intentional, and the remaining fires were classified as unknown. Therefore, there is an important socio-cultural component associated with fire causes in Portugal, similar to the case in other regions of Southern Europe [2].

2.2. Cork oak stands

Cork oak is a species which has a very restricted distribution in the world. The largest continuous area of cork oak stands is located in the Iberian Peninsula, especially in the southwest. Cork oak can also be found in the Landes region in France, down to Marrakech in Morocco and the easternmost distribution reaches Sicily and the Calabria region in Italy [6,7]. In Portugal, cork oak is found especially in the south, forming mono-specific stands but also in the rest of the country, often mixed with other species. It does not tolerate limestone or very moist soils and very rarely is found at altitudes above 800 m [6]. Therefore, cork oak has a potential distribution area much larger than the present surface, even if originally it should be found in mixed stands rather than as a single species, as happens nowadays in many areas [8].

Cork oak stands, unlike the case of timber-production species, are present in a wide range of structures and densities. The main reason for this variety has to do with the existence of different types of land use associated with cork oak. Natividade [6] distinguishes typical forest stands, that is, denser stands which are mainly used for the production of cork, from those which are part of an agroforestry system named *montado*.

This system, also known as *dehesa* in Spain, comprises scattered *Quercus suber/Quercus rotundifolia* (evergreen oak) trees sharing the same space with agriculture or pasture. This mixture has advantages in many ways, as trees are a source of additional income to the landowner (cork, firewood and fodder provided by foliage and acorns) and a guarantee of soil protection. The most common crops are wheat and other cereals and the most common livestock are cattle and sheep. Other land uses, which have been gaining importance in the *montado* areas are hunting and the breeding of a regional race of pigs. This latter activity was, in fact, the main historical reason for the expansion of the *montado* system starting in the 17th century [9]. Another reason (probably the main one) for the conservation of this system in large areas of Portugal is the existence of very ancient (at least since the 13th century, [10]) legislation protecting cork oak stands. This has prevented the occurrence of extensive clear felling by farmers, forcing them to keep the trees when pursuing agriculture in the same area. According to the results of the forest inventory [3] cork oak stands (pure and cork oak-dominant) corresponded to 712,813 ha. This represents 22% of all forest surface in Portugal. As a general trend, this area has increased during the last century (figure 3) through a protection policy, the establishment of new plantations, and the abandonment of agriculture in some regions. There was, however, a slight decrease of the cork oak forested area after 1939, presumably through the implementation of a wheat cultivation policy, which devastated and degraded large areas of cork and evergreen oak [11]. In the same way, cork production has increased consistently, although the peak of production has apparently been achieved by the mid-1960s, according to the moving average shown in figure 3 (n = 9, corresponding to the harvest cycle of cork). Cork oak is somehow competing with two other species which share similar soil and climate conditions: *Eucalyptus globulus* Labill. and *Pinus pinaster* Aiton. The first is an exotic species brought from Australia, which has grown enormously in importance, reaching a total surface of 672,000 ha, according to the last forest inventory. As for

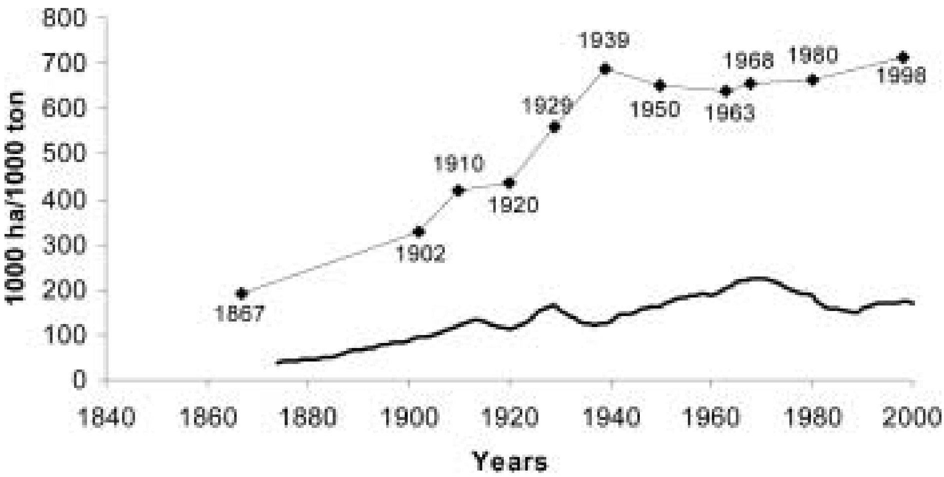

Figure 3. Estimates of cork oak surface (diamonds) and cork production (thick continuous line) in Portugal since 1867, according to [10] using a moving average ($n = 9$).

Pinus pinaster it is an indigenous species which was extensively used throughout 20th century, both by private owners and by the Forest Services to colonize large areas of coastal sandy soils, scrublands and barren land in mountainous areas [12]. Although very important until the 1970s, it decreased in importance because of forest fires. It is nevertheless the most widespread tree species in Portugal, occupying a total area of 976,000 ha [3].

One remarkable feature of cork oak forests is the fact that there are practically no public (i.e. state-owned) cork oak land plots, unlike the case with pine forests. According to Mendes *et al.* [13], only 0.4% of cork oak forests are publicly-owned. Despite the strategic ecological and economic importance of cork for Portugal, cork oak forests are almost totally managed by private owners. Moreover, the average size of land plots in Portugal is very small. At the national level, 85% of the forest land plots are less than 5 ha [14]. This carries obvious difficulties in terms of law enforcement and the establishment of management policies, viz the adoption of appropriate silvicultural practices and the prevention of forest fires. Nevertheless, the average size of land plots in the most important cork oak regions is high, when compared to the national average. In the region where cork oak mostly occurs, the Alentejo, the number of land plots with less than 5 ha is only 23.8%.

The results of the last forest inventory [3] show that one of the characteristics of cork oak is its preference for lowlands and carbonate-free soils. In Portugal, 92% of all cork oak stands are situated in areas below 400 m. The average density is 85 trees/ha (pure and mixed cork oak-dominant stands). This reflects the fact that 75% of all forest surface has a basal area below 10 m^2/ha (sum of cross-sectional areas of stems measured at breast height in one hectare). In 53% of pure stands there is an understorey (this stand class includes also bare soil) composed of different species of shrubs. This percentage is higher for mixed cork oak dominant stands (58%) and mixed cork oak dominated stands (72%). The difference to 100% corresponds to crops and pasture, involving the removal of understorey. The more frequent species of shrubs are *Cistus salvifolius* L. (present in 39% of all stands), *Ulex* spp. (36%) and *Cistus ladanifer* L. (34%). The presence of these species is typical of early stages of the ecological succession [15,16] and strongly reflects the type of management typical of cork oak stands. The frequent removal of understorey has negative consequences for the regeneration of the forest stands. This systematic removal, together with grazing, destroys the young cork oak trees and prevents the natural regeneration of the stands. According to IFN [3], only 33% of inventoried trees belong to the 20–70 cm CPH-Circumference at Breast Height class (the lowest class considered). Recent studies suggest also that this type of management using tillage practices, practically eliminates the lateral roots of cork oak trees, in the first 20–25 cm of soil (unpublished data). The proportion between pastures and crops is 4:1 in pure stands, 3:1 in cork oak-dominant stands and 6:1 in cork oak-dominated stands [3], which shows the importance of livestock-related activities in the *montado* system.

As for the naturalness of cork oak ecosystems, there is conclusive evidence that there are no pristine cork oak stands in Portugal as in the rest of the Iberian Peninsula [8]. In fact, the mono-specific stands which exist nowadays are a result of reforestation practices or the simple selection made by man. Originally cork oak trees probably shared the same areas with other species, forming mixed stands including other *Quercus* species and *Pinus pinaster* [8]. Cork oak stands would have occupied a much larger area of the Portuguese territory. Figure 4 shows the probable distribution of cork oak in the 15th century according to Bernardo [17]. This map was partly based on toponymic names, showing a remarkable importance of cork oak in regions where it is almost absent nowadays: the northwest and central west regions of Portugal. Even in more recent maps, such as the cartographic information included in figure 5 (adapted from Natividade [6]) and the map shown in figure 6 published in 1960, we can still see important areas of cork oak stands in these regions. Probably these were partly replaced by eucalyptus stands after this species began to be intensively cultivated in this area, despite the legislation forbidding this type of conversion. These land-use changes reflect very closely the structure of land plots since these regions are characterized by very fragmented rural properties, where extensive forest management and law enforcement are more difficult to implement.

2.3. Burned cork oak stands

There is evidence that the expansion of cork oak has been significantly driven by the occurrence of fire in the Mediterranean Region [8]. In fact, fire works as a selection factor enabling cork oak trees to prevail over other less fire-resistant species. More recently, man has probably influenced cork oak expansion in an indirect way [7] by significantly altering the natural fire regime [18].

One of the characteristics of the *montado* system is its low vulnerability to fire. Understorey removal for crop or pasture cultivation is responsible for a very low fuel load, which considerably reduces fire hazard [19]. This explains the low fire ‘preference’ for *montado*s [20] when compared to other forest systems in Portugal. Since an important part of the cork oak surface corresponds to *montado*s (at least 43% considering surface of crops and pastures in cork oak stands), the proportion of cork oak stands burned is considerably lower than other forest systems in Portugal. But, the period 2003–2005 represents a particular situation in the relationship between cork oak burned area and the total burned area in Portugal (figure 7). Table 2 shows the total surface of cork oak stands burned in Portugal between 1990 and 2005. The surface burned in 2003 is considerably higher than in other years, which is consistent with the large area burned in the whole country. When compared to the remaining burned area, however, the statistics show a much higher proportion of burned cork oak stands. This can be explained by the extreme meteorological conditions during the fire season of 2003. Very high temperatures and very low air moisture were responsible for the worst fire

Figure 4. Estimated cork oak distribution in the 15th century, according to [17].

season ever registered in Portugal. In these circumstances, fire shows much less preference for the different fuel complexes and spreads much more easily across different landscape types [21]. Nevertheless, an important part of the burned area was located in non-cultivated sloping regions with a fuel load higher than in typical *montado*s. For example, figure 8 and table 3 show that an important part of the burned cork oak area is located in the southern region of Algarve, corresponding to areas where the typical *montado* management is more difficult to implement due to the existence of higher slopes. These situations inevitably correspond to areas considered to pose a higher fire risk [22].

Figure 5. Map of the distribution of cork oak corresponding to the period 1990–1995 (grey areas) [3,4] contrasted with the distribution published in 1950 by Natividade [4] (dots).

3. Resistance of cork oak to fire

Cork is known for its insulating properties, which make it an excellent material for a wide range of industrial applications. This characteristic results from the presence of suberin in an unusual proportion in the cell walls of cork [6]. This substance has remarkable insulating properties which are the result of millions of years of evolution and an advantage for survival after fire occurrence [8]. The insulating properties of cork can provide adequate protection to

Figure 6. Map of cork oak distribution published in 1960 by the Portuguese Forest Services.

the dormant buds which exist in the tree trunk and canopy. The destruction of the canopy stimulates these to develop by triggering hormonal mechanisms [23]. The result is that soon after fire occurrence, cork oak trees normally start to regenerate the burned canopy. In fact cork oak is the only European tree with above-ground sprouting capability similarly to the genus *Eucalyptus* from Australia [24,25]. Yet few studies have been done on the resistance of cork oak to fire. Some causal factors are intrinsic to the tree itself, but others are a consequence of the management and harvesting processes.

Among these, the age of cork, that is, the number of years after the last bark stripping, is undoubtedly a critical one [19,25,26] since it strongly influences the thickness of cork [6,27].

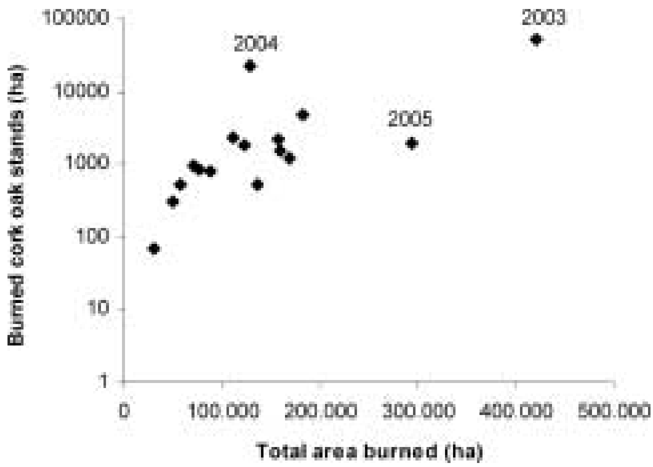

Figure 7. Relationship between total burned area and cork oak burned area in Portugal between 1990 and 2005.

One of the oldest references to cork oak resistance is Lamey (1983) [26], presenting a simple model of mortality as a function of cork age (figure 9). Natividade, probably the most prolific author on cork oak issues, has never studied the effects of fire, and the only reference to this topic in his widespread book, *Subericultura* [6], is a simple reference to Lamey's work. More recently, Pausas [25] presented a stem death model where the probability of stem death for trees with Diameter at Breast Height – DBH > 10 cm, is almost nil (figure 10). This author produced also a canopy recovery model (figure 11) relating this variable with DBH and with

Table 2 Burned cork oak stands (in ha) between 1990 and 2005 measured with two different cartographic basis: IFN'95 – National Forest Inventory (DGF) [4]; COS'90 – Land Cover Map (CNIG) [3]. Data on burned surface from DGRF – Direcção Geral dos Recursos Florestais.

Year	IFN'95	COS'90
1990	526	1463
1991	4701	6714
1992	523	968
1993	310	469
1994	824	2575
1995	1190	3560
1996	817	2374
1997	70	177
1998	2255	4747
1999	980	1977
2000	1502	2685
2001	2339	3749
2002	1791	3337
2003	51057	65765
2004	21892	31035
2005*	1965	2859
Total	**92744**	**148164**

* Provisional data

Figure 8. Map of cork oak distribution based on the Land Cover Map – 1990 (CNIG) [3], and the Forest Inventory – 1995 [4]. Black spots represent cork oak stands burnt from 1990 to 2005. *Source*: DGRF.

bark thickness. According to the field data used to produce the models, only one tree died out of 115 sampled trees (DBH ranging from 10 to 50 cm, and bark thickness ranging from 1 to 5 cm). Some 32% of the trees sprouted from basal buds because of stem death. Tree recovery was positively related to tree diameter and to bark thickness. In another study, Cabezudo *et al.* [28] present a study carried out in southern Spain where only 50% of all trees survived the fire. Dubois and Prodon [29] presented another survival model but in this case with applicability at the branch level (figure 12). Developed from a study carried out in southern France this model shows that 50% of all burned branches > 7 cm diameter and 100% of those > 11

Table 3 Distribution of cork oak burned surface by region (NUTS II).

	2003		2004		2005	
Regions NUTS II	(ha)	(%)	(ha)	(%)	(ha)	(%)
Norte	1405	2	1077	3	1125	34
Centro	2108	3	1435	4	364	11
Lisboa e Vale do Tejo	24596	35	1077	3	265	8
Alentejo	28812	41	8254	23	960	29
Algarve	13352	19	23684	66	629	19
Total	70274	100	35885	100	3310	100

cm diameter can survive after fire. In another study in Sardinia, Italy [30], 200 completely scorched cork oaks of different ages were monitored. The observed mortality was only 5% for trees not harvested in the last 30 years, and 40% for trees which had been stripped several times (trees 60 to 80 years old) with the last stripping two years before the fire. Depending on post-fire management practices (coppicing or branch pruning), the percentage of viable plants ranged from 94% to 20%.

In a recent study in Portugal at Tapada Nacional de Mafra, 30 km north of Lisbon, we monitored 63 completely scorched cork oak trees, DBH ranging from 15 to 140 cm, after a severe wildfire occurred in 2003. Two years after the fire, all trees but one survived and all had sprouted from the canopy (unpublished data). The thick bark of all trees contributed to these results, since no bark stripping has occurred in this area for about 30 years. Therefore, this should not be thought representative of most Portuguese cork oak stands, because very few adult trees are not harvested in Portugal.

Many questions about cork oak resistance remain to be answered. For management purposes it would be important to know how fire can increase tree mortality in different soil and climate conditions. There is some concern in Portugal about tree mortality in cork oak

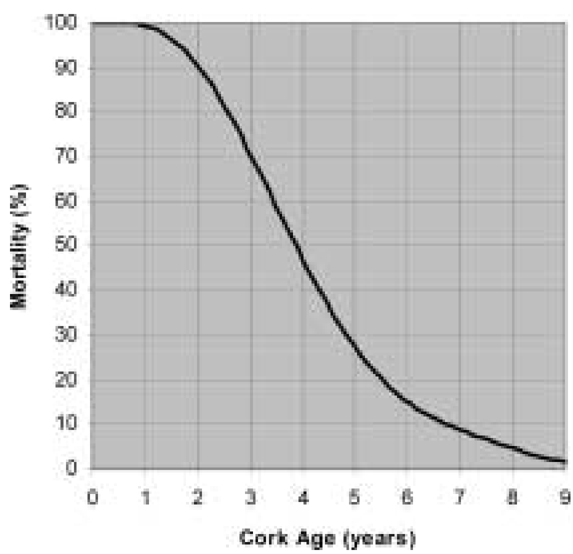

Figure 9. Mortality model for cork oak adapted from Lamey by [19].

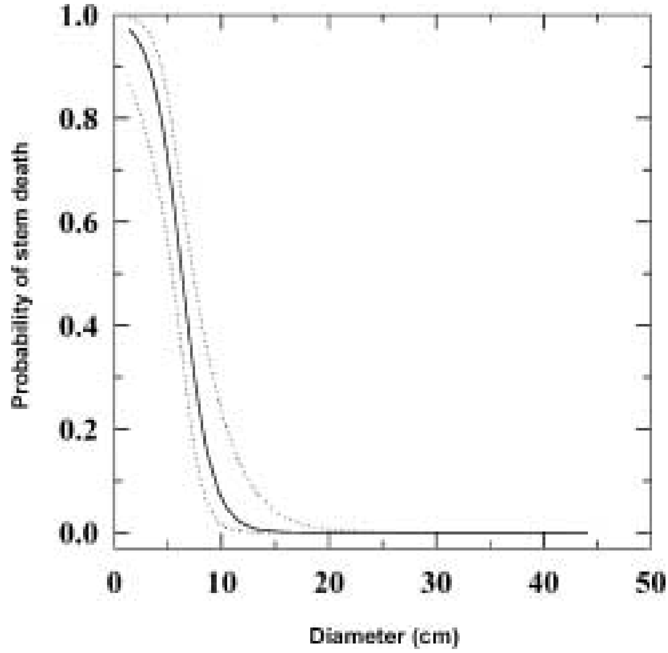

Figure 10. Model for stem death of cork oak reproduced from [25]. Figures from: Pausas, J.G., 1997, Resprouting of *Quercus suber* in NE Spain after fire. *J. Veg. Sci.*, **8**, 703–706.

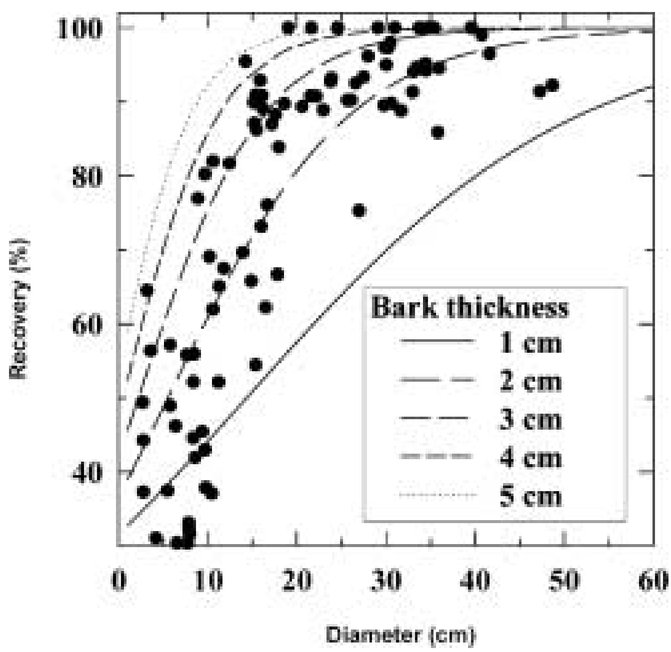

Figure 11. Tree recovery model for cork oak reproduced from [25]. Figures from: Pausas, J.G., 1997, Resprouting of *Quercus suber* in NE Spain after fire. *J. Veg. Sci.*, **8**, 703–706.

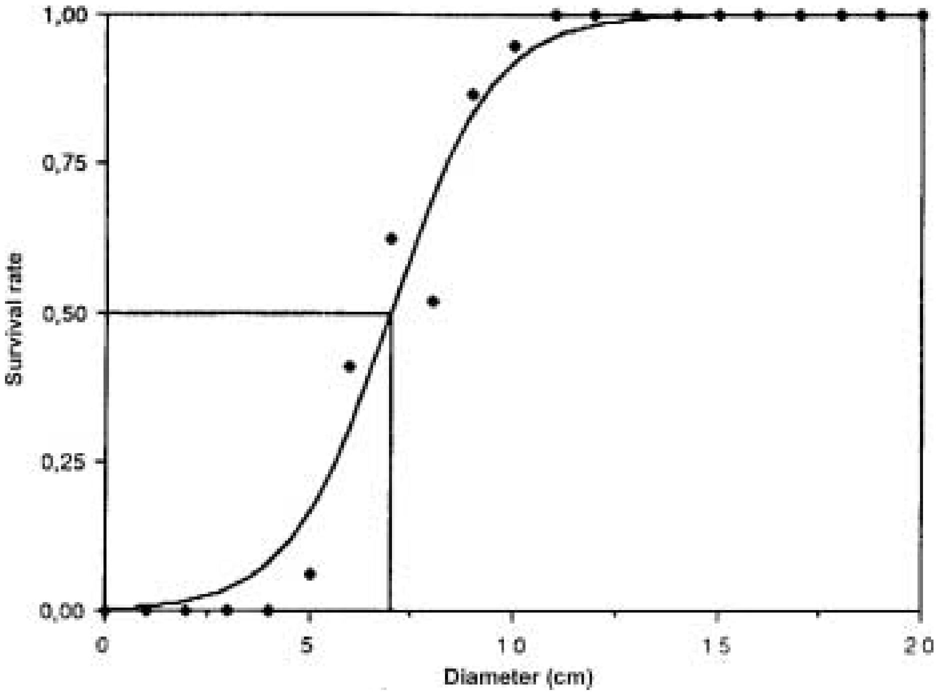

Figure 12. Model of branch survival reproduced from [29].

stands. It is generally recognized that a wide range of biotic and abiotic factors can contribute to this mortality [31]. Among the biotic factors there is evidence that fungi (genus *Phytophtora*) can be responsible for a progressive decay, as happens with other oak trees in Europe [32]. There is also evidence that trees which are affected by environmental factors or poor management practices (deep ploughing and excessive canopy pruning), and inadequate cork harvesting [7,33–35] are more susceptible to decay. Although no specific studies about these matters have been reported, it is reasonable to assume that tree stress caused by a wildfire can be an additional factor promoting the development of the disease caused by *Phytophtora* spp. fungi. If other factors are added such as poor management practices and/or less favourable soil and meteorological conditions, tree mortality after fire is probably considerably increased. Therefore it is important to carry out studies in areas corresponding to different kinds and magnitudes of stress to secure more consistent information about cork oak mortality after fire. It is important also to study the more critical situation of cork harvesting in the first years after fire. The Portuguese government has recently issued a law allowing this practice despite the age of cork, so as to minimize short-term economic losses to cork producers. But no study has supported this new legislation, despite the lack of knowledge at this level. Given the nature and the number of the different variables involved, a good approach to these questions would be the development of a consistent mortality model for cork oak integrating the most significant variables. This would be an important contribution to promote adequate management practices for cork oak stands in a fire prevention perspective. One of the direct applications of this modelling effort could be the evaluation of the applicability of prescribed burning techniques for fuel reduction, since there are considerable economic advantages from this practice compared to mechanical methods.

4. Post-fire management

The type of cork oak management practised in Portugal depends on the type of systems which are present. In systems where grazing and cultivation is absent, the understorey attains a higher development corresponding to situations of high combustibility and fire hazard. The management in these areas is frequently limited to the harvesting of cork, although many farmers use also fuel reduction techniques, normally corresponding to soil tillage practices. On the other hand, the *montado* system is typically an intensively managed system, though management efforts are often focused on the crop or the livestock, rather than on the forest component. This puts at risk the sustainability of the system. Yet these practices have been used by farmers for generations. Post-fire management techniques are not well established among farmers; perhaps because fire has never reached levels of importance as in recent years. In terms of post-fire management, we can distinguish two types of concerns: the rehabilitation of burned stands and the control of soil erosion.

4.1. Rehabilitation of burned stands

Despite the considerable resistance of cork oak to fire, the consequences of a wildfire in a cork oak stand can be very different, depending on the characteristics of the wildfire and the characteristics of the stand, as it happens in other types of forest [36]. Therefore, actions which can be taken to minimize the effects of fire depend very much on those characteristics. Before a decision is made, it is necessary to evaluate the post-fire situation to assess fire severity. As in most cases in forestry, the decision is normally in terms of active intervention or letting nature take its course. In the case of burned cork oak trees, the usual management operations are: premature cork stripping, branch pruning and coppicing (in case of severe damage). Pintus and Ruiu [37] present field experiments after a wildfire in Sardinia in a young stand (67% of CPH ranging between 45 and 90 cm) where cut trees have recovered in a higher percentage than trees which had not suffer any intervention. Pintus [38] showed that there is a higher rate of recovery when the cutting is performed earlier, before the next growing season (8 months after fire), than after a more extended period of time (16 months). The advantages of coppicing burned cork oak trees are mentioned by other authors [30,39]. Barberis *et al.* [30] present results that show the benefits, in terms of survival and growth, of coppicing adult (more than 40 years old), recently harvested (two years before fire, cork thickness of 4–5 mm), severely damaged trees. Fifteen years after coppicing, about 10% of suckers had reached the minimum diameter (19 cm at breast height) for the first bark stripping according to the Italian regulations. For younger trees, coppicing did not bring any advantage. This study also shows that branch pruning causes the higher mortality and that the oldest trees are the most affected by fire. But the decision of cutting or leaving is not straightforward, since this depends very much on the age of cork and on fire severity. Mortality seems to affect the two extremes of the diameter distribution (old and young trees) more than middle-aged trees [40]. Another aspect to consider is the possibility of harvesting the burned cork in order not to wait till the end of the harvesting cycle (minimum of nine years in Portugal). This can have economic advantages, but it can also be an additional stress to the tree and an additional factor of mortality.

In normal conditions, cork stripping constitutes a debilitating factor for the tree, making it more susceptible to biotic and abiotic agents [6]. On the other hand, stripping can only be properly performed when the tree is physiologically recovered, so that young cork tissues can be ripped at the phellogen (the cork cabium) cell layer [6]. This means that the canopy should be recovered so that the production of new cork cells can be re-established. Because of these constraints, some authors refer to the need of waiting between three and nine years, before a new cork stripping can be performed [19,40]. Associated with this aspect, [41] presents an interesting study aiming to determine whether burned cork can still be used for industrial purposes, viz. cork stoppers fabrication. Technically it can be possible, but several inquiries continue on this possibility, especially those concerning the possible negative consequences for wine quality.

4.2. Soil erosion

Protection against soil erosion is not a specific aspect of cork oak stands, but it has also to be taken into account, since soil erosion is adverse to the productivity of the stands. Among the effects of fire, soil effects (especially soil erosion) are one of the most studied. These studies originated a panoply of different post-fire rehabilitation procedures and techniques. These are short-term actions designed to mitigate soil degradation until natural vegetation regeneration stabilises the burned area. These treatments mainly aim to control soil erosion and runoff and to prevent off-site impacts of sediments and floods [42]. Among the most common post-fire rehabilitation measures are grass seeding, mulching, contour-felled logs, and check dams (straw bales, log, and rock dams) [42]. Other techniques include soil tillage for increasing infiltration, especially when a hydrophobic soil layer is formed. Many studies report the formation of a hydrophobic soil layer after fire [43–46]. This process works in combination with the higher impact of rain on the soil surface, both being responsible for a lower infiltration rate, contributing to higher runoff and erosion [47]. The magnitude of these processes depends on a multiplicity of factors including fire intensity, vegetation type, soil/relief characteristics and meteorological conditions [48].

Since erosion is a risk after fire, particular care must be taken with logging operations at the burned sites [49]. Logging should be done so as to prevent the formation of rills. Rills are frequently formed by skidding operations down slope. This is a less important problem in the case of cork oak since extensive logging is normally unnecessary. The fact that in many cases the burning of a cork oak stand does not lead to the removal of trees is an important advantage to soil conservation. Accordingly, measures to rehabilitate trees using coppicing techniques should be balanced with the important priority of preventing soil erosion.

5. Economic and ecological consequences of fires in cork oak stands

The cork oak manifests great value through both the economic and the ecological importance of cork oak stands, and the *montado* system in particular. In economic terms, the cork sector is responsible for 27% of the gross forestry production (data from 1998), for 27% of forestry exports (1994), for 16% of the gross added value of forestry (just cork and cork industries, data from 1993) and for 12% of employment in the forest sector [10]. The importance of the cork sector is even more relevant at the regional level, since it is one of the key activities in regions where there is a restricted range of economic activities and sources of income. This is the case in the Alentejo region, where the cork oak sector represents 25% of the whole gross added value of forestry and agriculture together (data from 1990, [10]).

As for the ecological value of the stands, the cork oak is the most represented species in the Natura 2000 Network in Portugal, corresponding to 24% of the total area registered in this network [3]. Most authors agree on the importance of cork oak ecosystems because of the associated animal populations and the overall biodiversity [6,7]. Moreover, the *montado* system represents a man-made landscape typical of the southwest half of the Iberian Peninsula which has also a very important cultural value, frequently acknowledged in landscape ecology papers and textbooks [50].

5.1. Economic consequences

The estimation of the economic consequences of forest fires in the Portuguese cork oak stands is not straightforward and has not yet been attempted. There are many aspects difficult to quantify, both because of their variability and because of the lack of available data, and also because certain costs are difficult to assess. We can distinguish different kinds of economic consequences according to the different effects produced by fire: dead trees, damaged trees, damaged cork, costs of rehabilitation (living trees, soil erosion, and reforestation) and environmental costs (CO_2, landscape, biodiversity). Although tree mortality may only occur in a small percentage, a certain loss of trees of different ages is to be expected. This loss corresponds to the loss of production potential for the following years; and it depends on the age of the trees. The older the tree, the lower the expected number of cork harvests. By law in Portugal, trees can be harvested only after attaining a minimum perimeter at breast height of 70 cm. Depending on site quality this perimeter can be attained when the tree is 30–40 years old. The number of potential harvests during the tree life is also very variable, since it depends on the site quality but also on cork quality, which decreases after a certain number of harvests [6]. Natividade [6] shows data from a single tree which reached maximum cork production (cork thickness) at the sixth bark stripping, decreasing thereafter until the 14th stripping. Assuming an average harvest cycle of nine years (the minimum according to Portuguese law) this particular tree was probably harvested for 117 years (13 cycles after the first stripping). The useful life of a tree can be very variable. This precludes any serious attempt to estimate the loss of production potential through tree mortality.

The economic consequences of fire for those trees burned which recover, are related to the delay until the next harvest. Although the burned cork may have some commercial value, it is negligible when compared with the commercial value of undamaged cork [41] and probably not enough to cover the harvesting costs. We can then consider that the income obtained from burned cork is practically non-existent, regardless of the age of cork at the moment of fire. Therefore, the question is how much time to wait until the tree is able to produce undamaged cork. This is related to the question of harvesting before the cork has completed the normal nine year cycle. Therefore, the economic consequences at this level will depend on the number of years to wait since fire until the first harvesting. There may, needless to say, be other consequences, since cork production of a burned tree may not be the same as if the tree was not damaged. This is a topic which, to our knowledge, has never been approached by any study.

On the subject of the costs of damaged cork, Piazzeta [41] distinguishes different kinds of damage, influencing the different potential uses of cork and also different strategies aiming to minimize economic losses. One of the strategies consists in extending the normal harvesting cycle until the burned cork reaches enough thickness to be transformed into cork stoppers (the most valuable industrial utilization of cork). Moreover, Piazzeta [41] concludes that even if a sufficient number of years elapse in order for the burned cork to reach the adequate thickness, different laboratory tests have proved the quality of burned cork to be lower than that of undamaged cork.

Rehabilitation costs are also difficult to estimate. They depend on the damages caused by fire and on the technical options taken. Rehabilitation of burned trees and measures to mitigate potential erosion have been mentioned. An estimate of this type of measure was proposed by Rosselló [51] in 2004 concerning the severe fire season of 2003 for all burned cork oak stands of Southern Europe. Based on the statistics of burned surface of 2003 (59,100 ha, which is even less than our own estimates for Portugal), Rosselló [51] estimated the costs of mitigating soil erosion (essentially soil tillage) as €60 million. For the rehabilitation of burned trees (pruning five years after fire), the same author estimated a total cost of €2 million. Reforestation costs were estimated assuming a total tree mortality of 20–25% which resulted in a final cost estimation of €30 million. Harvesting of burned cork was considered a rehabilitation measure and was estimated as €4 million (with no commercial value for burned cork). Finally, this author also considers the cost of livestock exclusion from the burned area, estimated as €6 million. Considering our estimate of burned cork oak surface in Portugal in 2003 and the unitary costs per ha considered by Rosselló [51], we reach the total amount of €121,449 million. This is a much higher unitary estimate than the one proposed by COTEC [52] of €136,850 million for a total burned area of 112,158 ha in 2001 (considering the major forest species).

As for the environmental costs, these are even more difficult to estimate given, for example, the non-existence of a consensual basis to determine the value of externalities such as landscape or biodiversity for Portugal. As for the carbon dioxide emissions there are several estimates and these can be directly related with the costs assumed by the signatories of the Kyoto protocol, which includes Portugal. Miranda *et al.* [53] estimated that when the burned area exceeds 100,000 ha the contribution of forest fires can reach 7% of the total Portuguese CO_2 emissions.

5.2. Ecological consequences

One feature of cork oak stands is their high biodiversity. Owing to the exceptional resistance of cork oak to fire, it would appear that the ecological consequences of wildfires in cork oak stands are less important than for other species (with the possible exception of *Eucalyptus globulus*) occurring in Portugal. Further, the other vegetation which is part of the ecosystem has remarkable conditions for regenerating [15,54] as typically happens in Mediterranean ecosystems [55]. In many cases the ecological consequences are much attenuated because of the remarkable resilience of cork oak ecosystems.

The ecological impact of fire depends very much on the type of management which was applied before fire occurrence. The type of management influences the type of vegetation and, therefore, the characteristics of cork oak ecosystems. As noted earlier, in typical *montados* there is a considerable reduction of spontaneous vegetation due to practices related to grazing and pasture/crop cultivation. This gives rise to a recurrent return to earlier stages of the succession [54,56], influencing in this way the composition of the understorey. Therefore, we can find a wide range of cork oak-based landscapes: from systems where all understorey was removed and replaced by one single cultivated species to stands representing much more advanced successional stages, with different species of shrubs and small trees. The effect of fire is closely related to the reproductive strategies of the species present at the time of fire, and often the reproductive strategies of Mediterranean species have been associated with the occurrence of fire [57–59]. An approach which has been widely accepted and used by several authors [58–60] divides species according to their regenerative strategies into: re-sprouters and seeders. The first group includes species which can regenerate after fire by re-sprouting from dormant buds. The second group includes species that are killed by fire, depending only on seeds to re-establish in the burned area. These species from fire-prone environments have developed a series of so-called fire adaptive traits [24]. These traits are responsible for the so-called resilience of Mediterranean plant communities to fire [60]. Seeders are typical of the first stages of the succession whereas most re-sprouters only establish seedlings on more favourable soil conditions [15]. Examples of seeders in cork oak stands are species of genus *Cistus*, *Lavandula, Rosmarinus* or *Halimium.* Examples of re-sprouters are species of genus *Arbutus, Pistacia, Rhamnus, Viburnum, Phyllirea* and *Laurus* [61]. Cork oak is a typical re-sprouter which means that it is unlikely to find many viable seedlings of this species during the first years after fire [16,55,62].

Animal communities are directly affected by the changes introduced by fire in the plant communities on which they depend. Several studies have been done on the impact of fire in animal populations, but to our knowledge only [63] has studied the specific case of cork oak stands. Because of their diversity and because they are conspicuous, birds constitute the group of animals normally preferred to assess ecological impacts. Because of their ability to disperse, birds surviving a disturbance can either emigrate from the modified habitat or remain in it (site tenacity). Each of these alternatives has an associated mortality risk: the failure to become established in a suitable habitat [65] or the impossibility of coping with the sudden decrease in shelter and resources [65–67]. Moreira *et al.* [68] studied the effect of prescribed fire in bird populations of northern Portugal, concluding that the structure of understorey vegetation can affect the composition and richness of ground and shrub nesters. For burned cork oak stands, it is reasonable to assume that the effect of fire on the understorey can be similar to the effect of management operations which regularly occur in the *montado* system. If trees manage to survive, it appears that the overall impact on animal populations in many situations can be only temporary and not very important, although there are no specific studies on this topic. Yet many stands do not have a typical *montado* structure and composition, presenting a developed shrub stratum. In these cases, fire severity can be high and ecological consequences may be very important.

6. Conclusions

There is a very high incidence of fires in Portugal, when compared to other countries sharing similar conditions of climate and vegetation. Cork oak has a very high resistance to fire which somehow mitigates the effects of wildfires in cork oak stands. Nevertheless, a high mortality may occur in many cases in recently stripped trees. Whenever there is a high risk of tree decay due to fire and other accumulated stresses such as bark stripping, soil tillage or branch pruning, there is a need for intervention by using coppicing techniques.

As for the ecological impacts, we consider that in many cases they are much lower than in other tree species, especially those which are not able to re-sprout. This aspect is a direct consequence of the high resistance of cork oaks to fire. It should be a major characteristic to be taken into account when planning reforestation initiatives in Portugal. Although situated in a very fire-prone region of Europe, Portugal is a European country with the best conditions for the best fire-adapted tree and moreover a highly valuable one, both from an economic and an ecological point of view. Therefore, instead of insisting on an alien species, which is not part of local ecosystems (*Eucalyptus globulus*), or insisting on a conifer species which is highly vulnerable to fire (*Pinus pinaster*), Portuguese authorities should concentrate on cork oak as an important part of the solution to mitigate the high incidence of forest fires in Portugal. Nevertheless, many knowledge gaps still exist in regard to the relationship between cork oak and fire. Filling of these gaps through adequate research programmes should be a priority for Portuguese research policy.

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References

[1] Pereira, P. and Fonseca, M., 2003, Nature vs. nurture: the making of the *montado* ecosystem. *Conservation Ecology*, **7**(3), 7.
[2] FAO, 2001, FRA global forest fire assessment 1990–2000. Forest Resources Assessment Programme, Working Paper 55. FAO, Rome, 495 pp.
[3] CNIG, 1990, COS'90, Carta de Ocupação do Solo de Portugal Continental. Centro Nacional de Informaçcão Geográfica, Lisboa, Portugal.
[4] DGF, 2001, Inventário Florestal Nacional: Portugal Continental, 3ª Revisão. Direcção-Geral das Florestas, Lisboa, Portugal, 233 pp.
[5] European Commission, 2005, Forest fires in Europe 2004. Report no. 5. European Commission, Brussels, 46 pp.
[6] Natividade, J., 1950, *A Subericultura* (Lisbon: Direcção-Geral dos Recursos Florestais e Aquícolas).
[7] Montoya J., 1988, *Los Alcornocales* (Madrid: Instituto Nacional de Investigaciones Agrárias).
[8] Carrión, J., Parra, I., Navarro, C. and Munuera, M., 2000, The past distribution and ecology of the cork oak (*Quercus suber*) in the Iberian Peninsula: a pollen-analytical approach. *Diversity and Distributions,* **6,** 29–44.
[9] Coelho, I., 1996, O Montado, a economia e o desenvolvimento do Alentejo. *Silva Lusitana,* **4,** 39–48.
[10] Mendes, A., 2002, A economia do sector da cortiça em Portugal. Evolução das actividades de produção e transformação ao longo dos séculos XIX e XX, in: *XXII Encontro da Associação Portuguesa de História Económica e Social* (Aveiro: Universidade de Aveiro), 268 pp.
[11] Reis, P., 1998, O Montado de sobro – Uso e gestão múltiplos do território, in: H. Pereira (Ed.) *Cork Oak and Oak/Sobreiro e Cortiça* (Lisbon: Instituto Superior de Agronomia), pp. 284–293.
[12] Neiva J., 2000, History and culture of Portuguese forestry, in: J.V. Neiva, M.J. Pinto and R. Pereira (Eds) *Forests of Portugal* (Lisbon: Direcção-Geral das Florestas), 255 pp.
[13] Mendes, A., Carvalho, M., Dias, R., Tavares M. and Feliciano D., 2004, *Evaluating Financing of Forestry in Europe – Portugal.* Country Report (Porto: Universidade Católica Portuguesa, Faculdade de Economia e Gestão).
[14] Instituto Nacional de Estatística, 1997, *A floresta nas explorações agrícolas 1995* (Lisbon: Instituto Nacional de Estatística).
[15] Silva, J. and Rego, F., 1998, Factors affecting the establishment of woody species after fire in Central Portugal, in: L. Trabaud (Ed.) *Fire Management and Landscape Ecology* (Fairfield: IAWF), pp. 103–114.
[16] Silva, J. and Rego, F., 1997, Establishment of Mediterranean woody species after fire in Central Portugal. *Silva Lusitana,* **5,** 193–209.
[17] Bernardo, H., 1946, A Indústria Corticeira em Portugal. *Anais do Instituto de Ciências Económicas e Financeiras,* **14,** 117–253.
[18] Vázquez, A. and Moreno, J., 1998, Patterns of lightning- and people-caused fires in peninsular Spain. *International Journal of Wildland Fire,* **8**(2), 103–105.
[19] Amo, E. and Chacón C., 2003, *Recomendaciones selvícolas para alcornocales afectados por el fuego* (Mérida: Cuadernos Forestales, IPROCOR).
[20] Nunes, C., Vasconcelos, M., Pereira, J., Dasgupta, N., Alldredge, R. and Rego, F., 2005, Land cover type and fire in Portugal: do fires burn land cover selectively? *Landscape Ecology,* **20,** 661–673.
[21] Moritz, M., 2003, Spatiotemporal analysis of controls on shrubland fire regimes: age dependency and fire hazard. *Ecology,* **84**(2), 351–361.
[22] Pereira, J. and Santos, M., 2004, *Áreas queimadas e risco de incêndio em Portugal* (Lisbon: Direcção-Geral das Florestas, Portugal).
[23] Kozlowski, T.T., Kramer, P.J. and Pallardy, S.G., 1991, *The Physiological Ecology of Woody Plants* (San Diego, CA: Academic Press).
[24] Gill, A., 1975, Fire and the Australian flora: a review. *Australian Forestry,* **38,** 4–25.

[25] Pausas, J., 1997, Resprouting of *Quercus suber* in NE Spain after fire. *Journal of Vegetation Ecology,* **8,** 703–706.
[26] Lamey A., 1893, *Le chêne-liège, sa culture et son exploitation* (Paris/Nancy: Berger-Levrault et Cie éditeurs).
[27] Reis, A., 1997, Espessura da cortiça de reprodução ao nível do fuste de 1.30 m: possíveis causas da sua variação. *DGF Estudos e Informação,* Nˆ 316.
[28] Cabezudo, B., Latorre, A. and Nieto, J., 1995, After fire regeneration in a *Quercus suber* forest in the South of Spain (Istan, Malaga). *Acta Botânica Malacitana,* **20,** 143–151.
[29] Dubois, C. and Prodon R., 1991, Survie du chêne-liège (*Quercus suber* L.) après incendie, in: C. Edelin (Ed.) *L'Arbre. Biologie et Developpement* (Proceedings of the Deuxiéme Colloque international sur l'Arbre, Montpellier. *Naturalia Monspeliensia* A7), pp. 596–597.
[30] Barberis, A., Dettori, S. and Filigheddu M.R., 2003, Management problems in Mediterranean cork oak forests: post-fire recovery. *Journal of Arid Environments,* **54,** 565–569.
[31] Santos, M. and Sousa, E., 1998, Bases para a recuperação do montado de sobro e futuras linhas de actuação, in: H. Pereira (Ed.) *Cork oak and oak/Sobreiro e Cortiça* (Lisbon: Instituto Superior de Agronomia), pp. 294–302.
[32] Brasier, C., 1996, Phytophthora cinnamomi and oak decline in southern Europe. Environmental constraints including climate change. *Annales des Sciences Forestières,* **53**(2–3), 347–358.
[33] Correia, T. and Mascarenhas, J., 1999, Contribution to the extensification/intensification debate: new trends in the Portuguese *montado*. *Landscape and Urban Planning,* **46**(1–3), 125–131.
[34] Santos, B. dos, 1977. *ABC do podador de sobreiros* (Lisbon: DGF).
[35] Sampaio, J., 1977, *À la recherche d'une politique économique pour le liége au Portugal* (Lisbon: publisher not known).
[36] Hély C., Flannigan, M. and Bergeron Y., 2003, Modeling tree mortality following wildfire in the Southeastern Canadian mixed-wood Boreal forest. *Forest Science,* **49**(4), 566–576.
[37] Pintus, A. and Ruiu P., 2004, La réhabilitation des suberaies incendiées. *Colloque Vivexpo 2004: 'Le chêne-liège face au feu'.*
[38] Pintus, A., 2003, *La régénération des suberaies parcourues par les incendies* (Portel: II Encontro da Cortiça).
[39] Ben Jamâa, L., 2004, Les feux de forêts dans la suberaie tunisienne. *Colloque Vivexpo 2004: 'Le chêne-liège face au feu'.*
[40] Amandier, L. 2004, Le comportement du Chêne-liège après l'incendie: conséquences sur la régénération naturelle des suberaies. *Colloque Vivexpo 2004: 'Le chêne-liège face au feu'.*
[41] Piazzeta, R., 2004, Réhabilitation des suberaies incendiées: Quelles perspectives pour l'utilisation du liège brûlé en bouchonnerie? *Colloque Vivexpo 2004: 'Le chêne-liège face au feu'.*
[42] CEAM, 2005, *Post-fire rehabilitation measures* (Valência: CEAM – Centro de Estúdios Ambientales del Mediterrâneo).
[43] DeBano, L., 1966, Formation of a non wettable soils involves heat transfer mechanism. USDA Forest Service Research Notes PSW-46, General Technical Report PSW-132, Pacific Southwest Forest and Range Experimental Station, Berkeley, CA.
[44] DeBano, L., 2000, Fire-induced water repelency: an erosional factor in wildland environments, in: *Proceedings of Conference Land Stewardship in the 21st century. The Contributions of Watershed Management* (Tucson, AZ), pp. 307–310.
[45] Certini, G., 2005, Effects of fire on properties of forest soils: a review. *Oecologia,* **143,** 1–10.
[46] Keizer, J., Coelho, C., Matias, M., Domingues, C. and Ferreira A., 2005, Soil water repellency under dry and wet conditions for selected land-cover types in the coastal zone of central Portugal. *Australian Journal of Soil Research,* **43,** 297–308.
[47] DeBano, L., 2000, The role of fire and soil heating on water repellency in wildland environments: a review. *Journal of Hydrology,* **231–232,** 195–206.
[48] Neary, D., Klopatek, C., DeBano, L. and Ffolliot, P. 1999, Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management,* **122,** 51–71.
[49] European Commission 2004. Working Group on Soil Erosion task group 4.1 on measures to combat soil erosion. Final report. European Commission, Directorate-General Environment, Brussels.
[50] Farina, A., 1999, *Principles and Methods in Landscape Ecology* (Dordrecht: Kluwer).
[51] Rosselló, M., 2004. Les effets des incendies de l'été 2003 dans les suberaies européennes. *Colloque Vivexpo 2004: 'Le chêne-liège face au feu'.*
[52] COTEC 2004. Benchmarking de sistemas de prevenção e combate a incêndios florestais. Report of Work Group 1.
[53] Miranda, I., Coutinho, M. and Borrego, C., 1994. Forest fire emissions in Portugal: a contribution to global warming? *Environmental Pollution,* **83**(1–2), 121–123.
[54] Méson, M. and Montoya, J., 1993, *Selvicultura Mediterrânea* (Madrid: Ediciones Mundi-Prensa).
[55] Keeley, J., 1986, Resilience of Mediterranean shrub communities to fires, in: B. Dell, A.J.M. Hopkins and B.B. Lamont (Eds) *Resilience in Mediterranean-type ecosystems* (Dordrecht: Dr. W. Junk Publishers), pp. 95–112.

[56] Capelo, J., 1992, Três modelos de sucessão vegetal em sobreirais: bases para o estabelecimento de normas racionais de maneio de matos, in: *Actas do II Encontro Nacional Sobre Montados de Sobro e Azinho* (Évora: Sociedade Portuguesa de Ciências Florestais), pp. 265–276.

[57] Noble, I. and Slatyer, R., 1980, The use of vital attribute to predict successional changes in plant communities subject to recurrent disturbance. *Vegetatio,* **43,** 5–21.

[58] Keeley, J. and Zedler, P., 1978, Reproduction of Chaparral shrubs after fire: a comparison of sprouting and seeding strategies. *The American Midland Naturalist,* **99**(1), 142–161.

[59] Trabaud, L., 1987, Fire and survival traits of plants, in: L. Trabaud (Ed.) *The Role of Fire in Ecological Systems* (The Hague: SPB Academic), pp. 65–89.

[60] Naveh, Z., 1975, The evolutionary significance of fire in the Mediterranean Region. *Vegetatio,* **29**(3), 199–208.

[61] Costa, J., Aguiar C., Capelo, J. and Neto, C., 1998/99, Aproximação à biogeografia de Portugal Continental. *Quercetea,* **0,** 0–56.

[62] Callaway, R., 1992, Effect of shrubs on recruitment of *Quercus douglasii* and *Quercus lobata* in California. *Ecology*, **73,** 2118–2128.

[63] Prodon, R., Fons, R. and Athias-Binche F., 1989, Impact ecologique des incendies sur la faune des suberaies. *Scientia Gerundensis,* **15.**

[64] Bélichon, S., Clobert, J. and Massot, M., 1996, Are there differences in fitness components between philopatric and dispersing individuals? *Acta Oecologica,* **17,** 503–517.

[65] Bendell, J., 1974, Effects of fire on birds and mammals, in: T.T. Kozlowski and C.E. Ahlgren (Eds) *Fire and Ecosystems* (New York: Academic Press), pp. 73–138.

[66] Newsome, A. and Catling, P., 1983, Animal demography in relation to fire and shortage of food: some indicative models, in: F.J. Kruger, D.T. Mitchell and J.U.M. Jarvis (Eds) *Mediterranean-type Ecosystems. The Role of Nutrients* (Berlin/Heidelberg/New York: Springer), pp. 490–505.

[67] Prodon, R. and Pons, P., 1993, Postfire bird studies: methods, questions and perspectives, in: L. Trabaud and R. Prodon (Eds) *Fire in Mediterranean Ecosystems.* Ecosystems Research Report 5 (Brussels: Commission of the European Communities), pp. 332–343.

[68] Moreira, F., Delgado, A., Ferreira, S., Borralho, R., Oliveira, N., Inácio, M., Silva, J. and Rego, F., 2003, Effects of prescribed fire on vegetation structure and breeding birds in young *Pinus pinaster* stands of Northern Portugal. *Forest Ecology and Management,* **184,** 225–237.

Appendix

List of abbreviations

APCOR: Associação Portuguesa da Cortiça.
CNIG: Centro Nacional de Informação Geográfica (former official Cartographic Services).
COS'90: Carta de Ocupação do do Solo (National Land Cover map referred to 1990).
CPH: Circumference at Breast Height.
DBH: Diameter at Breast Height.
DGF: Direcção-Geral das Florestas (former designation of DGRF).
DGRF: Direcção-Geral dos Recursos Florestais (Portuguese Forest Services).
FAO: Food and Agriculture Organization.
IFN'95: Inventário Florestal Nacional (National Forest Inventory referred to 1995).
NUTS II: Nomenclature of Territory Units, Level II, adopted for European Union countries.

Names and location of the Portuguese Regions NUTS II (figure A1).