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Resprouting of *Quercus suber* in NE Spain after fire

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Abstract. Many Mediterranean species have evolved strategies that allow them to survive periodic wildfires. *Quercus suber* trees resprout after fire, some from stem buds and others from basal buds only. In the former case the canopy recovers quickly. In the latter case the stem dies but the tree survives and regrows from basal sprouts. The probability of stem death and the degree of height recovery were studied after a fire in a *Q. suber* forest in NE Spain using logistic regression analysis. The results suggest that most trees survive after fire; the probability of stem death is negatively related to tree diameter; and recovery is positively related to tree diameter and to bark thickness. Implication for management and conservation of cork-oak forests are discussed.

Keywords: Cork oak; Disturbance; Mediterranean; Sprouting.

Nomenclature: de Bolòs & Vigo (1984-1995).

Introduction

Many Mediterranean species have evolved strategies that allow them to survive periodic fires (Naveh 1975; Gill 1981). In the Mediterranean basin, incidence of fire has recently increased due to human impact and may continue to increase as a result of global climate change (Torn & Fried 1992; Beer & Williams 1995; Davis & Michaelsen 1995). We need to understand and quantify the response of Mediterranean species to fire in order to be able to predict their dynamics and to propose alternative management strategies to preserve them. I present a statistical model of the response of *Quercus suber* (Cork oak) to fire. *Q. suber* is considered a fire-resistant species because it is able to resprout after fire. In Mediterranean communities, most woody plants resprout after disturbance, often from subterranean structures (James 1984). The bark (cork) of the cork oak provides protection for the stem buds and the species resprouts from the stem; this is the only European tree with above-ground sprouting capability. Knowledge of the response of individual species to fire disturbance (Dell et al. 1986) would help to predict the future of the current vegetation with the help of models (Noble & Slatyer 1980; Austin et al. 1997).

Q. suber is an evergreen tree with sclerophyllous leaves which grows in carbonate-free soils in the Mediterranean Basin. It constitutes forests or open woodlands where it is the main tree species, or coexists with other Mediterranean trees, e.g., *Q. ilex*, *Q. rotundifolia*, *Pinus pinea* and *P. pinaster*. The natural distribution of *Q. suber* is in the W and NE of the Iberian peninsula, N Africa, a narrow band in the south of France and the Italian coast, and some Mediterranean islands, e.g. Corsica, Sardinia and Sicily. All these areas have a dense population and a high tourist pressure. The species is currently considered an endangered species and has priority in European research and conservation agenda. *Q. suber* forests are managed mainly for cork production from the bark and for acorn supply to pigs and boars. 52 % of the *Q. suber* forest area is found in the Iberian Peninsula. Recurring cork extraction is a major stress factor affecting water balance and tree productivity (Correira et al. 1992; Werner & Correira 1996). No artificial product has yet been found that can replace cork for wine and champagne bottles.

The present work aims to describe the effect of fire on *Q. suber* trees and their recovery after fire.

Methods

Study area and fire

On 10 and 11 August, 1994 a forested area of ca. 8700 ha burnt in the NE Montseny Mountains between Barcelona and Girona (Catalonia). This area was covered by Mediterranean vegetation, predominantly forest and woodlands dominated by *Q. suber*, but also other forests and woodlands with *Quercus ilex*, *Pinus pinea* and *P. pinaster* and Mediterranean heathlands (brolles) with *Cistus* spp. and *Erica* spp. In most of the area the fire burnt both the understorey and the overstorey. The *Q. suber* forests are managed for cork production with an inter-extraction period of bark of ca. 10 - 12 yr.

The climate of the area is Mediterranean with a clear maritime influence – subhumid to humid xerotherm bioclimate (Bagnouls & Gaussen 1957). Mean annual precipitation at the Girona meteorological station (95 m a.s.l.) is 806 mm with peaks in spring and autumn and a dry period in summer; the mean annual temperature is 14.8 °C (mean January temperature = 7.2 °C; mean August temperature = 23.3 °C). The bedrock type of most of the burnt forest area is granodiorite, which produces acidic nutrient-poor soils.

Sampling

In March 1996, just before the second growing period started (after the fire), four 375 m^2 plots of burnt *Q. suber* forest were selected (Table 1). Plots were chosen to be homogeneous in structure and position (slope, topography, etc.) and with apparently similar fire intensity. All plots had *Q. suber* as the main tree, and also *Q. ilex, Pinus pinea,* and *P. pinaster*. Fire burnt both the understorey and the crowns, and all pines were killed. The stems of *Q. ilex* were also killed and showed basal resprouting while *Q. suber* trees were resprouting from the base and from the canopy. DBH, tree height (pre-fire height), bark thickness at breast height and the height to the tip of the tallest living shoot (recovery height) were recorded for all *Q. suber* trees in each plot. Bark thickness was measured with a bark gauge at four places around the trunk and means calculated (on *Q. suber* trees, bark thickness is not affected by fire). Height was measured using a SUUNTO clinometer, except when the top was easily reached. Pre-fire height was measured as the height of the tallest dead shoot. Because of the low flammability of *Q. suber* trees and the protection by the bark, tree tops are often left intact, so for most of the trees the height measured can be considered as pre-fire height. Some small trees which had lost their tops and thus could not be measured, were not included.

The vegetation of each site was also analysed.

Data analysis

For the sake of a better comparison, tree DBH bark thickness (subject to variation due to management) was subtracted from the DBH to give an 'inside-bark DBH'.

A first observation showed that almost all *Q. suber* trees resprouted; some did so from the stem buds (epicormic) and others from basal buds only (in the latter case the stem is assumed to be dead). Thus, two regression analyses were carried out, one to compute the probability of stem death and the other to estimate the amount of recovery. Recovery was computed as the percentage of the height recovered from the pre-fire height (proportion height recovery) for all trees. For both regression analyses, the first predictor variables were DBH and bark thickness; differences between plots were then tested to see whether some of the unexplained deviation was due to differences at the sites (i.e. environmental or management differences). Interaction terms were also tested. Logistic regressions were applied assuming binomial error distributions (McCullagh & Nelder 1989). Results were displayed graphically without taking into account the plot term because our emphasis is on the species response (based on individual parameters) rather than the differences between plots.

Table 1. General characteristics of the four *Quercus suber* forests.

	S1	S2	S3	S4
Altitude (m)	190	480	510	450
Exposition	W	SSE	SSE	SE
Slope (°)	21	25	18	13
Density (trees/ha)	1048	960	453	613
Basal area (m^2/ha)	30.1	28.9	17.8	24.6

Localities: S1: Riera de Berenguer-Can Plana, Riells del Montseny, Girona; S2: below Santa Barbara, Sant Feliu de Buixelleu, Girona; S3: Riera de Gualba, Gualba, Barcelona; S4: Sant Feliu de Buixelleu, Girona.

Results

Quercus suber density ranged from 613 to 1048 trees/ha and basal area from 17.8 to 30.1 m^2/ha (Table 1). Tree density may be slightly underestimated because very young trees may have been burnt completely. All but one of the 115 trees sampled survived the fire.

The number of understorey species (herbs and shrubs) ranged from 11 to 19 (Table 2), most of them (55 - 78 %) being species with resprouting ability. In all plots the non-sprouting *Cistus salviifolius* dominated clearly.

Stem death

Of the sampled trees, 32 % had a dead stem and they sprouted from basal buds. No trees with diameter greater

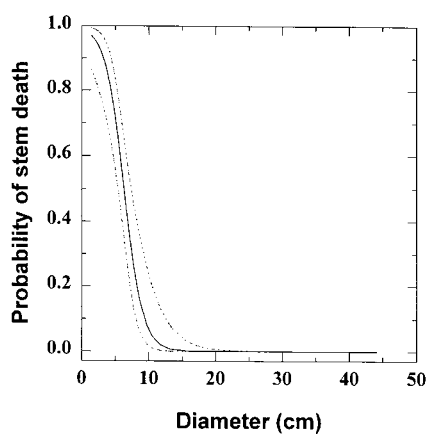

Fig. 1. Probability of stem death in relation to tree diameter (inside-bark diameter at breast height). Details of the model in Table 3 (without the 'plot' term). Dotted lines refer to 95% confidence interval.

Table 2. Rélevés of the understorey layer (height < 1m) in the four sampled plots. The only live tree species in the overstory were *Quercus suber*. Values are % cover classes: +: cover < 1 %; 1: 1 - 10 %; 2: 11 - 25 %; 3: 26 - 50 %; 4: 51 - 75 %; and 5: 76 - 100%. Species with an asterisk (*) have some resprouting ability.

		S1	S2	S3	S4
*	*Arbutus unedo*	1	1	+	1
*	*Brachypodium retusum*	+	+	+	·
*	*Calicotome spinosa*	+	+	+	·
*	*Carex* gr. *flacca*	·	·	+	·
*	*Carex halleriana*	·	·	+	·
	Cistus monspeliensis	·	·	+	+
	Cistus salviifolius	5	5	5	5
*	*Dactylis glomerata*	·	+	·	·
*	*Daphne gnidium*	·	+	·	·
*	*Dorycnium hirsutum*	1	+	+	·
*	*Erica arborea*	1	+	1	1
*	*Euphorbia characeas*	·	·	+	·
*	*Galium* gr. *lucidum*	·	+	·	+
	Geranium robertianum	+	·	·	·
*	*Lavandula stoechas*	·	·	1	+
*	*Lonicera implexa*	+	·	·	·
	Pinus sp. (seedling)	·	·	·	+
	Prunella grandiflora	+	·	·	·
*	*Psoralea bituminosa*	·	+	+	+
*	*Pteridium aquilinum*	·	·	+	·
*	*Quercus ilex*	·	+	+	·
*	*Quercus suber*	+	2	1	+
*	*Quercus humilis*	+	·	·	·
*	*Rosa* sp.	+	·	·	·
*	*Rubia peregrina*	1	+	+	·
*	*Rubus* sp.	+	·	1	·
	Saponaria ocymoides	·	+	·	·
*	*Sarothamnus arboreus*	·	1	·	·
	Senecio vulgaris	·	·	+	·
*	*Smilax aspera*	+	·	·	·
	Taraxacum gr. *officinale*	·	·	+	·
	Ulex parviflorus	+	·	·	+
	Verbascum sp.	·	+	·	·
*	*Viburnum tinus*	+	·	·	·
	Vicia cracca	·	·	·	+
	Vicia sp.	+	1	·	·
	Number of species	18	17	19	11

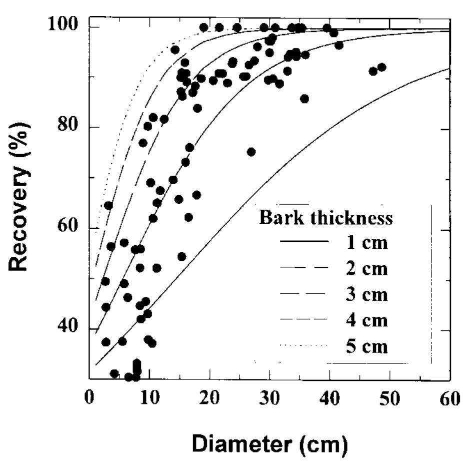

Fig. 2. Recovery of height after fire as a function of tree diameter (inside-bark diameter) and bark thickness. Different lines are the contour lines for different bark thickness. For details of the model, see Table 3 (without the ‘plot’ term).

Table 3. Analysis of deviance for predicting stem death and proportion of height recovered. D = tree diameter; Bark = bark thickness; + = addition of variables to the model. Levels of significance: **** = $p < 0.0001$; *** = $p < 0.001$; * = $p < 0.05$.

Source of variation	Residual deviance	df	Change in deviance	df	*p*
Stem death					
null		144.48	114		
+ D	62.78	113	81.7	1	****
+ Plot	52.39	112	10.39	3	*
Recovery					
null	5062.7	114			
+ D	1870.5	113	3192	1	****
+ Bark	2328	113	2680	1	****
+ D*Bark	1616.2	111	74.22	1	****
+ Plot	1596.1	108	20.05	3	***

than 12 cm showed stem death. Stem death was negatively related to tree diameter (Fig. 1, Table 3) and the model explained 59.8% of deviance. Bark thickness did not explain a significant proportion of deviance after taking tree diameter into account. There was a slightly significant ($p = 0.02$) plot effect (Table 3); the interaction term (diameter × plot) was not significant.

Tree recovery

Most sampled trees recovered, but to a widely varying degree, from ca. 3 % to 100 % (mean = 65.8 %). Recovery degree was positively related to DBH and bark thickness (Table 3, Fig. 2). The interaction (DBH × bark thickness) and the plot term were also significant. Other interaction terms were not significant.

Discussion

All but one of the trees sampled survived the fire. The data do not allow quantification of fire-induced mortality, but suggest that mortality of *Q. suber* by fire is very low, probably due to the insulating capacity of the bark.

Stem death was negatively and recovery positively related to size; this size-dependent variation in sprouting within the species has also been reported for other species (e.g. Stohlgren & Rundel 1986; Strasser et al. 1996). The finding that larger trees cope with fire better than smaller trees also agrees with the results of others.

Bark thickness showed a positive relationship with recovery, probably because the bark insulates the tree from the heat of the fire. Both the required duration of external temperature sufficient to kill the cambium and the maximum cambium temperature are inversely related to bark thickness (Hare 1965; Uhl & Kauffman 1990). This result suggests that bark-stripping for cork production may reduce the ability of the trees to recover from fire; it also increases water stress (Correira et al. 1992; Werner & Correira 1996). There was no significant effect of bark thickness on stem death. This may be due to (1) the correlation of bark thickness with diameter ($r = 0.71$); (2) the fact that the bark of small trees (suffering stem death) has never been extracted and the variation in thickness is low; or/and (3) the fact that measurement of bark thickness in trees with stem death was difficult and the error may be larger than for other trees.

Recovery estimates are based on the proportion of the height recovered, which is not linearly, but maybe asymptotically related to biomass recovery. Stem death and degree of recovery were shown to be different in different plots, which may be due to differences in environmental conditions, resource availability, or/and fire intensity.

Experiences in the study area and comparison with similar unburned sites (e.g. Trabaud & Outric 1989) suggest that the dominance of *Cistus salviifolius* is due to fire, which may be related to the large seed bank, improved light conditions after fire, and germination stimulation (Roy & Sonié 1992; Trabaud & Outric 1989).

Q. suber is probably one of the tree species best adapted to fire because of its low mortality and its ability to resprout and recover. It is the only European tree that resprouts from stem buds, as do most eucalypts (Gill 1975, 1981; Strasser et al. 1996). It contributes to a fast regeneration of the landscape after fire. Together with its economic importance, this makes the species a good candidate for reforestation programs in fire-prone areas.

These results have implications for the disturbance dynamics of Mediterranean vegetation. They suggest the importance of individual-based processes for community dynamics which should be incorporated in individual-based simulation models (Strasser et al. 1996). Other Mediterranean species should be included in this research, e.g. *Pinus halepensis* (Thanos et al. 1996) to further improve predictions on the long-term changes of Mediterranean vegetation related to global climate changes.

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