LONG-TERM RESEARCHES ON POST FIRE RECOVERY TECHNIQUES OF CORK OAK STANDS

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The cork oak shows a good resistance to fire events due to the properties of its bark and a high capacity to resprout after intense fire events from basal suckers. Two experimental trials aiming to evaluate post fire recovery techniques enclosing the influence of the grazing disturbance were conducted in Sardinia. In the first trial, where the experimental activities started in the 1985 in northern hills of Sardinia, a traditional coppicing of severe damaged cork oak trees was compared with the branch pruning.. The coppicing, suggested when high damage levels due to the fire occur, showed a percentage of recovered plants higher than 95%. The early sucker thinning did not produce any significant advantage. The branch pruning showed lower percentages of living trees, going from 20% to 77% in relation to the number of the bark stripping the plants have before the fire. The second case study (Sardinia, central hills) was mainly addressed to the evaluation of the grazing effects after fire. As in the first case, the fire event occurred two years after the bark stripping. The results reveal that the intense grazing after fire causes the death of all coppiced trees. On the other hand, almost all plants recovered after the fire in not grazed plots. The trials showed that a preliminary evaluation of the degree of the trees damage due to the fire is necessary before to apply any recovery technique. Finally, the results give useful information for the management of cork oak stands after fire events, a very common situation in the Mediterranean areas where cork oak is diffuse.

Keywords: coppicing, grazing, cork oak, Sardinia, wildfire.
Parole chiave: ceduazione, pascolamento, sughera, Sardegna, incendi.

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1. Introduction

Quercus suber is a sclerophyllous evergreen tree species widespread in the Western Mediterranean area, both in Europe and in North Africa, where it covers more than 2.3 million hectares (Bernetti, 1995; Oliveira and Penuelas, 2004; Cowling *et al.,* 2005).
The species grows in warm-humid areas with at least 450 mm annual rainfall, from sea level to 2000 m asl (Elena-Rossellò and Cabrera, 1996; Toumi and Lumaret, 1998). Cork oak prefers siliceous soils and it is able to grow on poor and extremely acid soils, but the species avoids limestone substrates (Aronson *et al*., 2009; Vessella and Schirone, 2013).
The wide diffusion beyond of its natural range is justified by the many uses of cork and, to a lesser extent, of acorn (stoppers for wine bottles and house thermal insulation, in the first one case, and animal feed in the second). Its resistance to fire and the ability to recover after severe fires also accentuates the ecological role of the species.
It is well known that wildfires affect around 500,000 hectares every year in the European Union, 0.7 to 1 million hectares in the Mediterranean Basin. This causes a serious impact on the environment and on socio-economic activities, especially in Southern Europe and Northern Africa where is located the most part of cork oak stands (FAO, 2011).
Indeed, *Q. suber* has been considered a highly-fire-resilient species, being the only European tree with stem and crown resprouting capability (trough epicormic buds) after intense crown-fires.
The vulnerability to fire is functional to bark thickness and, then, to the numbers of years from debark and burn severity (Catry *et al*., 2012). Wildfires also contribute to the phenomenon of "cork oak decline" caused by a complex of abiotic and biotic factors (Catry *et al*., 2009), favoring the subsequent attack by pathogens (Costa *et al*., 2010).
In Italy the 90% of cork oak stands are located in Sardinia (about 120,000 ha), the Italian region most affected by wildfires: during the period 1995-2009 the island experienced 2,500 fires per year, with an annual mean burned surface of 17,000 hectares (Salis *et al.*, 2013). Dettori *et al.* (2008) pointed out that cork oak surfaces affected by fire in Sardinia were more extended than those occupied, in some years, by new cork oak plantations financed by the (EC) 2080/92

Regulation; only in specialized areas, such as North East Sardinia (Gallura), the ratio was reversed.
The large number and extent of fires in a region that has evergreen oaks in a key component of the natural vegetation (Biasi, 2010) have resulted in the spread of traditional forest recovery techniques, briefly summarized in removing parts of crown burned in less serious cases and cutting to the foot of the trees severely compromised. Their effectiveness has been confirmed in previous researches (Barberis *et al*., 2003).
The aim of this study is to investigate, through long term observations, the effects on burned cork oak stands both of the interaction with the pastoral activity and the effects of early thinning of suckers to get single-stem plants to facilitate the extraction of the oak bark.

2. Materials and methods

The study areas are located in two different experimental sites (Fig. 1) located in Sardinia (Italy), characterized by granitoid intrusive formation of Paleozoic Hercynian cycle, Mediterranean Macrobioclimate, and Mediterranean pluvioseasonal-oceanic Bioclimate.
The first study area (Berchidda, site 1) is located in Gallura region on the northern hillslopes of Sardinia. In agreement with the "Bioclimate map of Sardinia (Italy)" (Canu *et al.,* 2014) the site is included in the Isobioclimate class 26 (Upper Mesomediterranean, Lower Subhumid, Euoceanic Weak). The stand site is characterrized by shallow loamy-sand soils, steep slopes (20-30%), mean cumulative annual rainfall of 860 mm and mean annual temperature of 13.8 °C, with a xeric moisture regime (USDA, 1997). The site is covered by a pure but unevenly aged cork oak stand subjected to regular stripping every 10 years, according to regional low. A fire event, occurred in the July 1985 (two years after the cork stripping), caused severe damages to the trees (trunk and crown) and a reduction of the understory biomass.
The observations, started in autumn 1985, continued until 2001 with annual measurements repeated in 2010 and 2013. The experimental design is based on two post-fire recovery approaches. About two hundred damaged trees, randomly distributed in the stand, were selected and treated by:
(a) traditional trunk coppicing at soil level;
(b) branch pruning near their insertion on the stem;
A third parcel not managed was used as control.
The treatments were applied to: i) unstripped trees, roughly less than 30 years old; ii) trees stripped only once, about 40 years old; iii) trees stripped several times, aged between 50 and 80 years. On the trees subjected to traditional coppicing, the number of the new suckers was recorded. In the 1990, 5 years after the fire, 50% of the coppiced trees of each age class was subjected to a slow and progressive thinning, until the number of suckers was reduced to only one by 1995. The other 50% of coppiced trees (not thinned) were used as control.
The second study area (Orotelli, site 2), is located in the Nuoro province, central Sardinia. The mean annual temperature and rainfall are 14.8 °C and 700 mm, respectively. The altitude ranges from 595 to 620 m above sea level. The soils are moderately shallow, acidic or sub-acidic. The site is included in the Isobioclimate class 27 (Upper Mesomediterranean, Lower Subhumid, Semicontinental Weak) (Canu *et al.*, 2014).
In the 1998 summer an extended fire interested most of the large municipal Orotelli area, extensively characterized by cork oak stand managed in a silvo-pastoral system. Here the strong grazing pressure due to an excessive and uncontrolled number of sheep and cattle, kept in wild pasture hindered the natural regeneration of a degraded forest.
The trial started identifying different study plots, interested by fire attack at soil and crown level. Therefore, on March 1999, four square areas (400 m² each), were localized and, with the agreement of the Sardinia Forest Service, we proceeded to start the recovery process. The different plots were recognized and treated as shown below:
a) traditional trunk coppicing at soil level, fenced by metallic net to avoid grazing;
b) traditional trunk coppicing at soil level, not fenced;
c) control 1: untreated burned trees;
d) control 2: untreated not burned trees.
In the same areas, 16 years after the fire event (2014), a plan of experimental observations was set up to evaluate the efficiency in reconstitution of the burned cork oak forest, comparing trunk coppicing with control thesis. At the same time we observed the effects of grazing in the burned areas. The removal of vegetal biomass was conducted with "continuous grazing with high load", deduced applying the method IMPAFORMED (Pulina *et al.,* 2002). This method reconstructs the grazing load through detection of direct mechanical effects of grazing on vegetation. In both Berchidda and Orotelli sites we proceeded with the determination of:
i. survival percentage, i.e. the number of plants with clear symptoms of vegetative growth;
ii. number of suckers per stump, diameter and height;
iii. crown cover;

1. Results and Discussion

Site 1 (*Berchidda*)
The results confirm the validity of the traditional technique of trunk coppicing at soil level, when trees are severely damaged by fire, in terms of survival and rapid development of the suckers with timely recovery of land cover by vegetation. Indeed, in agreement with the previous study by Barberis *et al.* (2003), the trees subjected to traditional trunk coppicing showed a percentage of living trees always higher than 93% for all age class (Fig. 2). The brunch pruning showed lower percentages of living trees, going from 20% to 77% in relation to the plant age and, then, to the number of bark stripping before the fire. For the control, the highest number of living trees (95%) was observed for the unstripped oaks, whilst the lowest (62%) was recorded for the trees stripped several times. During the recovering process, the youngest and unstripped trees have quickly produced a high number of suckers (over 50 suckers per stump), but also the oldest and frequently

stripped trees have produced a good number of suckers (27, on average). After 25 years, coppiced treatments show a good soil cover degree, mainly in not thinned coppices (Fig. 3) while the branch pruning treatments clearly do not show a sufficient soil cover percentage for any age classes. The soil cover is, as expected, higher in untreated stands than other treatments.
These results confirm that suckers vigor was negatively related with the age of the stump, whilst the sucker height and diameter were not significantly influenced by the thinning intensity (Tab. 1). After 25 years the untreated trees do not show consequences (in terms of growth) due to the fire. Coppiced trees (the treatment was applied to high damaged trees) show a breast height diameter close to the bark extraction minimum dimension.
In the younger and unstripped trees subjected to sucker thinning, the sucker growth was lower, probably due to the reduction of leaf area and to the fact that the root system is not well developed. No clear differences within the sucker growth in the unthinned stumps were observed in relation to the stump age.

Site 2 (Orotelli)
In a previous study, Bosu (2002) observed that four years after the fire and subsequent coppicing, the fenced trees showed a significant higher growth (in term of height, diameter and crown projection) than those grazed with high pressure of local breeds of sheep and cattle. Sixteen years after coppicing treatments (2014), it was observed that the recovery process and cork oak survival fails in the presence of continuous high load grazing. In fact, the vitality of stumps has been impaired, as in no case suckers exceeded the height of 0.05 m as a result of bites made by animals grazing. The intense grazing after fire caused the death of all coppiced trees.
On the other hand, most of the plants recovered after the fire in not grazed plots. We observed the higher number of living trees, equal to 96.8%, in the coppiced area without grazing, whit a density of about 3,600 suckers per hectare. These results show that the avoiding of grazing has allowed the diametric and longitudinal development of suckers, high 6 m (coppicing without grazing), compared to 8 m of the control 2, not burned area (Fig. 4). In the not fenced areas, the recolonization process after fire resulted in the claim of an actual vegetation consisting in a upper layer of sparse cork oak formation with sporadic presence of *Quercus pubescens*. Moreover, the strong grazing pressure limited the development of trees renewal and damaged the underbrush biodiversity, selecting not pabular species, e.g. *Cistus* spp., *Lavandula stoechas* L., *Daphne gnidium* L., *Pyrus amygdaliformis* Vill., *Crataegus monogyna* L.
Our results confirm that cork oak is well adapted to resist to fire events and, when necessary, fire recovery practices can greatly help the stands to regain its previous structure. In particular, in the spring following the fire the evaluation of fire damages degree is needed before to apply recovery techniques evaluating bark thickness, charring height, aspect and tree diameter (Catry *et al*., 2009).
When the trees are low damaged by fire, they are able to recover themselves by removing parts of the canopy and cork burned. In cases of severe fire damage, the traditional trunk coppicing showed the best results in terms of sucker height, soil cover and bark production; these positive results are obtained only if the stands are not subjected to grazing activities (as also indicated by the Sardinia Regional Law).
Recovery techniques help to limit the spread of the "cork oak decline", a phenomenon that in recent years has raised serious concerns in Sardinia (Lancellotti and Franceschini, 2013). Other recovery practices (i.e. branch pruning, earlier sucker thinning) did not show any positive result, but only higher costs. Cork oak confirms its potential also in recolonization/reforestation programs in fire prone areas, where other species could have more severe and, in some cases, irremediable consequences after a wildfire event.

Table 1. Influence of recovery treatments on tree height, diameter and crown cover of cork oak trees, after 25 years from the fire in Berchidda (Site 1).
Tabella 1. Influenza delle tecniche di recupero su altezza, diametro e proiezione delle chiome di sughera al suolo, 25 anni dopo l'incendio nell'area di studio di Berchidda (Sito 1) .

	Coppicing				
	Onesucker (thinned)	*More sucker (unthinned)*	*MeanCoppicing*	*Brunch pruning*	*Control*
TreeHeight (m)					
Unstripped	5.3	6.8	5.5	5.2	6.0
One stripping	6.3	5.6	6.0	7.0	5.9
More thanone stripping	5.8	6.1	6.8	6.0	6.0
mean	*5.8*	*5.9*	*5.8*	*5.9*	*6.0*
Trunkdiameter (cm)					
Unstripped	15.2	17.0	15.4	20.5	23.7
One stripping	19.6	17.8	19.1	25.4	26.3
More thanone stripping	17.8	19.8	18.8	25.8	29.3
mean	*17.7*	*18.7*	*18.0*	*22.7*	*25.2*
Crown cover (m^2)					
Unstripped	7.6	15.3	8.7	7.7	18.36
One stripping	12.9	11.3	12.5	12.5	21.48
More thanone stripping	9.1	12.7	10.8	14.1	33.18
mean	*10.3*	*12.5*	*10.9*	*9.7*	*20.7*

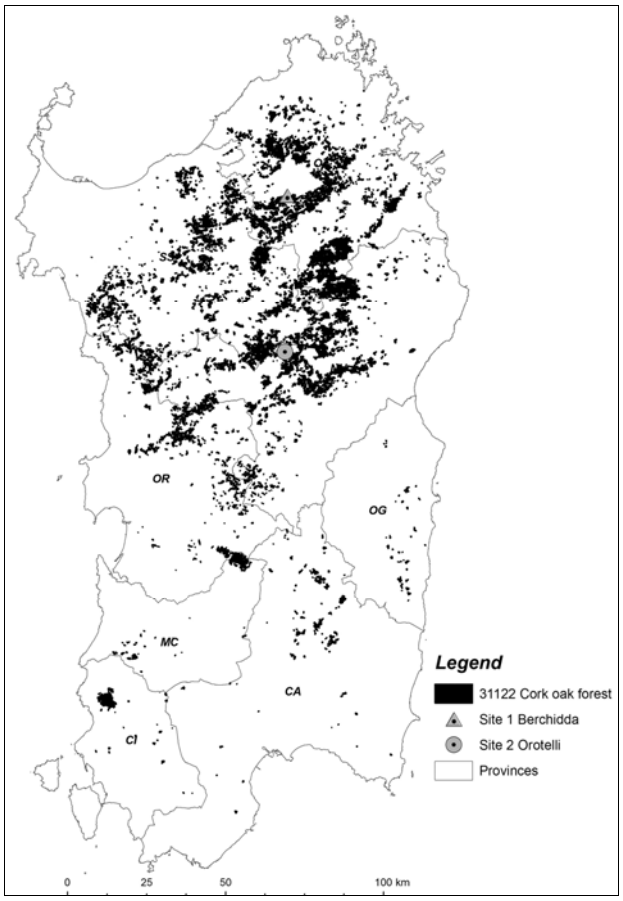

Figure 1. Location of the two study sites (Sardinia, Italy).
Figura 1. Localizzazione delle due aree di studio (Sardegna, Italia).

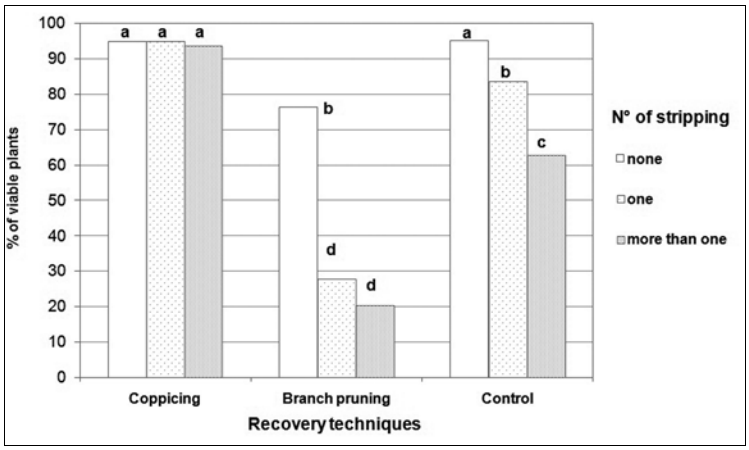

Figure 2. The influence of different treatments on percentage of living trees 15 years after the fire.
Figura 2. Influenza dei diversi trattamenti sulla vitalità delle piante a 15 anni dall'incendio.

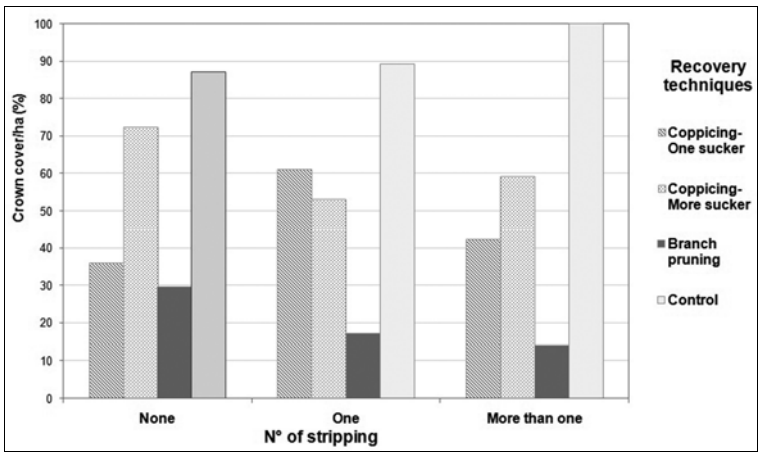

Figure 3. Soil cover after 25 years from the fire event.
Figura 3. Copertura del suolo registrata a 25 anni dal passaggio del fuoco.

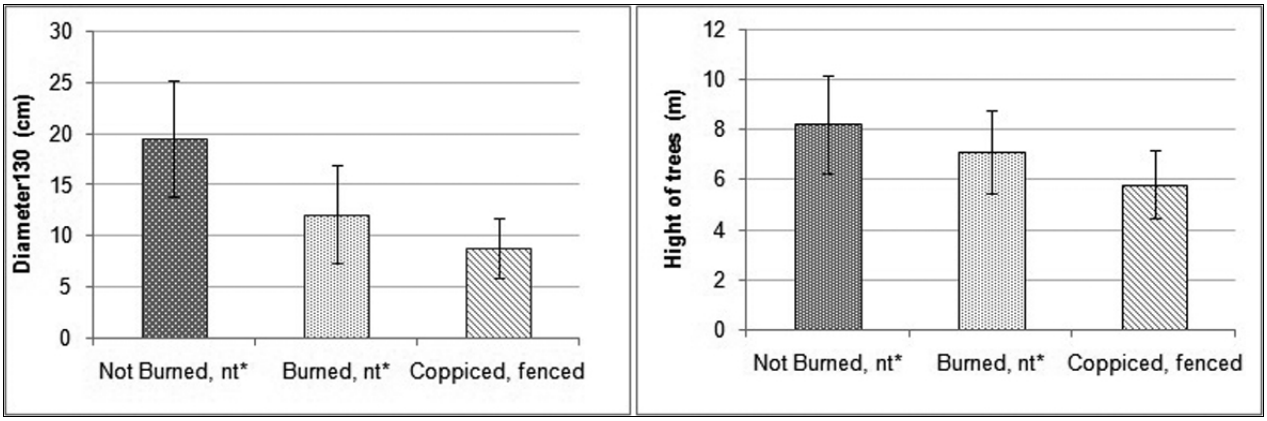

Figure 4. Diametric (left) and longitudinal (right) development of suckers, 16 years after fire event. nt = no treatment.
Figura 4. Sviluppo diametrale (a sinistra) e longitudinale (a destra) dei polloni, a 16 anni dall'incendio. nt = nessun trattamento.

RIASSUNTO

Esperienze di recupero post-incendio delle foreste di quercia da sughero

In due esperienze di lungo termine si sono confrontate in Sardegna differenti tecniche di recupero post-incendio di popolamenti di quercia da sughero, anche in funzione della presenza di animali al pascolo.
Nel primo caso (Nord Sardegna, recupero avviato nel 1985) lo studio ha confrontato la tradizionale ceduazione al piede delle piante gravemente danneggiate dal fuoco con il raccorciamento delle branche principali (capitozzatura) e monitorato il successivo accrescimento dei polloni, sottoposti o no, al precoce diradamento tradizionalmente eseguito.
I risultati hanno evidenziato che il tipo e l'entità della tecnica di recupero deve tener conto della gravità del danno apportato dal fuoco alle piante. Solo i soprassuoli gravemente danneggiati necessitano di ceduazione al piede, garantendo una vitalità superiore al 95%.
Il diradamento precoce dei numerosi polloni emessi dalle ceppaie si è rivelato di scarsa utilità, poiché non incrementa né lo sviluppo longitudinale e radiale del pollone, né, di conseguenza, la copertura del suolo da parte della chioma e la superficie generatrice del sughero. La seconda esperienza (Sardegna centrale, recupero avviato nel 1999) ha evidenziato che il pascolamento continuo con carico alto è incompatibile con lo sviluppo del ceduo derivante dalla capitozzatura poiché nessun pollone si sottraeva al morso del bestiame. Nelle parcelle protette dal pascolamento con gabbie metalliche, ceduate o lasciate a libera evoluzione, il recupero delle piante è stato pressoché totale sia in termini di vitalità sia di sviluppo nei confronti della porzione di sughereta non percorsa dal fuoco.
Lo studio permette di giungere a conclusioni trasmissibili, con la dovuta cautela, al settore operativo definendo con maggior dettaglio le fasi del *recovering* di sugherete specializzate percorse dal fuoco.

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