FACTORS AFFECTING POST-FIRE VITALITY AND RECOVERY OF CORK OAK TREES IN YFRI FOREST (NORTH-WEST OF ALGERIA)

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ABSTRACT

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The cork oak (Quercus suber L.) is a fire-adapted species due to the protection of dormant buds located under its cork bark. Post-fire resprouting in trees from these buds is an efficient means of plant adaptation. In this study, we examined the different types of the response of 644 trees, one year after a wildfire occurred in summer 2012 in the Tlemcen area. Furthermore, we determined the variables influencing the vitality likelihood of trees using multiple logistic regression. The dominant response is crown resprouting (67.7%), followed by tree death (23.9%) and basal resprouting (8.4%). The probability of tree vitality decreased with increasing fire intensity which associated with the importance of trunk injuries, decreasing bark thickness and tree height. This model is an interesting tool for diagnosing tree mortality or survival to assess the ecological and economic restoration actions for the forest.

Keywords: Cork oak, Wildfire; Tree vitality; Stripping quality; Bark thickness; Recovery model.

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INTRODUCTION

The cork oak *Quercus suber* L. is one of the most important forest resources of the western Mediterranean basin (Lamey,1893). These forests play a key role in the economy of this region with a positive trade balance. Globally, cork exports reached 1,484.4 million euros and more than 200.000 Ton in 2010 (APCOR, 2018).

Cork oak forests are of crucial importance to the economy and ecology of several Mediterranean countries, covering an area of 2,139,942 hectares worldwide (APCOR, 2018), a large part of which is located in rural areas threatened by human desertification.

In Algeria, cork oak forests originally covered an area of 460,000 ha (Lamey,1893). They extend from the Mediterranean littoral in the north to the Tellian chains in the south, but the vast massifs are located in the east of the country (Boudy, 1955). In 1990, the productive forest area declined to about 230,000 ha (Zine, 1992) with the remaining area being transformed into maquis. On the other hand, the annual cork production has also dwindled from about 26,000 tons before 1960 (Zine, 1992), to nearly 6,000 tons during the period (DGF, 2016).

Although several factors accounts for this situation, however, recurrent wildfires remain the major cause of the decline of the productive area. In fact, wildfires burn an annual mean surface of 33,000 ha during the period 1963-2018. Between the period 2000-2017 only, fire-affected around 5,250 ha of cork oak forest (Bouhraoua et al., 2014).

The resistance of the cork oak trees to high fire frequency and intensity in the Mediterranean basin has long been observed (Natividade,1956; Pausas,1997; Pausas and Keeley, 2017). Cork oak resistance to fire is a result of the presence of suberous bark that covers stems and branches from the young age trees (Lamey, 1893).

In the present study, the main objective is to develop statistical models as a tool for estimating the probability of post-fire trees survival in a cork oak stand burnt in summer 2012. Based on the short-term assessment of fire damage to trees and factors affecting tree vitality, we propose a forest management model for forest recovery and economic restoration stand.

MATERIAL AND METHODS

1.1- Study area

The current study is located in the cork oak forest of Yifri in the north west of Algeria. Formerly, the cork oak forest covered 1080 h, but has reduced over time (Bouhraoua et al., 2014). This massif is composed of natural stands of cork oak or shrub of cork oak . There are only a few traces of natural regeneration (Figure 1). The climate is Mediterranean with semi-arid bioclimate of mean cumulative annual rainfall of 560 mm and mean annual temperature of 16.5°C. The extreme values range from 3,8°C in January and 32,3°C in August (PDAU, 2011).

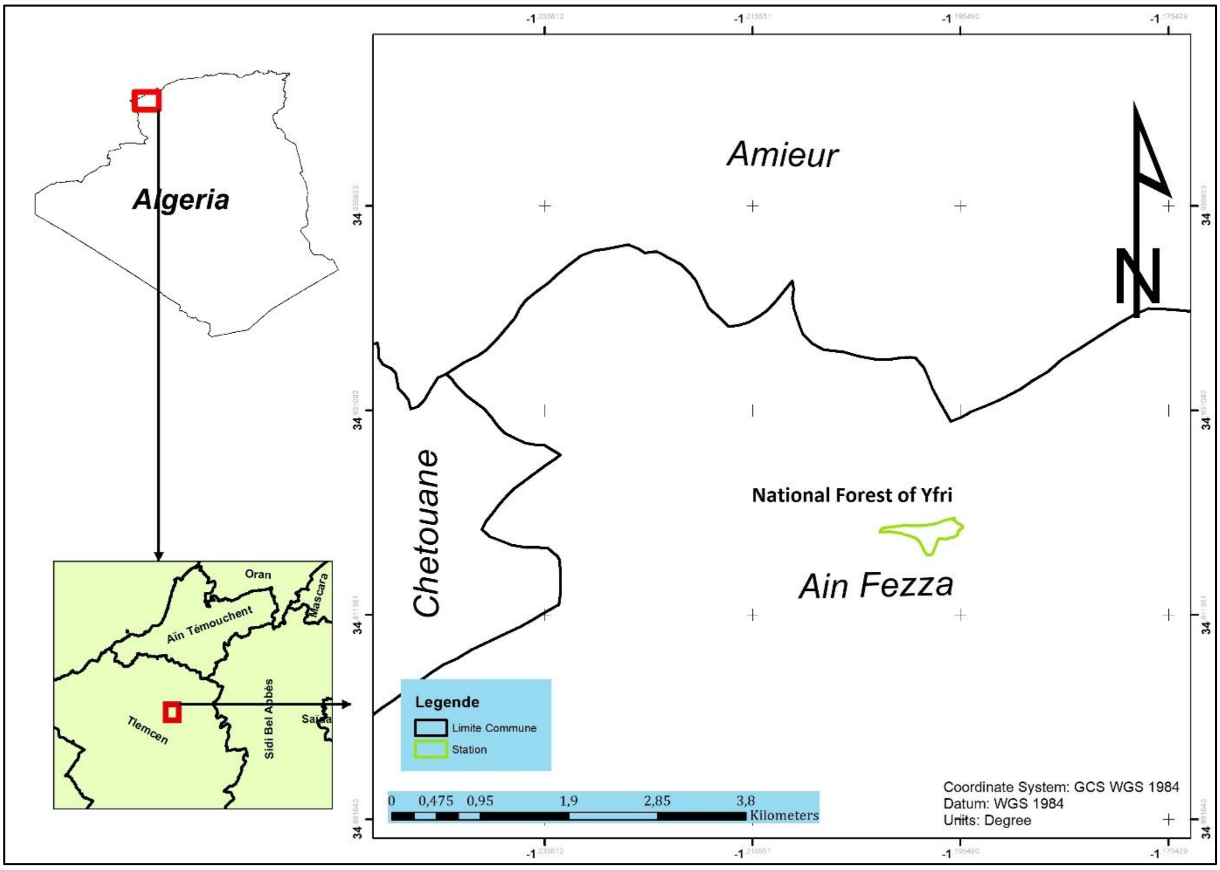

Figure 1: Map of study area (Yifri Forest).

The forest has experienced several wildfires over the last decade, burning variable areas; the most catastrophic was in summer 2012. This wildfire lasted for about 48 hours (from 9 to 11 August), burning more than 435 ha (Table 1) (CFT, 2014).

1.2-Data collection

The study site was selected based on the cork oak trees dominance, which visibly constitutes a submature forest stand. On the other hand, areas containing scattered shrubs of cork oak growing in sparse maquis were excluded from this study.

At the site level, several variables were included and measured:

i) topography: slope, exposure and elevation are calculated from the digital terrain model (Aster GDEM), ii)Characteristics of shrubs and subshrubs accompanying cork oak because they determine the fire intensity and its severity affecting forest stand (Trabaud, 1974; Quézel and Médail, 2003; Moreira et al., 2007).

Table 1. Summer 2012 fire Event

Stand	Value
Burnt area of vegetal formations (ha)	435
Burnt area of cork oak and holm oak (ha)	50
Date of fire	9 - 11 August
Maximum temperature of 3 days of fire °C	40-44°C
Wind speed (km. h^{-1})	Mean
Atmospheric pressure (atm)	764
Relative humidity (%)	20-40

The composition and abundance of species were evaluated from the Braun-Blanquet method (Braun-Blanquet, 1952). Indeed, the abundance (cover rate) of all plants was expressed from scorched stems remaining on ground and noted in five cover coefficient classes: 1 (species with a cover <10%), 2 (10-24%), 3 (25-49%), 4 (50-74%) and 5 (> 75%). In addition, the vegetation layers is ranging from: 1 (low shrub: between 0.5-2 m high) and 2 (high shrub: 2-4 m). The analysis of vegetation was made in autumn 2013. The plant inventory was based on the basal regeneration capacity of plants after fire (Pausas, 1997).

Burned trees

The sampling was conducted in autumn 2013 (*i.e* one year after the fire). For this, all partially or completely burned trees (n = 644) were measured: i) tree size (DBH, cm) taken at 1.30 m above ground level, ii) tree height (H,m) obtained by Blum-Leiss appliance, iii) state of stripped trees (EX): exploited (n = 387, presence of reproduction cork) or unstripped (n = 257, presence of virgin cork), iv) bark thickness (E,mm) measured at breast height using a bark gauge (average thickness from four measurements) and v) stripping height (HE, m).

The presence of trunk injuries (e.g. crevasses) expresses tree gravity as it facilitates the fire to reach the wood (Lamey,1893; Natividade,1956) According to the part of trunk damage (%) in relation to the bole height, five classes are distinguished: 1 (<1%), 2 (1-10%), 3 (11-24%), 4 (25- 49%), 5 (> 50%).

Fire intensity (IF) and the level of tree damage are visually measured by the proportion of above-ground biomass lost (Stephens and Finney, 2002). For this, we selected four increasing gradients of burn severity (Rigolot et al, 2014) according to: i) 1 (IF_1: canopy foliage partially scorched and cork singed on all or part of trunk height, ii) 2 (IF_2: foliage and thin twigs are entirely consumed and lightly charred cork), iii) 3 (IF_3: twigs and other small organs calcinate, tree completely charred) and iv) 4 (IF_4: only the architecture tree remains in place and strongly carbonized of cork surface). Besides we measured another indicator of fire intensity related to the flame height compared to tree total height and percentage of crown volume burned (%) (Moreira et al, 2007).

Depending on fire severity, four types of tree response are cited by some authors (Moreira, 2009):

i) resprouting exclusively from crown (C), ii) simultaneous resprouting from crown and base (CB), iii) resprouting exclusively from base (B) and iv) death (nil regenerative responses) (M).

1.3- Data analysis

To determine the variables influencing the post-fire response type of trees, we adopted multiple logistic regression or generalized linear model (GLM) based on binary responses coded in 0 and 1, (Catry et al., 2009). For modeling, we submitted these responses to the interaction tests between different independent (explanatory) variables collected at the tree level (**Table 2**). The ordinal variables were treated as continuous.

In this analysis, we coded the response "tree vitality" (n=644) by one of the trees was surviving and by zero if the tree was dead (Moreira and al, 2007). Tree survival was considered recoverable and maintained for their economic interest shortly (Catry and al., 2012). They consisted of trees with crown resprouting (C and CB), while irrecoverable trees without future silvicultural were destined to coppicing to favor the sprout stump. These trees were characterized by the nil crown regeneration (dead: M) or by basal resprouting (B).

The data analyzes were performed using the R software. For the GLM, we used the "*glm*" function of the "*stats*" package. In the first step, we started with a model including all explanatory variables and their importance was tested using the likelihood ratio ($\chi 2$). To check if the model selection obtained could be improved, we removed the second step, and all non-significant variables until only the remaining variables in the model were significant ($P < 0,05$). Model adjustments were also evaluated based on the Akaike (AIC) and Bayesian (BIC) information criteria.

For each model formulation, a diagnosis on the multi-collinearity of predictors was performed using the "*Imcdiag*" function of the "*mctest*" package (Imdad and Aslam, 2018). In addition to these tests, we calculated the correlation between the explanatory variables using the Pearson correlation coefficient (r) and the multiple correlations (R) between these variables and the dependent variable. In the case where the explanatory variables are linearly dependent on one another (strong correlation), we chose the model variable which better explains the response, (*i.e.* that most cited in previous works).

Table 2: Descriptive statistics of sampled-trees and study area

Variables	**Unit**	**Level of measurement**	**Mean (SD)**	**Range**
Diameter at breast height	cm	Tree	18.3 ±12.11	6-68
Tree height	m	Tree	5.86 ± 2.31	2-11
Reproduction cork thickness	mm	Tree	20 ± 5.71	2.5-45
Virgin cork thickness	mm	Tree	26.32 ± 4.55	20-36
Stripping height	m	Tree	1.89 ± 0.57	0.3-4.5
Exploitation status	2 cat.	Tree	-	0-1
Maximum charring height	%	Tree	96.02 ± 30.92	30-100
Minimum charring height	%	Tree	87.76 ± 25.98	10-100
Fire intensity	4 cat.	Tree	-	1-4
Trunk injuries	(%)	Tree	6.07 ± 18.01	0-95
Tree vitality	2 cat.	Tree	-	0-1
Elevation (Al)	m	Tree	949 ± 16.3	919-1000
Slope (P)	%	Tree	20.09 ± 9.4	0.51
Exposition (As)	-	Stand	N	-
Shrubs cover before fire	%	Stand	59. 04	-
Shrubs height before fire	m	Stand	2.66	1.8-3.5
Understory cover	%	Stand	72.15	-

RESULTS

1- Post-fire factors affecting the tree's vitality

Table 3 illustrate that among the 644 burnt sampled trees, 67.7% (n = 436) of trees survived after wildfire (63% of the unstripped trees and 71% of striped trees). The most dominant response type in trees was exclusive crown resprouting (C: 60.6%, n = 390), followed by simultaneous resprouting from the crown and base (BC: 7.1%, n = 46). However, the exclusive basal resprouting concerned about 8.4% of trees (n = 54); this type of regeneration is recorded more in unstripped trees than in those stripped trees. Finally, tree mortality affected around 23.9% (n = 154).

Before model formulation, multivariate statistical analysis revealed the presence of multi-collinearity between trees size variables with cork stripping. Thus, high tree size (r = 0.750) was systematically exploited (r = 0.624 and 0.648, respective correlations between stripping, diameter and height). The inclusion of diameter, a variable often implicated in post-fire tree mortality (Moreira, 2009), showed a non-significant effect in the model unlike tree height. Indeed, the introduction of this variable had slightly improved the model in terms of R^2 and some predictor estimates.

The model developed to predict the short-term vitality (*i.e.*, assessed one year after fire event) showed that this vitality was significantly affected by fire intensity when it was associated with decreasing order, trunk injuries, cork thickness, and tree height (Table 2). In fact, the trees survival decreased (*i.e*. mortality) with increasing fire violence and the importance of trunk injuries and decreasing bark thickness and tree height.

Finally, if all the predictor's coefficients were highly significant, the good correlations were verified between vitality, fire intensity (r = -0.346) and importance of crevasses (r = -0.340). Although these coefficients were small in the model and the effects were limited, these two variables alone can determine the tree vitality only when they were associated with bark thickness and tree height.

Table 3. Logistic linear regression to predict the post-fire vitality of cork oak trees: one year after fire (in October 2013). Models based on 644 trees burnt in 2012. Numbers in parentheses indicate results of inclusion of tree height.

Model	**Variables**	**Coefficient± standard error**	***Z-Valeur***	***P-value***
Factors of trees vitality	β_0(constant)	2.145±0.611 0.960±0.652	- -	- -
	Fire Intensity	-0.932±0.122 -0.877±0.120	-7.668 -7.298	<0.000 (<0.000)
	Trunk injuries	-0.054±0.009 -0.057±0.009	-6.208 -6.401	<0.000 (<0.000)
	Cork thickness	0.072±0.018 0.080±0.018	4.111 4.490	<0.000 (<0.000)
	Tree height	0.183±0.049	3.754	(<0.000)

** Model coefficients (± standard error): β0, intercept. Results of the likelihood ratio test (Z-value) and degrees of freedom and P-value: 0 '***', 0.001 '**', 0.010 '*', 0.050 '. Model performance: multiple R-squares; 0.245 (0.258), AIC: 638.6 (624.92).*

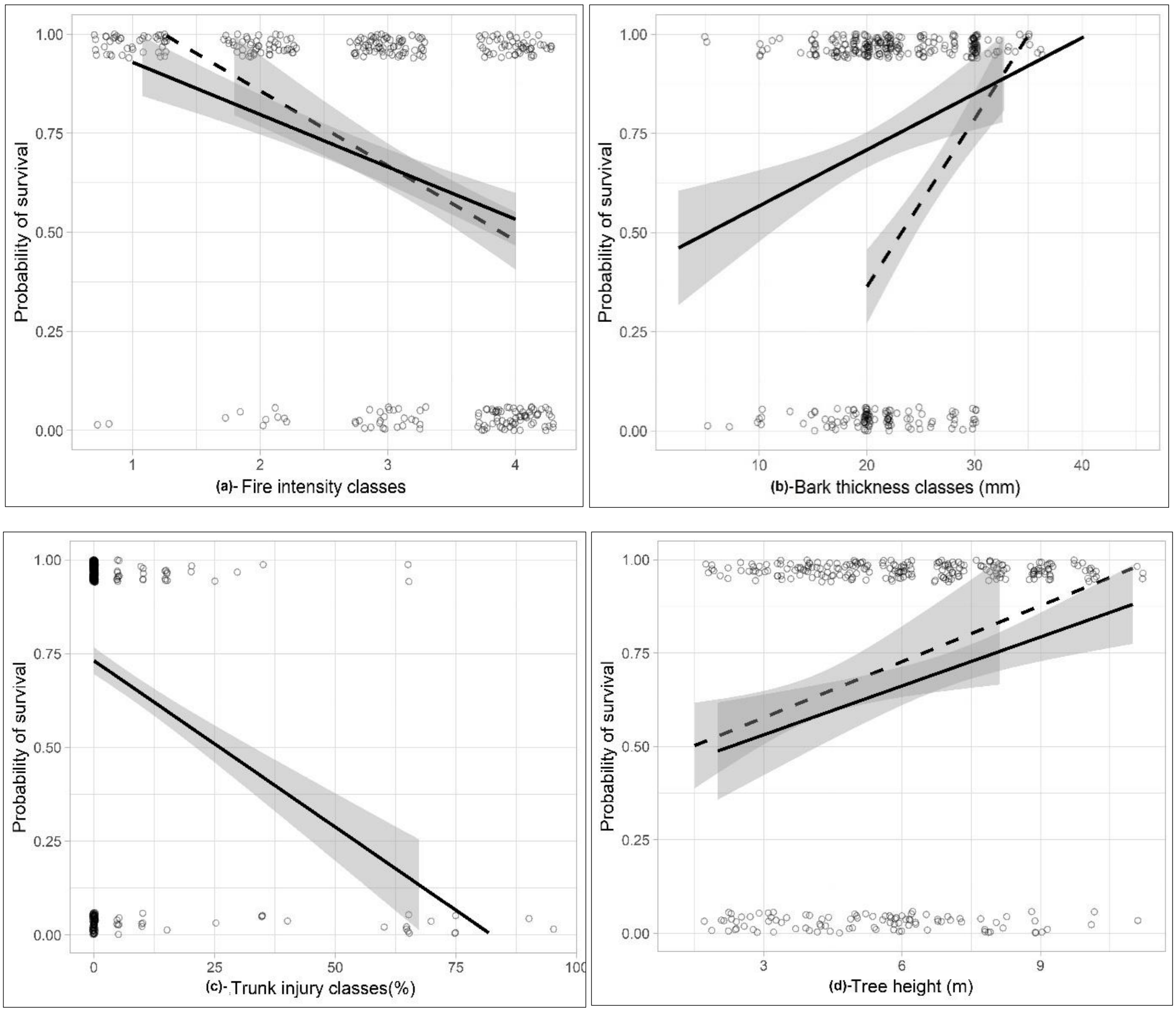

Figure 2: Logistic model prediction of cork oak survival, based on the table 3. Each figure shows probability of survival in relation to (a) fire intensity; (b) bark thickness; (c) trunk injury, (d) tree height. Each line represents unstripped trees with virgin cork (solid line), stripped trees (dashed line).

DISCUSSION

The assessment of the damage levels (*i.e*. fire severity) of 644 trees showed the post-fire relative importance of different response types. Overall, crown regeneration was more favored compared to stem death. However, the probability of basal regeneration and subsequent development will likely depend on several factors, including the vitality of the stump and the root system (level of tissue damage and accessibility to carbohydrate reserves), soil nutrients (Araya et al. 2016), and the eventual existence of additional factors of stress such as herbivory (Sirca et al., 2014; Catry et al., 2012b).

The statistical developed models showed that fire severity (*i.e*. degree of tree vitality) depends on several factors: i) fire violence suffered by trees, ii) level of protection to both dormant buds and internal living tissue localized under bark from the heat released by fire, and iii) individual tree characteristics.

Regarding fire intensity, the majority of trees (*i.e*. 68%) were exposed to high-intensity fire (*e.g*. IF_{3-4} gradient trees: total crown consumption). This factor showed a moderate effect on damage level (*i.e* low correlation) because trees are associated with a higher crown resprouting success (*i.e* 58%, n = 253). The probability of trees mortality is therefore considerably reduced at high levels of crown volume proportion scorched in exploited trees when compared to unstripping trees (Figure 2a). This response type is previously recorded in other woody plants such as giant sequoia, incense-cedar, and ponderosa pine (Scott, and al., 2002) On the other hand, in trees with low-intensity fire (*e.g*. IF_{1-2} gradient trees), the probability of mortality (i.e. 12% non-resprouters) is low in unstripping trees compared to exploited trees (Figure 2a).

The impact of fire intensity on trees depends on several factors; i) surface fuel accumulation, ii) fire exposure time and iii) environmental factors (Rigolot et al., 2004; Trabaud, 1974 ; Quézel and Médail, 2003). Indeed, the high fire intensity observed in the stand is induced by the presence of fuel composed mainly of highly inflammable species (*e.g*. shrubs and subshrubs) such as *Arbutus unedo*, *Phillyrea angustifolia* and *Pistacia lentiscus* (Dehane et al., 2017) and enriched by various plants of genus *Cistus*. The high fuel load (*i.e*. high recovery rate and shrub height) (Table 1), homogeneously covering more than 60% of the site area allowed the easy propagation of fire (Trabaud, 1974). In addition, with fuel accumulated near trunks, the flame increased the burning and fire residence time on trunks than on crowns (Pimont,2014) The behavior of this fire is aggravated by favorable climatic factors Table 1).

The level of resistance to fire and consequently, the level of damage is determined by factors related to the tree, mainly the bark thickness. Indeed, for different fire regimes (Pausas and Keeley., 2017), many previous studies focused on the importance of bark in fire protection in several woody plants (Leite and Pereira, 2017).

In general, the thicker the bark,the higher the protection and the lower the probability of severe level of damage. However, in contrast, to the bark thickness for coniferous and several broadleaved species, which increases with age (Catry and al., 2010), the cork oak harvested depends on the date of cork stripping when it reaches a commercial thickness of more than 27 mm, (Pereira, 2007). Moreover, the size of thickness that ensures maximum protection of internal tissues varies among different authors. However, a thickness greater than 2.0 cm ensures a tree survival probability of more than 60% (Moreira et al., 2007; Catry and al., 2012): this confirms our results where an average thickness of 2.62 cm offered protection for 75% of trees (Figure 2b). For the Algerian cork, Lamey has already reported, a mortality of 50% for a cork of four years (Lamey, 1893).

In stripping trees, cork-ring widths are more rapid in the first 4 years of cork growth (Natividade, 1956; Pereira, 2007), which are greater than 3mm yr^{-1} for European cork (Pereira,2007), and can reach 4.8 mm yr^{-1} for Algerian cork. The rapid formation of cork during this period constitutes an excellent thermal insulator for vascular cambium and xylem against new fire. Water and nutrients are well mobilized for crown resprouting (Ghalem and al., 2018) from undamaged epicormic buds of twigs, when the fire is of low intensity and branches when the fire is of high intensity (Moreira et al., 2007).

At the level of unstripped trunks and large branches, the virgin cork layer is thick resulting from several years of formation (Natividade,1956) and dormant buds deeply buried in the phellem becomes well protected against heat (Moreira et al., 2007). In our model, the probability of trees survival is lower (*e.g.* thickness equal between 20 and 30 mm) compared to reproduction cork (Figure 2b). This suggests that virgin cork burn more easily than reproduction cork (Pimont, 2014) or probably other factors may contribute to the high level of mortality.

In our studies, the model developed suggests other explanatory factors for trees mortality whose trunks were sufficiently covered by thick bark (e.g., 45% of overall mortality) i) trunk injury and ii) trees height. The high probability of mortality is determined in trees with highly injured trunk (Figure 2c). Indeed, a quarter of surface damaged of the trunk can induce high mortality of 50%. The majority of this damage is caused by severe wounds during the previous harvesting of cork (FAO.,2013; Keeley, 2009; Saccardy, 1937). Although cork oak has a great ability to heal lesions after stripping, larger areas affected do not close.

Among these injuries, we find the too deep longitudinal incisions reaching to wood and removal of all the bark (periderm and phloem) because of the flow slowing of sap related to catastrophic climatic events (heatwave and rain). The wood becomes exposed to the atmosphere and it dies and dries. After the rain waters action, the pathogenic fungi settle (Natividade, 1956). When a fire occurs (*e.g*. even at low intensity), it easily penetrates inside the trunk, which consequently reduces the post-fire probability of trees survival (IML, 2016).

Besides, the size of trees (*e.g*. total height) would intervene to partially explain the probability of mortality recorded. The relationship between tree height and level of fire protection is hypothesized to be related to the height of carbonization and heat transfer mode.

In fact, the lower the tree, the more the crown is completely exposed to fire and the more the mortality increases. Under these conditions, heat is transferred by conduction (*i.e.* from shrubs of other similarly tall species growing nearby). With a longer fire residence time (dry climate, high plant water content and reduced flammability (Trabaud, 1974; Quézel and Médail, 2003), heat flux becomes more important (Pimont, 2014) and organs are killed (Moreira et al., 2007). This indicates that young trees in the shrub layer (<4m) have a high probability of crown mortality than taller trees (Figure 2d). These trees come from natural regeneration by seedlings or by stump sprouts; they have a small diameter (<7cm) and are covered with a thin layer of virgin cork insufficient to protect them against the intense heat. Previous studies have shown that stems with a diameter of 7.5 cm, subjected to high-intensity fire have a 50% probability of mortality (IML, 2016). Finally, the height of the trees is related to growth that depends on age and also the quality of sites (Paulo et al., 2015).

Management recommendations

The cork oak is a Mediterranean tree known for its resistance to frequent fires, characteristic of the region climate (Pausas, 1997; Moreira et al., 2007) The results obtained showed that the study stand is subjected to a total fire (consumption of undergrowth and trees crown (Pimont, 2014) and high intensity (high energy released, and heating duration (Meddour et al., 2013).

This type of fire is exacerbated by the presence of a high and abundant shrubs with flames reaching several meters high (*e.g*. reaching the crown of many trees), hence the need for silvicultural actions. This involves forestry operations that reduce the vertical and horizontal fuel continuity, minimizing the vulnerability of the stand to large recurrent fires.

Despite this high intensity of the fire, the severity of damage and the ecological impact on the ecosystem is low because the majority of trees have survived and the stand has recovered its soil cover after 3 years from the fire event. A myriad of studies has shown that the resilience of forest ecosystems subjected to moderate-high fire frequency is based on the strong ability of crown resprouting and low stem mortality (Pausas and Keeley, 2017). Although epicormic resprouting is adaptive response in the ecosystem, a wildfire does not remain without economic impact on the forest (Carty and al., 2012; IML, 2016) because it reduces the cork production by postponing the harvests for a few years as well as depreciates the quality and market value of cork.

The restoration of high-value cork production is the mean objective of post-fire management. But it requires a long time varying from 40 years for trees replaced by reforestation and 20-30 years for coppiced trees (Natividade, 1956; Saccardy, 1937). During the first years of restoration, the young stand (*e.g.* low trees height and thin bark) is vulnerable to fire and the probability of stem mortality and low crown regeneration increases with the severity of the fire, hence the need for a special fire defense system.

A period of five years after the fire is sufficient to harvest the burnt cork from surviving trees already stripped and covered with a thick layer of reproduction cork (> 20mm) and unstripped trees with dimensions greater than 60cm in circumference (Keeley, 2009; Pimont et al., 2014). According to the rate of health recovery, an additional year (i.e. 6 years) is recommended to allow more vigorous trees to be harvested. In Europe, a minimum period of 2 to 3 years is recommended before stripping the burned cork. During this period, the trees would have recovered more than 75% of the crown volume they had before the fire (Catry et al., 2012; IML, 2016).

Regarding weakened trees covered with a thin layer of cork must be cut back to ensure better regeneration of the stand (Saccardy, 1937). The plantation is recommended in case of failure of stumps suckers, although it is more expensive and time-consuming than coppicing. It should be initiated as early as possible (first fall or winter after the fire) to avoid competition with regenerating vegetation.

CONCLUSION

Finally, the bad stripping quality and severe trunk injuries expose trees to the high probability of mortality after a fire, even if the bark is thick. Therefore, there is the need to employ an experienced cork stripper, who is more skilled to remove the cork without damaging the tree.

The good growth of this recovery is firstly subject to the amount of reserves present in the stump, the fertility of the station, the fire regime, the dendrometric characteristics of trees and the thickness of the cork. A fire affecting recently exploited trees exposes the stands to a very considerable risk of mortality; the forest manager must be aware of this threat. To reduce economic and forestry losses caused by wildfires, the monitoring of management methods and the planning of recovery actions concerning coppicing is a key element to mitigate the serious impact of this factor on cork oak forest and restore cork production as soon as possible.

The results of this study will provide a baseline information for forest managers to develop an appropriate management strategy to promote forest resilience to severe wildfires.

REFERENCES

APCOR. 2019. Cork, 2019. Available at: http://www.apcor.pt/wpcontent/uploads/18/19 Boletim-estatistico-18/19.pdf, accédé le 02 février 2020.

Araya, S.N., Meding, M., and Berhe, A.A. 2016. Thermal alteration of soil physicochemical properties: a systematic study to infer response of Sierra Nevada climosequence soils to forest fires. *Soil*, 2 : 351–366. doi:10.5194/soil-2-351-2016.

Boudy, P. 1950. Economie forestière nord-africaine.Tome 2 : Monographie et traitements des essences forestières, Larose Ed., Paris. 525 pp.

Boudy. P.1955. Economie forestière nord-africaine. Tome 4: Description forestière de l'Algérie et de la Tunisie, Larose Ed., Paris. 483 pp.

Bouhraoua, R.T., Piazzetta, R., and Berriah, A. 2014. Les reboisements en chêne-liège en Algérie, entre contraintes écologiques et exigences techniques. *Forêt Méditerranéenne*, 35 (2) : 171-176.

Braun-Blanquet, J., Roussine, N., and Nègre, R.1952. Les groupements végétaux de la France méditerranéenne. Dir. Carte Group. Vèg. Afr. Nord, CNRS. 292 p.

Catry, F.X., Moreira, F., Cardillo, E., and Pausas, J.G. 2012. Post-Fire Management of Cork Oak Forests. Pp.195-222. In: F. Moreira, M. Arianoutsou, P. Corona and J. De las Heras (Ed.) Managing Forest Ecosystems: Post-Fire Management and Restoration of Southern European Forests (Springer Publishing). doi: 10.1007/978-94-007-2208-8.

Catry, F.X., Moreira, F., Duarte I., and Acácio, V. 2009. Factors affecting post-fire crown regeneration of cork oak (Quercus suber) trees. Eur J Forest Res 128, 231–240 (2009). https://doi.org/10.1007/s10342-009-0259-5

Catry, F.X., Rego, F., Moreira, F. and Fernandes, P.M., and Pausas, J.G. 2010. Post-fire tree mortality in mixed forests of central Portugal. Forest Ecology and Management, 260(7):1184-1192. DOI: 10.1016/j.foreco.2010.07.010

CFT.2014. Bilan des incendies de forêts de la période dans la wilaya de Tlemcen. Conservation des Forêts de la wilaya de Tlemcen, Algeria. 3 pp.

Dehane, B., Hernando, C., Guijarro, M., and Madrigal, J. 2017. Flammability of some companion species in cork oak (Quercus suber L.) forests. Annals of Forest Science, 74, 60. https://doi.org/10.1007/s13595-017-0659-5

DGF.2016. Statistiques sur la Production annuelles du liège en Algérie. Direction Générale des Forêts, Algeria. 5 pp.

FAO.2013. State of Mediterranean forests 2013. Food and Agriculture Organization of the United Nations, Rome. 189 pp.

Ghalem, A., Barbosa, I., Bouhraoua, R.T., and Costa, A. 2018. Climate signal in Cork-Ring chronologies: Case studies in southwestern Portugal and northwestern Algeria. *Tree Ring Research,* 74 (1): 15-27. doi:org/10.3959/1536-1098-74.1.15

Imdad Ullah, M., and Aslam, M. 2018. Multicollinearity Diagnostic Measures. R package Version 1.2, https://cran.r-project.org/web/packages/mctest/index.html, 2018.

IML. 2016. Guide de Sylviculture dans les Pyrénées-Orientales. Institut Méditerranéen Liège Ed., Vives. 66 pp.

Keeley, J.E. 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International Journal of Wildland Fire*, 18 : 116–126.

Lamey, A.1893. Le chêne-liège, sa culture et son exploitation, Berger Levrault et Cie éditeurs, Nancy, Paris.289pp.

Leite, C., and Pereira, H. 2017. Cork-Containing Barks. *A Review. Frontiers in Materials*, Volume 3, article 63: 19. DOI: 10.3389/fmats.2016.00063.

Meddour-Sahar, O., Meddour, R., Leone, V., Lovreglio, R., and Derridj, A. 2013. Analysis of forest fires causes and their motivations in northern Algeria: the Delphi method. *IForest,* 6: 247-254. doi: 10.3832/ifor0098-006

Moreira, F., Catry, F.X., Duarte, I., Acácio, V., and Silva, J.2009. A conceptual model of sprouting responses in relation to fire damage: an example with cork oak (*Quercus suber* L.) trees in Southern Portugal. *Plant Ecology,* 201: 77-85.

Moreira, F., Duarte, I., Catry, F.X., and Acácio. V.2007. Factors affecting post-fire cork oak survival in southern Portugal. *Forest Ecology and Management*, 128(3):231-240

Natividade, 1956. Subériculture, édition française de l'ouvrage portugais. Subericultura, École nationale des eaux et forêts, 1956., 304 pp.

Paulo, J.A, Palma, J.H.N., Gomes, A.A., Faias, S.P., Tomé, J., and Tomé, M. 2015. Predicting site index from climate and soil variables for cork oak (Quercus suber L.) stands in Portugal. New Forests, 46(2): 293-307

Pausas, J., and Keeley, J.E. (2017). Epicormic Resprouting in Fire-Prone Ecosystems. *Trends in Plant Science,* 22 (12): 1008-1015. http://dx.doi.org/10.1016/j.tplants.2017.08.010.

Pausas, J.1997. Resprouting of Quercus suber in NE Spain after fire. Journal of Vegetation Sciences, 8(5): 703-706. doi.org/10.2307/3237375

PDAU. 2011. Plan directeur d'aménagement et d'urbanisme de la commune d'Ain Fezza (Tlemcen), Tlemcen. 156 pp.

Pereira, H. 2007. Cork: Biology, Production and Uses. Elsevier Publishing, Amsterdam. 336 pp.

Pimont, P., Dupuy, J-L., Rigolot, E., and Duché, Y.2014. Les effets du passage d'un feu dans un peuplement arboré: synthèse des connaissances et applications pour le gestionnaire forestier méditerranéen. *Forêt Méditerranéenne,* 35 (1) : 17-30.

Quézel, P., and Médail, R. 2003. Ecologie et biogéographie des forêts du bassin méditerranéen. Elsevier Editions Scientifiques. Collection environnement, Paris. 574 pp.

Rigolot, E. 2004. Predicting post-fire mortality of *Pinus halepensis* Mill. And *Pinus pinea* L. *Plant Ecology*, 171: 139–151.

Saccardy, L.1937. Notes sur le chêne-liège et le liège en Algérie. Bulletin de la Station de Recherche Forestière Nord Africaine 2. 271-374 pp.

Sirca, C., Filigheddu, M.R., Zucca, G.M., Cillara, M., Bacciu, A., Bosu, S., and Dettori, S. 2014. Long-term researches on post fire recovery techniques of cork oak stands [online]. In Proceedings of the Second International Congress of Silviculture, Florence, 26-29 November 2014. Available from https:// aisfdotit.files.wordpress.com/2016/03/vol_1_2cis_rev.pdf.

Stephens, S. L., and Finney. M. A. 2002. Prescribed fire mortality of Sierra Nevada mixed conifer tree species: effects of crown damage and forest floor combustion. *Forest Ecology and Management*, 162 (2-3) : 261-271, doi:10.1016/S0378-1127(01)00521-7.

Trabaud, L. 1974. Apport des études écologiques dans la lutte contre le feu. *Revue Forestière Française* n° spéciale, 140-153.

Zine, M. 1992. Situation et perspectives d'avenir du liège en Algérie. Actes du Colloque Les Subéraies méditerranéennes. Vives, France. 98-107.