ARTICLES

Mediterranean Botany
ISSNe 2603-9109

EDICIONES COMPLUTENSE

https://doi.org/10.5209/mbot.77999

Post-fire regeneration of cork oak (*Quercus suber*) in Kiadi forest (Akfadou- Algeria)

Tassadit Dib[1], Dimitrios Kazanis[2], Margarita Arianoutsou[2], Mahand Messaoudene[3]† & Fazia Krouchi[1]

Received: 18 September 2021 / Accepted: 20 May 2022 / Published online: 16 January 2023

Abstract. Cork oak (*Quercus suber*), a West Mediterranean species, is known for its ecological, economic and social values. Wildfires are one of the most serious problems threatening *Quercus suber*, endangering its occurrence in its distribution area. Therefore, the knowledge of species behavior after the fire and the factors influencing their responses are particularly important for forest management. In this study, we assessed the post-fire vegetative recovery in 730 trees affected by wildfires in 2014 in the Kiadi cork oak forest, located on the Western side of Akfadou Mountains in Algeria. Six months after the fire, individual tree mortality was very low (7.26%), and nearly all the trees sampled survived the fire since almost all trees resprouted from the canopy and some showed basal resprouts. Moreover, the crown recovery and the basal resprouting were not correlated with each other. The performed redundancy analyses (RDA) revealed that the cork oak post-fire response was highly correlated with individual characteristics and with the environmental data. The main variables influencing the likelihood of good or poor vegetative recovery were the understory height and cover, soil characteristics, fire severity, tree status (alive/dead trees), tree diameter and tree exploitation. Our results confirmed the fire resistance of cork oak, which is also the only Algerian tree to resprout. Hence, this makes the species a good candidate for reforestation programs in fire-prone ecosystems.

Keywords: Cork oak, post-fire recovery, forest management, Kiadi forest, Akfadou, Algeria.

How to cite: Dib, T., Kazanis, D., Arianoutsou, M., Messaoudene, M. & Krouchi, F. 2022. Post-fire regeneration of cork oak (*Quercus suber*) in Kiadi forest (Akfadou- Algeria). Mediterr. Bot. 44, e77999. https://doi.org/10.5209/mbot.77999

Introduction

Forest fires are a recurrent disturbance across the Mediterranean basin, with nearly half a million hectares burned yearly (FAO, 2006). Mediterranean-climate ecosystems are among the most fire-prone biomes in the world (Keeley, 2013). In fire-prone ecosystems, most plant species are adapted to fire (Eschel *et al*., 2000; Paula *et al*., 2009), either by being able to resist exposure to fire and its effects or by regenerating promptly after the fire. However, the number of fires and the burned area per year are likely to increase in the future through the extreme meteorological conditions with a prolonged drought period (very high temperatures and low rainfall), and vigorously increasing human pressure, particularly near the areas where populations concentrate, thus increasing the demand for fuel, food, and new lands for urban growth (Meddour *et al*., 2013). Accordingly, the study of post-fire tree response is important and essential to evaluate recovery options and provide recommendations. Oaks are known to show very high fire resilience due to their ability to regenerate by resprouting after a fire (Franklin *et al*., 2003) and/or to the protection of their thick bark (Oliveras *et al*., 2009). Cork oak (*Quercus suber*) is the only oak species with canopy resprouting ability, even if the entire crown is burned (Pausas, 1997). This is due to its extremely thick bark.

Cork oak is a native species of the West Mediterranean Basin, covering nearly 2.5 million hectares across Southern Europe and Northern Africa, from the Iberian Peninsula and Morocco to the Western rim of the Italian Peninsula, growing on a wide range of ecological conditions (Bernetti, 1995; Oliveras *et al*., 2009; Pausas *et al*., 2009). The species is well adapted to the Mediterranean-type climate with mild, wet winters and dry, hot summers (Pereira, 2007). It grows under at least 450 mm mean annual rainfall, from sea level to 2000m asl, prefers siliceous soils and can grow on poor and extremely acidic soils (Berberis *et al*., 2003).

Quercus suber ecosystems provide a range of social, economic, and ecological services far beyond timber

[1] Laboratoire de Production, Amélioration et Protection des Végétaux et des Denrées Alimentaires, Faculté des Sciences Biologiques et Agronomiques, Université Mouloud Mammeri. Tizi-Ouzou, Algérie. Email: dib.tassadit@yahoo.com, krfaz@yahoo.com
[2] Department of Ecology and Systematics, National and Kapodistrian University of Athens. Athens, Greece. Email: dkazanis@biol.uoa.gr, marianou@biol.uoa.gr
[3] Institut National de Recherches Forestières "INRF" d'Azazga. Tizi-Ouzou, Algeria.

exploitation (Natidivade, 1990; Catry et *al*., 2012 a). Despite its value, several factors such as diseases, over-harvesting, over-grazing, land-use changes and forest fires threaten the species presence in several areas (Pausas, 1997; Silva & Catry, 2006). In Algeria, wildfires are considered as the major cause of cork oak decline (Messaoudene *et al*., 2009; Bekdouche et *al*., 2011), which, in the last decades, reduced the area of its distribution from about 410,000–480,000 ha (Saccardy, 1938; Quezel & Medail, 2003) to 229,000 ha (DGF, 2006).

Although cork oak is widely considered as a fire resilient species, numerous studies suggest its variable responses to fire (Pausas, 1997; Berberis *et al*., 2003; Catry *et al*., 2009; Moreira *et al*., 2008; Catry *et al*., 2010; Moreira *et al*., 2010). However, the reasons for such variability are poorly understood (Catry *et al*., 2012 b). Tree survival and regeneration ability are influenced by several factors related to fire severity, fire regime, community dynamics and individual tree characteristics (Ryan, 1982; Miller, 2000; Gonzalez & Dutt, 2007). Keely & Rundel (2005) suggested that environmental variables such as slope, insolation, precipitation and soil characteristics (structure, texture, nutrients availability, etc.), are variables which can also regulate post-fire patterns. However, in the Northern part of Algeria, particularly in our study area, no published data have been reported on this subject.

In this paper, we aim to: (1) characterize the post-fire responses of cork oak species in term of its resprouting ability and recovery and (2) investigate the main tree and stand characteristics likely to influence these responses. We hypothesize that tree resistance to fire and post-fire recovery depend on individual tree characteristics, edaphic factors and fire severity. Identifying these factors and forecasting tree responses may allow for minimizing fire damage through proper recommendations for improving the management of cork oak ecosystems.

Methods

Study area and fire

Data on post-fire tree responses were compiled from a wildfire that occurred on August 11th, 2014 in Kiadi cork oak forest (Figure 1); located in the Western side of Akfadou forest, Northern Algeria (36°40'42.03" N; 4°31'7.35" E). The site has Mediterranean climate with mean annual precipitation ranging from 900 to 1000mm (Messaoudene, 1989). Kiadi forest covers an area of 144.85ha (BNEF, 1989), with an altitude ranging from 700 to 860 m asl and slopes varying from 15 to 45%. The main bedrock type of the burned area is sandstone; the dominant soil is brown humic, with topsoil varying from 1 to 4cm. The unburned Kiadi forest had an understory composed by fire-prone shrubby and herbaceous species, such as *Arbutus unedo*, *Erica arborea*, *Phillyrea angustifolia*, *Cistus salviifolius*, *Cytisus triflorus*, *Crataegus monogyna*, *Rubus ulmifolius*, *Phillyrea latifolia*, *Myrtus communis*, *Thymus vulgaris*, *Ampelodesmos mauritanica* and *Asparagus acutifolius.* During the 2014 fire, the Kiadi cork oak forest was burned in a rather heterogeneous way, as suggested by the differences in the consumption of the cork oak crown biomass, and by a severe fire with a higher intensity compared to previous years. It consumed more than 30% of the total area of the forest.

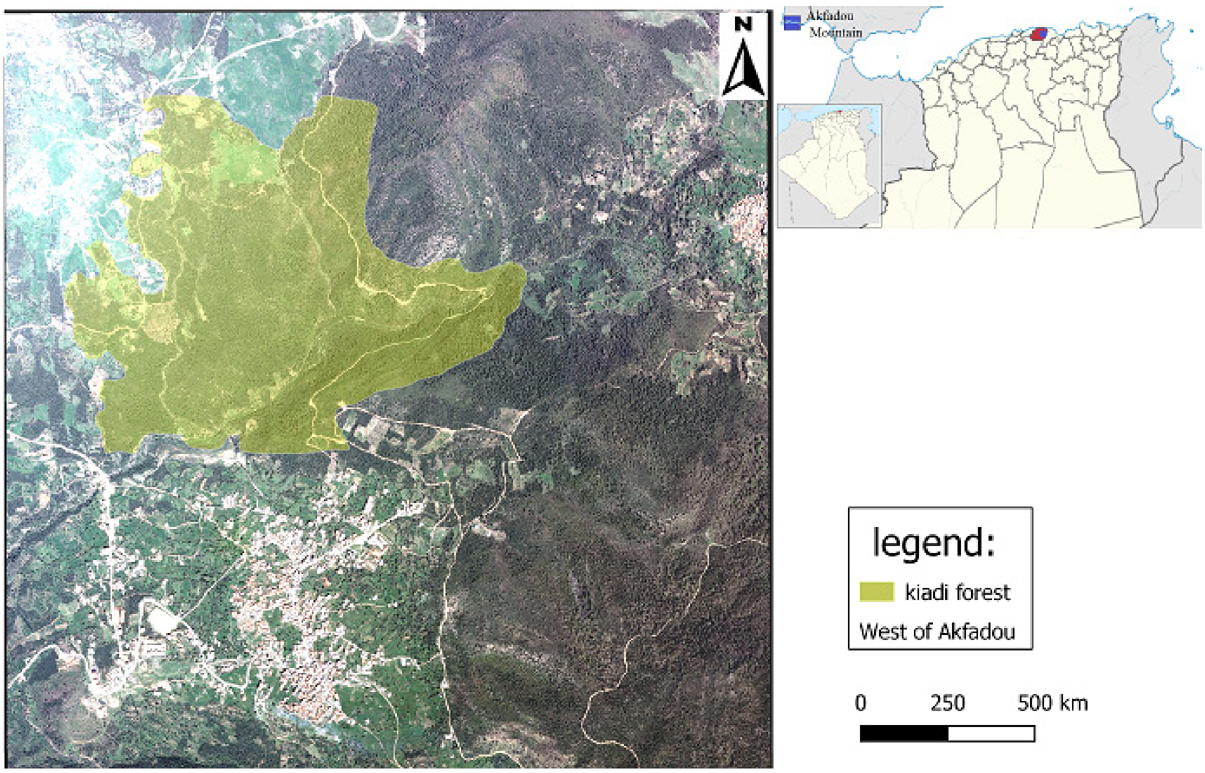

Figure 1. Study area (Kiadi cork oak forest, Akfadou, Tizi-Ouzou, Algeria).

Sampling

According to their burn severity classes, nine zones were selected for sampling across the burned area, with easily observed, contrasting levels of tree crown biomass consumption. Each zone was identified in the field and delimited on Google Earth image with appropriate coordinates one month after the fire. The area and distance between the zones were defined according to the number of trees inside each zone. Six months later, a line transect was established in the center of each zone that had the length of the zones. Along each transect, circular plots of 200m^2 were systematically established at intervals of around 70m. A total of 79 plots were selected and sampled (Table 1).

Within each circular plot, the tree and woody understory vegetation cover was visually estimated using the phytosociological scale of Braun Blanquet (1936), classified as sparse (0–25% cover), medium (25–50% cover), dense (50–75% cover) or very dense (75–100% cover). Simultaneously, the understory average height (cm) was measured in each plot with a decameter and partitioned into 5 range classes (0–50, 50–100, 100–150, 150–200, 200–250). Furthermore, environmental variables were recorded in each plot: 6 aspect categories (North, East, South, West, South-West, and North-West), elevation (m asl), and slope (measured with a clisimeter). Additionally, the soil characteristics of color and humidity were studied during the first six months after the fire, a period where no important rain was noticed. The soil color was carefully estimated visually, and only two different colors were observed, then classified as binary variable; 1: brown vs. 2: rust. Soil humidity was measured on the top level of the soil, monthly after the fire, inside each plot and defined as humid or dry plots.

Table 1. Number of sampled trees per zone

Zone	1	2	3	4	5	6	7	8	9	Total
Number of plots	8	10	8	12	10	11	10	5	5	79
Number of trees	75	96	6	119	92	95	89	3	43	730

Within each plot, all cork oak individuals were sampled individually, and several variables were measured for each tree (Table 2). A total of 730 trees were assessed. The post-fire stand structure was described by measuring the diameter at breast height (DBH) of all standing cork oak trees using a tape. Cork bark thickness at breast height was estimated as the average of four measurements made with a bark gauge at opposite sides around the trunk. Tree bark exploitation status was defined as a binary variable (presence /absence of cork stripping) based on the presence of harvesting marks on the stem; cork stripping was registered to separate trees in which cork exploitation had started and taken place at least once from trees that had never been stripped. For the exploited trees, stripping height was recorded using a decameter and classified into four equal interval classes.

For each tree, individual status was appointed to as ‘dead’ or ‘alive’ based on a careful visual inspection. The tree was considered dead when no green foliage was present and it had a damaged trunk. Individual status estimation included an estimation of fire severity and damages on the tree, according to Amandier’s (2004) classification of four degrees, namely 1st degree (slightly burned: scorched leaves only, protected trunk), 2nd degree (moderately burned: burned leaves, protected trunk), 3rd degree (highly burned: charred trees, ground cleaned) and 4th degree (very highly burned: charred cork, completely uncovered wood). Finally, the post-fire response of each cork oak tree was recorded as follows: recovered from the crown and resprouted from the root.

Canopy recovery was visually estimated as the proportion of main branches on the canopy showing signs of regeneration and classified into four different classes according to Catry (2006): 0–25% (low recovery), 25–50% (moderate recovery), 50–75% (high recovery) and 75–100% (very high recovery). In the case of trees presenting basal resprouting, i.e., from below-ground organs, the number of resprouted shoots was recorded, together with the height of the dominant (tallest) resprout from the root crown of each tree.

Table 2. Summary of the variable assessed in the study area

Variable	Level of measurement	Minimum	Maximum	Mean	S.D.	C.V. (%)
Understory cover (4 categories)	Plot	-	-	-	-	-
Tree cover (4 categories)	Plot	-	-	-	-	-
Understory average height (cm)	Plot	10	240	82.759	56.48	68.25
Aspect (6 categories)	Plot	-	-	-	-	-
Elevation (m)	Plot	725	860	795.59	34.05	4.28
Slope (%)	Plot	10	50	29.59	9.80	33.11
Soil color (brown vs. rust)	Plot	-	-	-	-	-
Soil humidity (humid vs. dry)	Plot	-	-	-	-	-
Diameter at breast height (cm)	Tree	5.5	130	25.88	10.99	42.47
Cork bark thickness (cm)	Tree	0.1	4.5	1.6	0.67	41.34
Cork stripping (presence/absence)	Tree	-	-	-	-	-

Variable	Level of measurement	Minimum	Maximum	Mean	S.D.	C.V. (%)
Stripping height (cm)	Tree	100	410	209.15	72.52	34.67
Tree status (dead/ alive)	Tree	-	-	-	-	-
Fire severity (4 degrees)	Tree	-	-	-	-	-
Number of resprouted branches	Tree	0	19	1.07	2.49	232.72
Crown post-fire regeneration (4 categories)	Tree	-	-	-	-	-

Data analysis

The main data analysis was performed at two spatial scales (plots and trees). As dependent variables, we used crown recovery and basal resprouting. These post-fire responses were considered in relation to the explanatory variables that were sampled at the plot level and at the tree level. In addition, the interaction between canopy recovery and resprouting ability was examined to tackle the relationship between the two modes of tree response to fire.

For the examination of the two types of vegetative responses after fire, we performed firstly descriptive statistics (Table 2) to have a global view of population structural variables. The analysis included a standard procedure of comparison of means. To highlight factors affecting vegetative postfire recovery, constrained ordination techniques have been performed using CANOCO software (ver. 4.5 for windows). Data collected regarding post-fire tree performance were tested against individual tree characteristics and plotted environmental variables by redundancy Analyses (RDA). Furthermore, Pearson's correlation analyses were performed to identify the variables with high and significant influence on good or poor post-fire recovery. Correlations between environmental variables and explanatory variables were low; the highest values were observed for tree variables. Only variables with a magnitude greater than ±0.60 were displayed graphically to show the relationship between variables.

The comparison between post-fire canopy recovery (based on stages of crown recovery) and basal resprouting (based on the presence or absence of basal buds) was analyzed by chi-square test and displayed by graphs to show the relationship between them and to highlight the best post-fire regeneration mode of post-fire cork oak response in Kiadi cork oak forest.

Results

Kiadi cork oak post-fire responses

From all 730 *Quercus suber* trees sampled, 7.26% did not survive after fire (individual mortality) while the remaining trees presented canopy regeneration, with 71.92% good crown recovery and only 20.82% intermediate crown recovery. From overall regenerated trees, 76.3% of them regenerated only from their canopy crown and 23.7% showed crown and basal resprouting.

A summary of descriptive statistics for the studied variables is shown in Table 2. Average bark thickness and mean diameter at breast height were respectively 1.6 cm and 25.88 cm, the mean cork stripping height of all stripped trees inside the study area was 209.15 cm. The study area's exploited trees represented 19.87% of the total sample. Mean understory height was 82.75 cm and the dominant understory classes were the very dense and medium ones followed by dense and sparse understory covers. Most trees were located North-East oriented (45.56% of all trees), North (22.78% of all trees) and South (10.13%of all trees), whereas the less common orientations were North-West (7.59% of all trees), East (6.33% of all trees) and South-West (6.33% of all trees).

The performed redundancy analysis (RDA), for which data collected regarding post-fire tree performance were tested against individual tree characteristics and plot environmental variables, revealed that the cork oak post-fire response represents a linear response to both individual characteristics and environmental data. This analysis indicated the most significant (p-value <0.05) individual and environmental variables only for trees sufficiently influenced by them (fit=13%).

According to Figures 2 and 3, which show the number of burned trees in each zone and the number of recovered trees per zone, respectively, cork oak's post-fire response was not similar between the defined zones. Individuals from zones 4, 6, 7, 8 and 9 were moderately burned or slightly burned, while those of the other zones were severely or very severely burned (Figure 2). The number of recovered trees after fire was highly significant in zones 4, 6, 7 and 9 at the time that individuals in the other zones showed a low rate of recovery (Figure 3). These results indicate a clear correlation between burning severity and post-fire crown regeneration and the recovery rate.

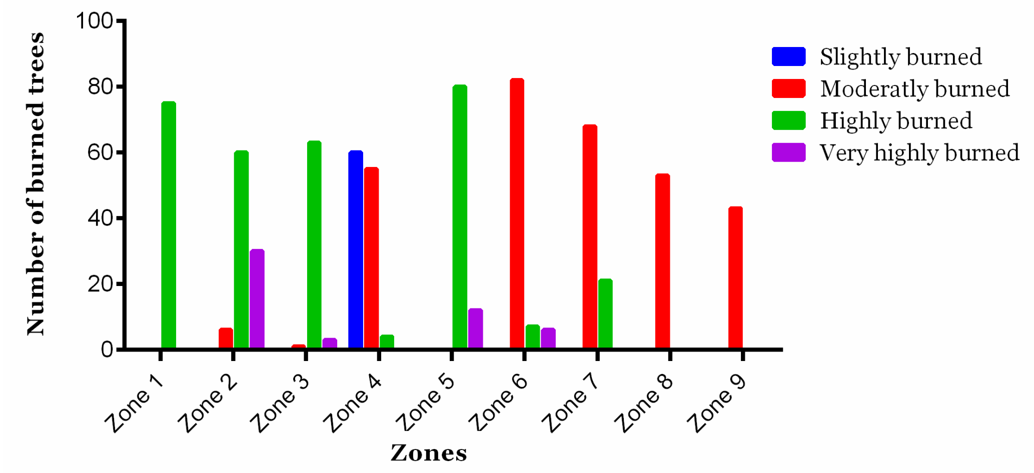

Figure 2. Number of burned trees in each zone as per fire severity class.

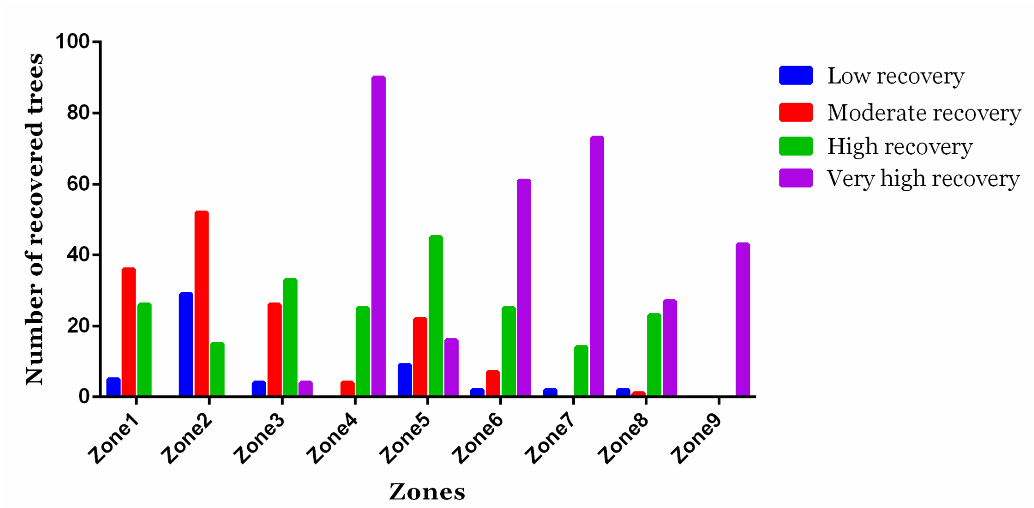

Figure 3. Number of recovered trees in each zone as per recovery class.

Kiadi Cork oak post-fire crown recovery

According to the results of the RDA, it is clearly shown that the major factor affecting the crown recovery of cork oak was tree damage caused by fire (Figure 4), which is highly and negatively correlated with the explanatory variable ($r = -0.73$; p-value < 0.05); the higher the fire severity, the higher the probability of low crown recovery (Figure 6a). Tree diameter was positively correlated to the recovery, as the biggest the diameter was, the better the recovery (Figure 6b). In the present study, bark thickness was a distant factor in the cork oak post-fire crown recovery (Figure 6c). Moreover, the exploited trees were more damaged by fire than the unexploited ones. The tree status analysis (alive or dead individuals) (Figure 6d) has shown a better result with the less damaged individuals rather than the considered dead ones. In addition, two plot variables [understory height (Figure 6e) and shrub cover (Figure 6f)] were positively correlated to the crown recovery with correlation coefficients of $r = 0.66$ (p-value <0.05) and $r = 0.68$ (p-value <0.05), respectively. The orientation of plots played an important role in the recovery of trees (Figure 6g). The soil color analysis has shown better results with brown soils than rust ones (Figure 6h). From the plot environmental variables, the RDA results (Figure 5) highlighted the importance of soil humidity towards high crown recovery despite its low correlation with the explanatory variable (Figure 6i). Likewise, despite the low explanatory values from the RDA analysis, our results indicate that the post-fire recovery is better explained by tree factors rather than the plot ones.

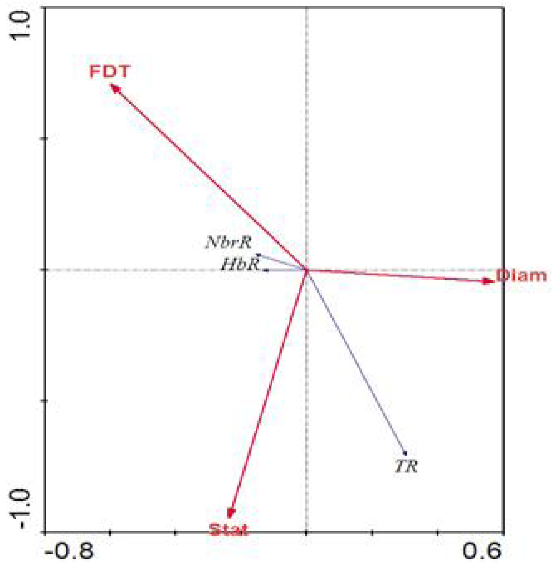

Figure 4. Ordination biplot (RDA) of cork oak trees and individual tree variables: (TR: tree recovery, NbrR: number of resprouts, HbR: height of the biggest resprout, FDT: fire severity, Diam: tree diameter and Stat: tree Status).

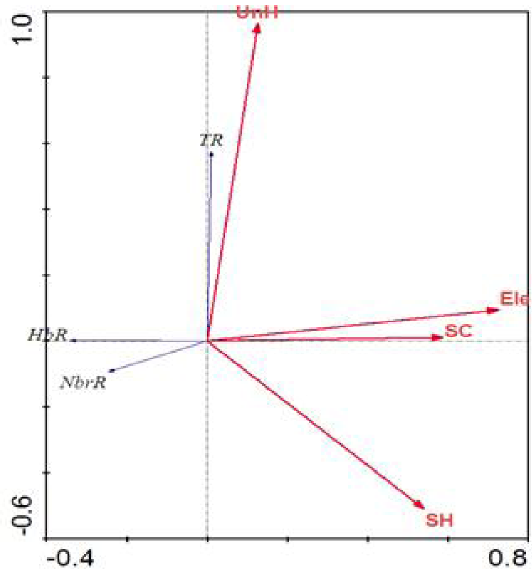

Figure 5. Ordination biplot (RDA) of cork oak trees and plot environmental variables: (TR: tree recovery, NbrR: number of resprouts, HbR: height of the biggest resprout, UnH: Understory height, Ele: Elevation, SC: Soil color and SH: Soil humidity).

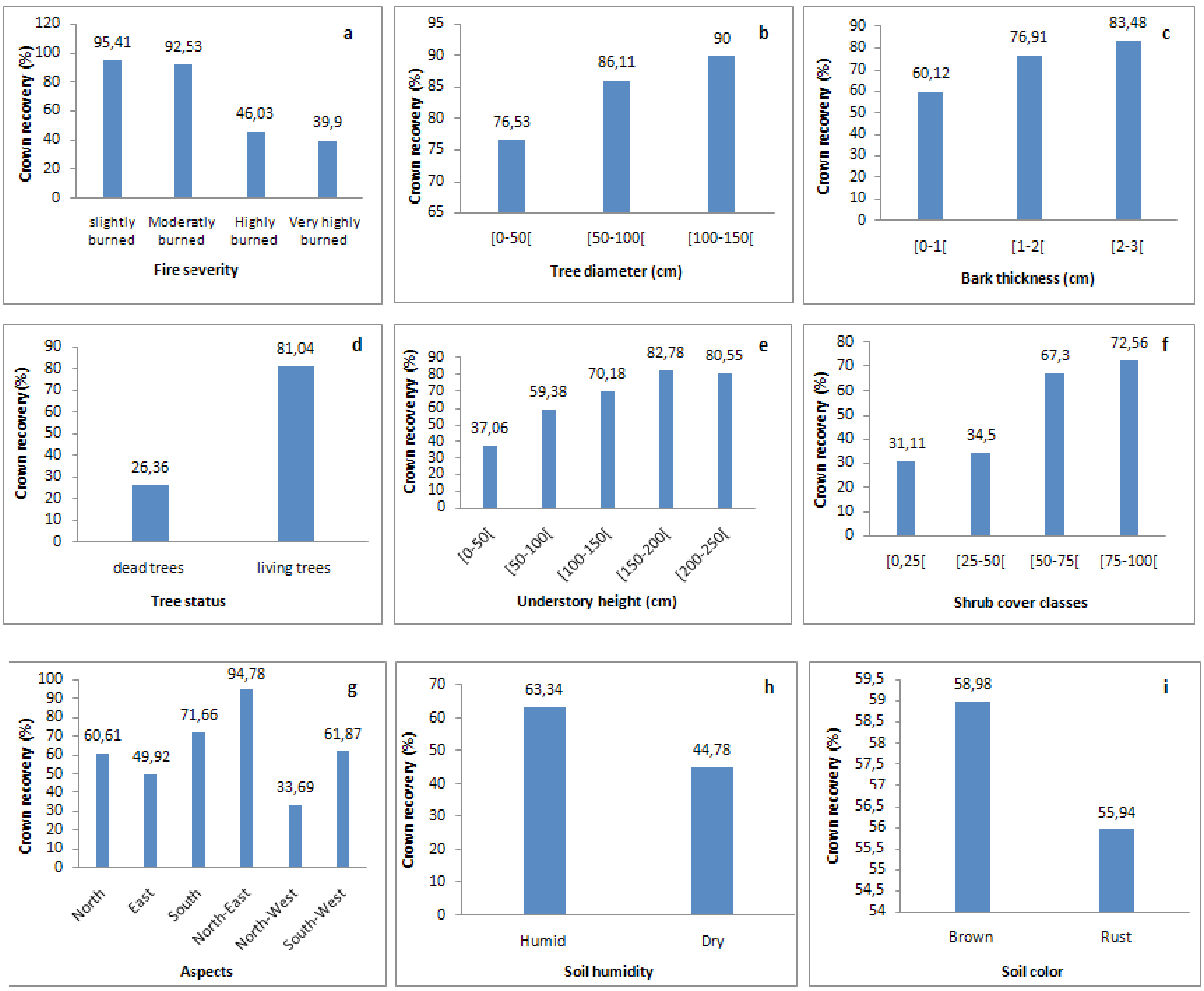

Figure 6. Percentages of trees presenting post-fire crown recovery for each of the highly correlated variables.

Kiadi cork oak basal resprouting

From all of the Kiadi cork oak trees, 23.7% showed basal resprouting with different rates. The result of the RDA highlighted the fire severity as a main factor affecting this type of post-fire tree response (Figure 4). The number of the basal resprouts increased with fire severity (Figure 7a). Trees burned from crown only resprouted better than trees with dead stems (Figure 7b), although these later ones had some signs of resprouting. Tree basal resprouting ability was highly and negatively affected by tree diameter (Figure 7c), the youngest trees, which had smaller trunk diameters, showed a higher number of resprouts than larger trees. The evaluation of the impact of environmental variables on cork oak resprouting (RDA analyses) showed the influence of the mean soil humidity measured during the first six months after fire on the resprouting ability of trees (Figure 7d), while it is better in brown soils rather than in rust ones (Figure 7e). Furthermore, the study pointed out that recovery of the understory species (Figure 7f) was negatively correlated with resprouting tree response; the higher the understory, the lower the resprouting ability. The orientation of plots has shown an important relation with the resprouting ability of trees (Figure 7g).

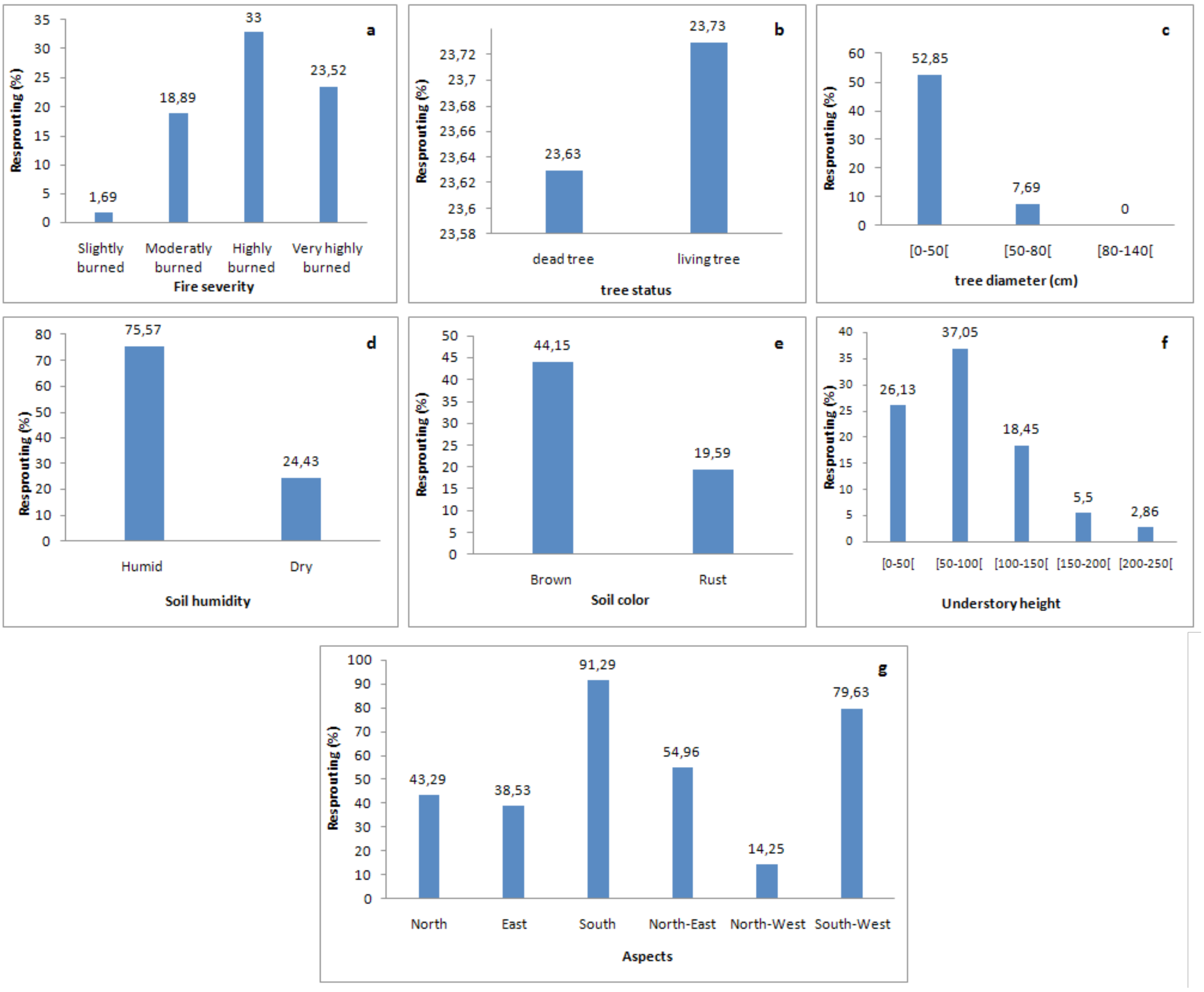

Figure 7. Percentages of trees presenting post-fire resprouting for each of the highly correlated variables.

Relation between Kiadi cork oak crown recovery and basal resprouting ability

The results of the X^2 test have shown that crown recovery was independent of basal resprouting of trees (p-value < 0.05). There was no correlation between the two types of cork oak post-fire responses. The same single tree could simultaneously present both types of regeneration (Figure 8).

Figure 8. Histogram displaying the relation between the two types of cork oak post fire responses (the resprouting ability variability in function of crow recovery).

Discussion

The results of our study revealed that *Quercus suber* is a very resilient species to fire. Overall, it resprouted from the crown and some of them presented resprouting from underground buds. There was no negative correlation between the two regeneration types on the same individual: the development of one type didn't exclude the development of the other. Since the studied cork oak trees recovered highly from the crown, it can be considered as a key plant trait that allows immediate regeneration of the species and ensures the resilience of the cork oak forest (Pausas & Keeley, 2017). Our data do not allow quantification of fire induced mortality, but they suggest that mortality of *Quercus suber* by fire is very low. A number of arborescent individuals stand out from this pattern and resprout from the trunk or branches in the crown canopy even after a high-intensity fire.

Factors affecting the post-fire response of cork oak could be related (1) to individual tree related variables, (2) to various site related variables, and (3) to fire related variables. Bark thickness is global, a key adaptation to fire (He *et al*., 2012) and a major determinant of post-fire response for cork oaks (Moreira *et al*., 2007). The bark insulates the tree from the fire. Insulating capacity increases with bark thickness (Dickinson & Johnson, 2001; Silva *et al*., 2005) thereby providing a higher level of protection to both the buds and the living tissues in the cambium on which resprouting is strongly dependent. The RDA result ruled out the bark thickness parameter, showing that it does not impact the crown and basal cork oak post-fire regeneration modes. Since in our study area, trees have almost a similar bark thickness (i.e., above 4 cm), we presumed that the studied trees had the same level of protection by their bark. This was pointed out previously by Moreira *et al*. (2007), who found that trees with bark thickness above 4cm are well protected against heat injury and are very unlikely to die or suffer stem mortality.

It was hypothesized that stripping would be a strong determinant of the expected level of post-fire damage on trees since the process of extracting highly insulating cork oak initializes major periodic stresses across the life span of a tree (Costa *et al*., 2004; Moreira *et al*., 2007). However, *Quercus suber* is a very special species because the regular bark extraction for cork production makes this species particularly vulnerable to fire (Pausas, 1997; Catry *et al*., 2009). Our results have shown that the bark thickness is not related to tree resprouting and recovery. This might be explained by the fact that when trees have thinner bark they are not exploited and in case of stripping, the presence or absence of a thin bark is acting similarly on trees responses after fire. Another explanation would be that the stripping process in our study area was properly performed, as trees do not suffer from wounds after the stripping operations. Costa *et al*. (2004) have shown that cork stripping damage has negative effects on tree health and growth.

Trees with larger stem diameters usually have thicker bark and, thus, higher post-fire survival (Dickinson & Johnson, 2001). Similarly, in our work, trees with larger DBH had higher survival probability. To recover and support regrowth, a plant needs surviving meristems and stored carbohydrate reserves (Bond & Midgley, 2001). Older plants should have higher below-ground reserves (Gurvish *et al*., 2005) and, consequently a higher capacity to mobilize them in response to disturbance (Bellingham & Sparrow, 2000). The relation between the basal resprouting of cork oak trees and the tree size was found negative; the higher the diameter of trees, the lower the basal resprouting. This result could be explained by the fact that the biggest trees were less damaged by fire, so they are resprouting from their canopy crown. On the other side, the youngest ones were more damaged by the fire and consequently used their below-ground reserves to recover from bases (Kauppi *et al*., 1988; Johansson, 2008).

The topographical characteristics of the studied area were important variables defining post-fire crown regeneration and basal resprouting of cork oak trees. As shown in other studies (Rothman, 1983; Viegas, 2004), cork oak survival decreases with slope because, in steeper slopes, water retention is lower and fire spreads faster and with higher intensity. Steeper slopes are more susceptible to soil erosion and nutrient loss, so soils are usually thinner and less productive (Shakesby, 2011). These harsher conditions could reduce tree vigor and, consequently their ability to produce and maintain viable basal resprouts (Catry *et al*., 2013). On the other hand, this parameter was positively related to crown recovery which might be explained by the fact that the variation in the slope was not that wide to influence the condition of the crown. Plot's orientations didn't reveal any impact on the post-fire regeneration, either with a crown or basal resprouting. Previous studies showed that in the Mediterranean basin, South facing slopes receive higher solar radiation, and hence plants are exposed to increased temperature and reduced water availability (Kutiel & Lavee, 1999; Sternberg & Shoshany, 2001). Our results can be explained by the presence of suitable plot characteristics, within our study area, allowing the resprouting of the species in slopes of all aspects.

Soil characteristics are significant predictors of cork oak mortality and post-fire resprouting responses (Lopez & Castell, 1992; Serrasolses & Alloza, 2004; Moreira *et al*., 2007). In this study, the color and humidity of the soil directly influenced species regeneration. Soil color was highly and significantly related to the regeneration of the species; both crown recovery and basal resprouting were better in brown soils rather than in rust ones because, brown forest soils tend to develop mainly on mature forests, contributing to the development of deep plant roots and consequently the easy access to groundwater and nutrients (David *et al*., 2007). The canopy crown recovery was better under well-drained soils, which tend to have higher holding capacity (Pereira & Tomé, 2004). The high rate of water availability in the soil after fire proves that the plot was not very heated by fire, favoring the recovery of the trees. Under high fire severity, the soil dries out more quickly, weakening or damaging the root system of trees. Consequently, the canopy crown recovery gets low and leaves place to the basal resprouting (Moreira & Martins, 2005).

In the study area, the environmental factors were simultaneously favorable to the post-fire tree recovery and to the understory. Fire stimulates soil mineralization, thus, promote consequently, the regrowth of all vegetation. In contrast, Rothermel (1983), Catry *et al*. (2006), Moreira *et al*. (2007) and Pleininger *et al*. (2010) demonstrated that, in general, variables related to the standing structure are significant predictors of cork oak mortality because fire severity usually, increases with increasing understory height. Our work showed the opposite, which might be a consequence of the crown recovery simultaneous correlation with the understory height positively and with the basal resprouts negatively.

It is commonly known that tree mortality can be immediate or delayed for some time after fire occurrence, and it can also vary with species, pre-fire vigor of trees and fire severity. As previously discussed by Catry *et al*. (2013), tree status was negatively correlated with crown and basal resprouting on cork oak trees, with a better regeneration in the considered alive tree. In the present study, trees appeared to die immediately after the fire and showed crown and basal regeneration six months later. This result concludes that cork oaks can regenerate even though they may need some time to achieve it. Pintus & Ruiu (2004) suggested that it is important to allow adequate time to trees for their response to fire before making any decision on post-fire management.

Fire severity plays a significant role in cork oak tree reaction after the fire. In the present study, trees with a good crown recovery were those less affected by the fire. Intense fire limits plant regeneration engenders tree death (Pausas *et al*., 2009) and considerably affects species' population dynamics (Gill *et al*., 2009). Moreira et *al*. (2008) proposed a conceptual model of cork oak vegetative individual response after fire, indicating that every response is a function of the fire severity and damage on tree. On the other hand, fire severity is highly and positively correlated with the basal resprout appearance. It is often assumed that the higher the intensity of the disturbance, the lower the height at which buds resprout new shoots (Bellingham & Sparrow, 2000). Consequently, after a severe disturbance, most resprouting species resprout from buds located at the plant's root crown (Pausas & Keeley, 2017). Although there is relatively little information about the effect of fire severity on the number of basals resprouts, previous studies showed that different tree species might respond differently to increasing fire severity (Masaka *et al*., 2000).

Conclusion

In conclusion, our research showed that most cork oak trees inside Kiadi forest recovered their green biomass and resprouted from the disturbance. Moreover, this work provides a better idea of how cork oak responds after fires. The two post-fire regeneration modes were present differently without any correlation between them; however, they were related to tree and plot variables. Obtained results provide evidence of a strong impact of fire severity on the cork oak tree post-fire responses.

Results from this study are useful to forest managers and authorities as they provide data about Kiadi cork oak forest post-fire recovery and the importance of ensuring the sustainability of the forest in the context of fire risk. Cork oak post-fire restoration is necessary, mainly through assisting natural regeneration. Compared to planting, the management of resprouting is a powerful technique to restore cork oak Mediterranean forests, with several advantages. Furthermore, well-studied tree bark stripping techniques should be applied on trees with sufficient cork thickness at an adequate period. Ultimately, understanding the post-fire response of cork oak trees to variations of fire severity provides managers with valuable information not only for predicting immediate post-fire crown recovery of the species but also for forecasting potential forest structure and dynamics for decades into the future.

Quercus suber is probably one of the species best adapted to fire because of its low mortality and ability to resprout and recover. It is the only Algerian tree that resprouts from above-ground buds; it contributes towards the resilience of forest landscapes to fire.

Acknowledgements

The Algerian government has provided support for an internship of one month at the faculty of biology, National and Kapodistrian University of Athens, Greece. This paper is dedicated to the memory of Dr. Messaoudene Mahand (1954–2016), forest researcher at the National Institute of Forest Research "INRF", Azazga, Algeria.

Author contribution

T.D.: Conceptualization, data collection, investigation, funding acquisition, analysis performance,writing; D.K.: Conceived and designed the analysis, analysis performance; M.A.: Methodology, writing-review and editing; M.M.: Conceptualization, methodology, funding acquisition; F.K.: Writing, review and editing, supervision.

Conflict of interest

None.

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