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# Impact of different factors degrading cork oak stands in the Mediterranean region: A case study from Algeria

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**Abstract:** In recent years, the cork oak forests that characterise the Mediterranean region have been exposed to various factors that result in their degradation. These cork oak trees, due to increasingly accentuated anthropogenic activity, undergo withering at different scales.The objective of the study is to assess the impact of various factors that degrade cork oak forests in the Mediterranean region located in northeastern Algeria, and this was achieved by prospecting 22 sampling locations. This allowed the creation of a database containing 745 trees that were observed and 27 measured variables. Different readings were then taken into consideration based on measurements and sometimes on ratings. The impact of several biotic and abiotic factors, which affect and damage the health of cork oak, was identified. These factors include in particular the infestations by xylomycetophagous insects such as *Platypus cylindrus* and *Xyleborus* sp., which can potentially infest the cork oak trees that we observed one year after bark harvesting. On the other hand, the stationary descriptors such as altitude, slope, exposure, etc., are important for the dendrometric and exploitation characteristics, but their unfavourable values do not necessarily lead to tree mortality; for example, medium to low slopes, associated with average altitudes of 600 m a.s.l., may ensure the healthiest trees like in our case study. Finally, we were able to find that certain decline factors may affect a particular category of trees, either because they are older, taller or have a large girth, or because they are subject to inadequate debarking.

**Keywords:** Algeria; *Quercus suber* L.; dieback factors; phytosanitary constraints; insect pests

Forest diebacks have become a major environmental theme since the 1980s (Bénézit 1991; Landmann 1991). They are defined as phenomena caused by a set of factors interacting and succeeding one another in a particular way and leading to general deterioration (notably in appearance and growth) and gradual deterioration, often ending in the death of the tree (Manion 1981).

In the Mediterranean region, forests are particularly greatly affected by these plagues under the impact of multiple pressures, acting concurrently and in many cases chronically, often making it illogical to search for a single cause (Desprez-Loustau et al. 2006; Raffa et al. 2008). These forests share multiple common traits related to climate, soil and floristic composition, but they also share many health problems such as insect pests, diseases, other biotic factors (such as invasive woody species or grazing) and abiotic factors (such as fires, pollution or other disasters) (Plan Bleu 2009; Briens, Garavaglia 2013; FAO et Plan Bleu 2020).

For this region around the Mediterranean, forest dieback is highly dependent on global changes (changes in societies and lifestyles combined with climate change), and it has become a serious ecological and socioeconomic problem (Vennetier 2012). The disappearance of the forest increases soil erosion, destroys some of the flora and fauna

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and has a negative influence on the climate and water resources (Garavaglia, Besacier 2014).

Taking the example of cork oak forests, the first findings of their decline date back to the 1960s (Becker, Lévy 1982; Delatour 1983), however, the phenomenon was not clearly recognized until the 1980s and 1990s and seemed to accelerate again as early as in the 2000s. The percentage of affected areas varies by location and the severity of damage varies as well, including loss of vigour, defoliation and mortality in some cases (Doufène 1998). Since then, the decline of oak in these Mediterranean forest ecosystems has been considered a major concern for managers, landowners and researchers, as in recent decades a decline in oak vigour and increased mortality have threatened these forests and, consequently, the goods and services provided by these systems (Avila et al. 2017).

The decline of cork oak (*Quercus suber* L.) has become a problem of the whole Mediterranean region, referring to various studies on its health and dieback problem that have already been conducted in the countries of its range such as Spain (Luque, Girbal 1989), Portugal (Barros et al. 2002), Italy (Moricca et al. 2016) and Tunisia (Touhami et al. 2020). Some studies were done in Algeria, such as Ghanem et al. (2016) and Daas (2015), conducted in the north-east of the country, and Bouhraoua (2003) and Belhoucine et al. (2011), which were done in the northwestern region. According to these different studies, there are two interdependent groups of factors that affect cork oak forests: intrinsic factors, such as tree aging and gland irregularity, and extrinsic factors, which are biotic and abiotic stresses such as insect pests, fungal diseases and fires.

The combined effects of these different factors will directly or indirectly lead to a gradual reduction in tree vigour, thus promoting the survival of biotic agents that accelerate dieback (Jamâa et al. 2005; Gil, Varela 2008; Catry et al. 2017). Such biotic agents include insect pests which attack leaves, fruits and trunks. According to Daas et al. (2016), the action of some phytophagous beetles (e.g., *Curculionidae, Tortricinae* and *Lymantriinae)* is one of the main causes of defoliation; xylophages weaken the trees, and gland pests have a direct impact on regeneration.

However, the causes for decline of *Q. suber* L. are not clear yet. Climate change and forest fires are certainly having a major impact all over the world, but for the Mediterranean cork oak we also point out other strong pressures such as overgrazing, increases in the outbreaks of disease and the exploitation problems, which are documented in Tunisia, Morocco and even in Portugal and other countries (Bonneau et al. 1988; Jamâa et al. 2005; Papanastasis 2009; Kim et al. 2017). The objective of this study is to assess the impact of various factors that cause degradation and withering on the health of cork oak trees. The study was carried out in a Mediterranean environment in which the cork oak trees were ecologically distributed. Specifically, the study was conducted in the northeast of Algeria, which is recognized as an important agroforestry location and has a strong history of growing cork oak trees.

## MATERIAL AND METHODS

### Study area

The study sites are located precisely in the Jijel region, in northeastern Algeria, between latitudes 36°10' and 36°50'N and longitudes 5°25' and 6°50'E. It is a forest-oriented region, where cork oak is the main species, occupying almost 79% of the total forest area (Figure 1). Cork oak in Jijel enjoys a temperate climate with mild winter and significant rainfall, which is characteristic of Mediterranean areas. Temperatures range from 20 °C to 35 °C in summer and 5 °C to 15 °C in winter, while the average annual rainfall varies from 800 to 1 200 mm·year$^{-1}$ spread over a period of about six months.

The studied forest is monospecific, dominated by only one species of cork oak, that has a density

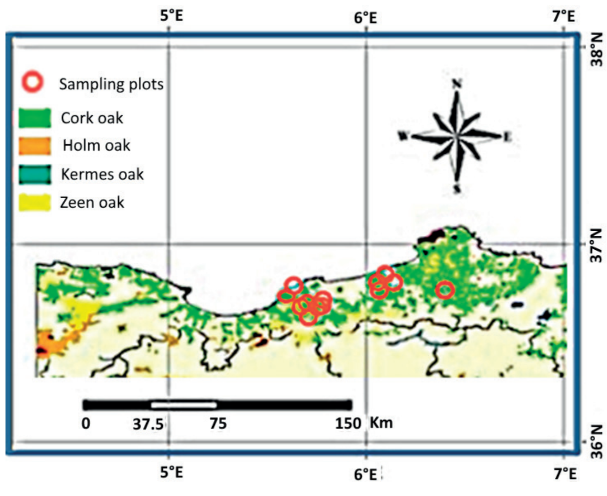


Figure 1. Location of sampling plots in the study area, situated in the north-east of Algeria and its main forest ecosystems

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from 150 to 350 trees per ha. The age of its stands is unevenly distributed, ranging from mature to old trees of great size (60 to 150 years). The main part of trees have already been stripped several times, and the usual cork harvesting cycle in the region is 8 to 10 years, for which we were able to point out different damage of faulty exploitation.

**Sample and variables**

A total of 22 sample plots were considered in this study, forming part of 12 study sites corresponding to distinct forest districts (Figure 1, Table 1).

The study sites were selected in the supposedly natural habitat of the species, taking into account certain stationary and forest variables (e.g., altitudinal gradient and bark harvesting period) on the one hand, and the presence of insect pests such as xylomycetophagous ones on the other. According to the objective of the study, which is to look for a combination of factors degrading cork oak, it is suggested that we will address the following points:

(*i*) The impact of bark harvesting compared to a reference station that has never been debarked (P16).

(*ii*) The impact of xylomycetophagous insects by comparing infested and non-infested sites.

(*iii*) The effect of biotic (undergrowth and anthropozoogenic actions) and abiotic interactions (slope, exposure, altitude, fire passage, etc.).

The number of plots per site depends on the homogeneity and size of each forest district. For example, sometimes we opt for four plots if there are different exposures and the forest environment is large enough, whereas for other sites only one plot was sufficient if the habitat is homogeneous enough and the stand is not very large.

Table 1. Stationary characteristics of 22 plots selected according to 12 study sites

| Plot No. | Site No. | Altitude (m) | Slope (rating) | Exposure | pH | OM (%) | EC (μs) | Undergrowth | Natural seedlings | Human disturbance | Pasture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (ratings) | | | |
| P01 | 1 | 830 | 3 | N | 5.7 | 12.6 | 15.1 | 3 | 4 | 3 | 2 |
| P02 | | 840 | 2 | S | 5.8 | 12 | 22.2 | 2 | 2 | 3 | 3 |
| P03 | | 887 | 2 | N | 5.7 | 12.7 | 19.7 | 2 | 3 | 3 | 1 |
| P04 | | 887 | 3 | S | 6.0 | 13.9 | 14.7 | 3 | 2 | 1 | 0 |
| P05 | 2 | 895 | 4 | S | 5.5 | 11.8 | 31.1 | 1 | 1 | 2 | 2 |
| P06 | | 915 | 3 | N | 5.7 | 13.9 | 44.9 | 2 | 1 | 4 | 4 |
| P07 | 3 | 475 | 1 | N | 5.5 | 55.2 | 30.7 | 3 | 3 | 3 | 4 |
| P08 | | 491 | 2 | N | 6.2 | 9.76 | 29.7 | 3 | 4 | 1 | 2 |
| P09 | | 475 | 2 | N | 6.0 | 7.88 | 30.5 | 2 | 4 | 1 | 1 |
| P10 | | 453 | 1 | N | 6.1 | 10.8 | 26.4 | 2 | 3 | 4 | 4 |
| P11 | 4 | 51 | 2 | N | 6.1 | 5.82 | 16.7 | 3 | 4 | 0 | 0 |
| P12 | | 35 | | NE | 6.2 | 7.81 | 24.8 | 4 | 3 | 0 | 0 |
| P13 | 5 | 833 | 4 | SW | 6.9 | 18.8 | 26.1 | 3 | 2 | 1 | 2 |
| P14 | 6 | 165 | 4 | N | 5.8 | 11.7 | 42.2 | 2 | 1 | 3 | 4 |
| P15 | 7 | 630 | 1 | SE | 6.3 | 11.2 | 18.2 | 0 | 1 | 4 | 2 |
| P16 | 8 | 37 | 3 | N | 6.5 | 34 | 42.1 | 1 | 1 | 3 | 3 |
| P17 | 9 | 531 | 1 | N | 6.1 | 24.5 | 30.3 | 1 | 2 | 2 | 3 |
| P18 | 10 | 602 | 3 | S | 6.5 | 38 | 27.2 | 1 | 2 | 0 | 1 |
| P19 | 11 | 751 | 2 | SW | 6.3 | 18 | 43.4 | 2 | 2 | 0 | 1 |
| P20 | | 751 | 2 | S | 6.2 | 18.6 | 48.2 | 2 | 1 | 2 | 3 |
| P21 | 12 | 494 | 2 | SE | 6.8 | 12.5 | 67.1 | 2 | 1 | 0 | 0 |
| P22 | | 494 | 2 | SE | 6.6 | 10.7 | 65.4 | 2 | 1 | 0 | 0 |

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With regard to the size of the sample plots, since our forests are quite dense, we opted for circles with a radius of 20 m, which covers an area of 1 256 $m^2$.

Within each plot, we carried out several surveys of different types (measures, ratings, or observations). These surveys are divided into two main categories, one of which characterizes the observation plots (stationary surveys) and the other is characteristic of sample trees. This corresponds to a set of variables giving information on the health status of the cork oak and thus explaining the problem of its dieback.

*Plot variables.* Different ecological descriptors characterizing each sample plot were considered, assigning them a corresponding assessment from data already provided, laboratory analyses or direct field observations (Tables 1 and 2). The measured variables were: (*i*) altitude (m; recorded with a GPS in the centre of each plot); (*ii*) pH (measured with a pH meter at a 1 : 2 soil to water suspension ratio); (*iii*) organic matter (measured by using the weight lost by an oven-dried (105 °C) soil sample when it is heated to 400 °C); (*iv*) electrical conductivity (measured with a conductivity meter at a 1 : 5 soil to water suspension ratio). The other plot variables were evaluated on the basis of rating scales.

*Tree variables.* Several parameters of each sampled tree were assessed during the period from March to June 2017, except for the observation of the insect infestation which lasted for next 2 years (until the year 2019). These include dendrometric and exploitation measurements, combined to surveys characterising the health state of the crown and trunk as summarised in Table 3.

The whole set of surveys that were recorded were: (*i*) trunk diameters and circumferences (taken from the forest compass at breast height, about 1.30 m from the ground); (*ii*) total height of trees (taken with a Blum-Leiss instrument but sometimes it was estimated visually; (*iii*) debarking height; (*iv*) number of debarkings (counting of the number of times the cork layer was harvested); (*v*) defoliation or leaf loss (this evaluation consists of cutting the tree crown into four homogeneous zones, estimating the losses per zone and then defining the score); (*vi*) discolouration or abnormal colouration (it was carried out in the same way as defoliation, for which the crown was cut into four equal zones, then the proportion of foliage showing abnormal discolouration was estimated for each zone, and the four zones were added together to define the corresponding score); (*vii*) traces of fire (the presence or absence); (*viii*) number of stump releases; (*ix*) number of stump releases; (*x*) number of xylophagous holes; (*xi*) number of active ambrosiophagous holes; (*xii*) surface of cork dehiscence (proportion of the trunk area without cork bark regrowth); (*xiii*) presence of cracks (missing part of the trunk corresponding to the altered wood).

The variables characteristic of the trunks were taken by observing the trees from the base to the height of the first branches (from 0 to 3 m at maximum). Each trunk was examined and described using a number of parameters as summarised in Table 3.

*Variable of the dieback level.* It is a synthetic variable that provides information on the degree of dieback (DDep) based on the levels of defoliation and discolouration, tree defects (deformation or reduc-

Table 2. List of selected variables for each sample place

| No. | Code | Variable | Measuring units / Rating scales |
|---|---|---|---|
| 01 | Alti | altitude | metres (m) |
| 02 | Slop | slope | 0 – none to very low (0%–3%); 1 – low (4%–9%); 2 – moderate (10%–15%); 3 – steep (16%–30%); 4 – very steep (> 31%) |
| 03 | Expo | north exposure | 0 – other exposure; 1 – north exposure |
| 04 | pH | pH | value |
| 05 | OM | organic matter | % |
| 06 | EC | electrical conductivity | µs |
| 07 | UnGr | undergrowth | 0 – absent to very low (0%–10%); 1 – low (11%–25%); 2 – medium (26%–50%); 3 – dense (51%–75%); 4 – very dense (> 75%) |
| 08 | NaSe | natural seedlings | 0 – no young seedlings; 1 – low number; 2 – medium; 3 – high number; 4 – very high number |
| 09 | HDis | human disturbance | 0 – no sign; 1 – low; 2 – medium; 3 – strong; 4 – very strong |
| 10 | Past | pasture | 0 – no grazing; 1 – low; 2 – medium; 3 – strong; 4 – very strong |

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Table 3. List of selected variables for cork oak sample trees

| No | Code | Variable | Measuring units / Rating scales |
|---|---|---|---|
| 11 | Heig | total height | metre (m) |
| 12 | Circ | circumference | metre (m) |
| 13 | Deba | debarking | 0 – not debarked; 1 – debarked |
| 14 | DebH | debarking height | metre (m) |
| 15 | DebN | number of debarkings | value |
| 16 | FirT | trace of fire | 0 – absent; 1 – present |
| 17 | Stum | number of stump releases | 0 – no releases; 1 – low (1–4 releases); 2 – medium (5–10); 3 – high (11–20); 4 – very high (>20) |
| 18 | Defo | defoliation | 0 – none (0%–10%); 1 – low (11%–25%); 2 – medium (26%–60%); 3 – high (61%–95%); 4 – total (100%) |
| 19 | Disc | discolouration | 0 – none (0–10%); 1 – weak (15%–25%); 2 – medium (30%–60%); 3 – strong (65%–95%); 4 – total (100%) |
| 20 | XylH | number of xylophagous holes | 0 – none; 1 – low (1–10); 2 – medium (11–30); 3 – high (31–50); 4 – very high (>50) |
| 21 | AmbH | number of active ambrosiophagous holes | 0 – none; 1 – low (1–10); 2 – medium (11–30); 3 – high (31–50); 4 – very high (>50) |
| 22 | SCoD | surface of cork dehiscence | 0 – none; 1 – weak (1%–10%); 2 – medium (11%–25%); 3 – strong (26%–50%); 4 – very strong (>50%) |
| 23 | PCre | presence of crevices | 0 – none; 1 – weak (1%–10%); 2 – medium (11%–20%); 3 – strong (20%–30%); 4 – very strong (>30%) |
| 24 | Flow | various flows | 0 – absence; 1 – presence |

tion in growth) and pathological problems. The evaluation of this variable was established by adopting the DEPEFEU method, which is a protocol referring to the rating of different criteria (damage), whose synthesised average gives a final score that can take five categories of dieback (Table 4): 0 – healthy tree, 1 – mild dieback, 2 – moderate dieback, 3 – severe dieback and 4 – standing dead tree (Nageleisen 2000; Frank et al. 2005; Hamidi et al. 2014).

**Data analysis**

Through this study, we have compiled a database containing a total of 745 trees; also qualified as the number of observations and 27 variables based on measurements and ratings. This database is subsequently used for statistical analyses according to two guidelines:

(*i*) The first is to perform an analysis of variance with one classification criterion (one-way ANOVA) to determine whether there are significant differences for the dependent variable "the proportion of each tree category per plot", which we hope will explain the variability by the qualitative explanatory variable "dieback class" on the one hand, and by the variable "core condition" on the other. This analysis is followed by a test of multiple comparisons, which we have opted for Tukey's test.

(*ii*) The second principle is Principal Component Analysis (PCA), which is one of the most widely

Table 4. List of variables for tree health assessment

| No. | Code | Variable | Rating scales |
|---|---|---|---|
| 25 | DieC | dieback classes | 0 – healthy tree; 1 – slight dieback; 2 – moderate dieback; 3 – severe dieback; 4 – dead trees |
| 26 | HeTr | healthy tree | 0 – not healthy; 1 – healthy |
| 27 | DeTr | Dead Tree | 0 – not dead; 1 – dead tree |

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used methods of multivariate data analysis for finding out which variables show an effect on the health status of trees. It is an exploratory analysis of data, with the objective of analysing correlations between variables and identifying states that differ from the others.

The data were analysed by statistical software XLSTAT (Version 2016, 2016).

## RESULTS

On the basis of the acquired data, a distribution of different tree vitality classes in each sample plot was initially generated (Table 5). Figures 2 and 3 illustrate some symptoms and damage observed on our sample trees.

The observed degree of dieback indicates that the proportion of different tree classes varies according to the plots. An analysis of variance revealed very highly significant differences, for which different homogeneous groups (A, B, BC and C) could be identified (Table 5, Figure 4). Healthy trees predominated (group A; 52.98%), followed by moderately dying trees (group B; 18.4%), severely and slightly dying trees (group BC; 11.58% and 11.70%, respectively), and dead trees (group C; 5.34%). However, plots 17, 18, 19, 20, 21 and 22, which were attacked by xylomycetophages, showed the most severe dieback, with values ranging from approximately 20% to 58.6%.

Analysis of variance of the phytosanitary condition of the trunks showed very highly significant

Table 5. Distribution of dieback classes and trunk condition for each plot expressed as a proportion (%) of observed trees

| Plot No. | Dieback classes*** ($F$ = 34.42; $P$ < 0.0001) | | | | | | Trunks state*** ($F$ = 54.09; $P$ < 0.0001) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | healthy trees | slight dieback | moderate dieback | severe dieback | dead trees | debarked trees | ambrosiophagous holes | holes of other xylophages | diverse flows | presence of crevices | dehiscent cork |
| 1 | 30.4 | 39.1 | 15.2 | 8.7 | 6.5 | 82.6 | 0.0 | 47.8 | 39.1 | 67.4 | 47.8 |
| 2 | 62.2 | 6.7 | 15.6 | 8.9 | 6.7 | 75.6 | 0.0 | 35.6 | 11.1 | 17.8 | 37.8 |
| 3 | 44.4 | 28.9 | 15.6 | 2.2 | 8.9 | 97.8 | 0.0 | 17.8 | 60.0 | 77.8 | 40.0 |
| 4 | 71.2 | 9.6 | 13.5 | 3.9 | 1.9 | 86.5 | 0.0 | 17.3 | 25.0 | 46.2 | 19.2 |
| 5 | 60.0 | 2.9 | 17.1 | 5.7 | 14.3 | 94.3 | 0.0 | 40.0 | 20.0 | 51.4 | 51.4 |
| 6 | 88.2 | 5.9 | 2.9 | 0.0 | 2.9 | 100 | 0.0 | 23.5 | 14.7 | 70.6 | 23.5 |
| 7 | 87.5 | 0.0 | 9.4 | 3.1 | 0.0 | 93.8 | 0.0 | 40.6 | 21.9 | 71.9 | 46.9 |
| 8 | 82.9 | 0.0 | 4.9 | 0.0 | 12.2 | 95.1 | 0.0 | 46.3 | 31.7 | 46.3 | 48.8 |
| 9 | 86.8 | 0.0 | 7.9 | 2.6 | 2.6 | 84.2 | 0.0 | 28.9 | 18.4 | 57.9 | 42.1 |
| 10 | 65.2 | 4.4 | 17.4 | 8.7 | 4.4 | 95.7 | 0.0 | 30.4 | 8.7 | 87.0 | 43.5 |
| 11 | 80.0 | 10.0 | 7.5 | 0.0 | 2.5 | 57.5 | 0.0 | 22.5 | 10.0 | 22.5 | 32.5 |
| 12 | 55.0 | 10.0 | 20.0 | 10.0 | 5.0 | 75.0 | 0.0 | 15.0 | 25.0 | 35.0 | 30.0 |
| 13 | 60.0 | 10.0 | 20.0 | 5.0 | 5.0 | 90.0 | 0.0 | 30.0 | 10.0 | 75.0 | 35.0 |
| 14 | 45.5 | 9.1 | 22.7 | 4.6 | 18.2 | 86.4 | 0.0 | 90.9 | 31.8 | 90.9 | 90.9 |
| 15 | 56.7 | 20.0 | 10.0 | 6.7 | 6.7 | 100 | 0.0 | 63.3 | 23.3 | 83.3 | 66.7 |
| 16 | 92.5 | 2.5 | 5.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 5.0 | 7.5 | 0.0 |
| 17 | 14.6 | 9.8 | 36.6 | 34.1 | 4.9 | 100 | 12.2 | 22.0 | 17.1 | 26.8 | 70.7 |
| 18 | 6.9 | 0.0 | 34.5 | 58.6 | 0.0 | 100 | 0.0 | 0.0 | 10.3 | 55.2 | 55.2 |
| 19 | 20.0 | 32.0 | 16 | 28.0 | 4.0 | 88 | 4.0 | 32.0 | 20.0 | 28.0 | 56.0 |
| 20 | 24.4 | 13.3 | 37.8 | 20.0 | 4.4 | 95.6 | 15.6 | 53.3 | 40.0 | 55.6 | 66.7 |
| 21 | 18.2 | 18.2 | 36.4 | 27.3 | 0.0 | 100 | 27.3 | 18.2 | 9.1 | 0.0 | 63.6 |
| 22 | 12.9 | 22.6 | 38.7 | 19.4 | 6.5 | 96.8 | 6.5 | 19.4 | 3.2 | 35.5 | 48.4 |
| Avg | 53.0 | 11.6 | 18.4 | 11.7 | 5.3 | 86.1 | 3.0 | 32.0 | 20.7 | 50.4 | 46.2 |
| GH | A | BC | B | BC | C | A | E | CD | D | B | BC |

***very highly significant difference (threshold of 0.1%); Avg – estimated mean; GH – homogeneous groups (A, B, C, D, E), the same letter indicates means which are considered equal

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Figure 2. Cork oak trunk that was debarked a year ago, showing white sawdust stains caused by xylomycetophagous insects digging entrance holes

Figure 3. Dehiscent cork (naked wood) caused by old wounds being overgrown with xylophageal insects (large exit holes of the genus *Cerambyx*)

differences. A two-by-two ranking of the means revealed different homogeneous groups (Table 5). For an average proportion of 86.13% of the debarked trees, the phytosanitary state of the trunks revealed the following proportions of trees: 46.2% with dehiscent cork surface, 50.4% with cracked trunks, 32. 04% with exit holes of wood-eating insects that attacked only dead wood, 20.7% with blackish sap flow, and 2.98% with attacks in full activity by wood-eating insects that dug small holes (Figure 5).

By focusing on pest attacks, we raised two categories of insects that can infest cork oak trunks: some attack only dead wood and do not pose any real danger (e.g. all the aforementioned cases of *Cerambyx*), whereas others attack live wood and pose a great threat to trees. These insects are

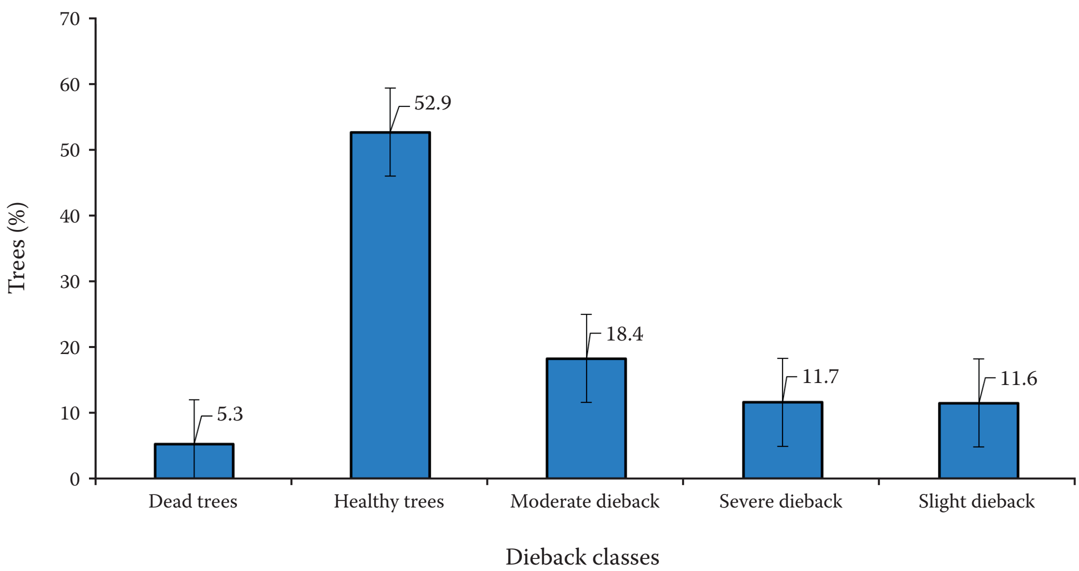


Figure 4. Proportion of trees by different health classe

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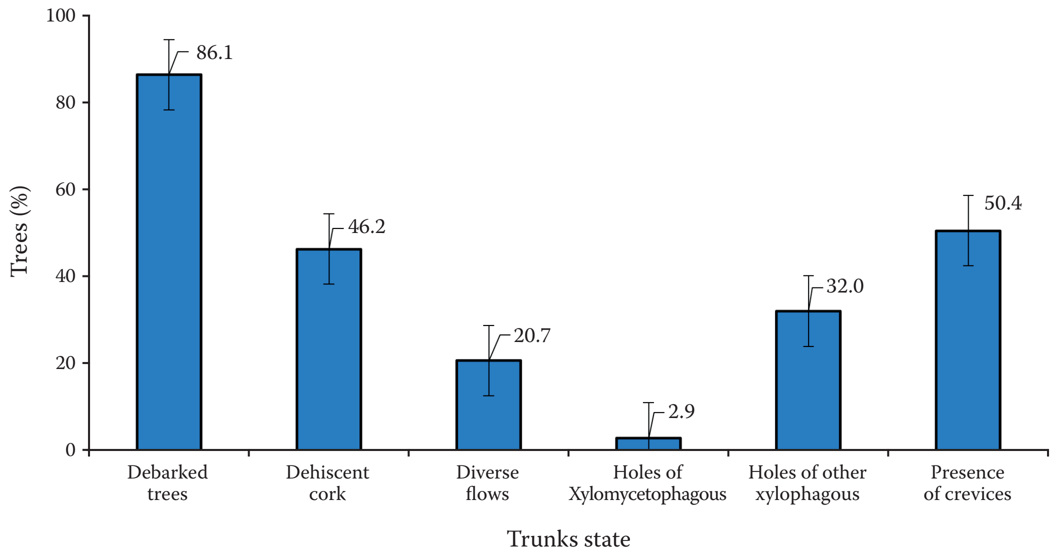


Figure 5. Proportion of trees by the trunk health status

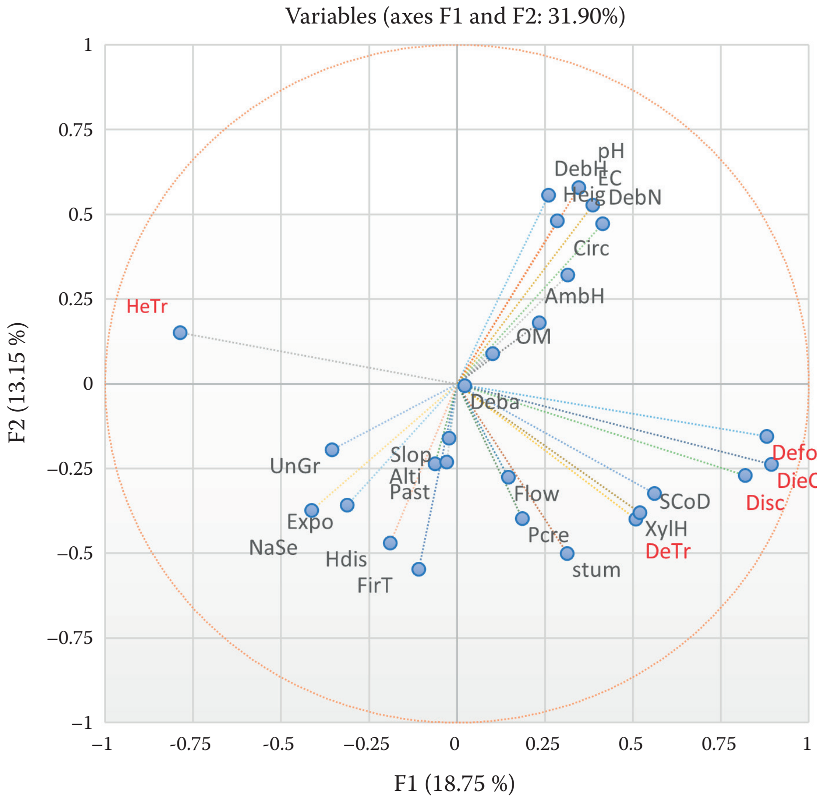


Figure 6. Representation of the different variables considered on the first and second axes (F1 and F2) of the PCA

Alti – altitude; Slop – slope; Expo – north exposure; OM – organic matter; EC – electrical conductivity; UnGr – undergrowth; NaSe – natural seedlings; Hdis – human disturbance; Past – pasture; Heig – total height; Circ – circumference; Deba – debarking; DebH – debarking height; DebN – number of debarkings; FirT – trace of fire; Stum – number of stump releases; Defo – defoliation; Disc – discolouration; XylH – number of xylophagous holes; AmbH – number of active ambrosiophagous holes; SCoD – surface of cork dehiscence; PCre – presence of cracks; Flow – various flows; DieC – dieback classes; HeTr – healthy tree; DeTr – dead tree

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xylomycetophagous pests, and the following species have been captured: *Xyleborus monographus*, *X. dryographus*, *X. saxeseni*, *Platypus cylindrus, Colydium elongatum* and *Oxylaemus cylindricus*.

To analyse ecological interactions that can affect the health of cork oak and, thus, the degree of dieback, we used principal component analysis (PCA) to explore 27 variables and 745 trees observed in our database.

According to the first two factorial planes retained, F1 and F2, the quality of the projection obtained after shifting from 27 variables to a smaller number of dimensions was represented by the total inertia rate of 31.90. The first and the second eigenvalue for the F1 and F2 axes was 5.06 and 6.75, representing 18.75% and 19.297% of the total variability, respectively.

The correlation circle (Figure 6) corresponding to the first two main components of the PCA highlighted variables with significant correlations. The points closest to the circle were more correlated with respect to variables close to the centre of the graph.

The first factorial plane (F1 axis) correlated well with the variables characteristic of the health state of the trees (Healthy, Dead, Defo, Decolon, SCoD, DieC, Stum, AMBH and XylH).

The degree of dieback is a synthetic indicator which reflects the health state of cork oak. It seemed to be influenced by the increase in the last parameters (Defo, Disc, SCoD, AMBH and XylH) but not by stationary parameters (FirT, pH, OM, EC, Slop, Alti, UnGr, HDis, Past, NaSe and Expo) or dendrometric and exploitation characteristics (Heig, Circ, Deba, DebH and DebN), which showed no significant correlations.

Cork oak has the particularity of stump sprouting to preserve its regeneration in response to constraints that lead to its mortality or accelerated deterioration. This finding was observed through positively significant correlations between variables quantifying damage to tree health (XylH, Flow, PCre and SCoD) and the aptitude of stump sprouting (Stum).

The correlations corresponding to the F2 axis of the factorial plane concerned the projection of the variables characterising the stationary descriptors on the one hand (FirT, pH, OM, EC, Slop, Alti, UnGr, HDis, Past, NaSe, Expo) and the dendrometric and exploitation parameters on the other hand (Heig, Circ, Deba, DebH and DebN). On the basis of the PCA graph, the following points could be raised:

(*i*) The infestation of trunks by xylomycetophagous insects was proportionally correlated both with the increase in the total circumference and height of the trees and with the number and height of harvests. In the field, *Platypus*, *Xyleborus* and other bark beetles only attacked trees that were unmasked for approximately 1 year.

(*ii*) The increase in dendrometric parameters (i.e., total circumference and height) positively influenced the quality of cork exploitation expressed in number and height. However, the cork quality seemed to be influenced by the presence of denser undergrowth.

The stationary variables characterising each plot revealed correlations in different ways. Electrical conductivity and pH positively correlated with dendrometric and exploitation parameters, whereas fire and human disturbance had a visibly negative impact. Similarly, other descriptors, such as altitude, grazing, slope and organic matter, had no significant effect.

## DISCUSSION

Forest diseases, e.g. in cork oak forest, are etiologically complex. They usually develop when trees experience stress due to interactions of several biotic and abiotic adverse factors, which gradually lead to a premature loss of tree vigour and vitality (Landmann 1991, 1994). This is commonly referred to as withering, which is an evolutionary process that gradually takes the tree from a healthy state with few symptoms to low-dieging, moderately withering, withering and highly diehard states in some cases.

Several factors may cause the symptoms and damage that we observed in our sample trees. The main factor is the infestation of trees by insect pests, which certainly causes a weakening of the trees, but does not necessarily lead to total dieback. In addition, human exploitation of cork can often cause serious injuries to the trunk, unless great care is taken. According to Cantat and Piazzetta (2005), cork harvesting is a stressor for the tree that can cause important, and sometimes irreversible, damage. The preceding statement was also observed by other authors like Catry et al. (2012); Hamidi et al. (2014); Hasnaoui et al. (2018).

Trees with cracks provide favourable shelters for different insects that lay their eggs in cork. Larvae grow in the small living layer just under the bark,

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where the sap circulates and where cork is made, as for *Lymantria dispar* (spawning, aged caterpillars and chrysalises) (Villemant, Fraval 1993). In addition, Daas et al. (2016) reported that the larvae of several *Scarabaeidae* develop in the rotten wood of old oaks (injured or even dead), as well as in stumps, and in the compost that forms in their hollows.

Furthermore, burned trees will be more vulnerable and can be colonised by bark and wood pests, leading to insect epidemics (Catry et al. 2016). According to Catry et al. (2009), fires often occur in our area and belong to the main threats to the decline of cork oak in the Mediterranean basin. According to Bouhraoua (2013), over a period of 27 years (1985–2012), forest fires ravaged a total cork oak area of about 200 000 ha or an average annual area of 7 300 ha. However, although the risk of fire is increasingly common in the Mediterranean region, the sclerophyll forests, of which cork oak is a part, are never completely destroyed after the fire passage. To prevent destruction, these forests recover from trunk and stump sprouting, while rapidly regenerating a large plant cover (Quézel 1976).

Considering the 745 trees we observed, and the 27 variables in the database, we obtained a PCA that allowed us to see which variables had a significant effect on different categories of dieback (Figure 5).

Healthy trees are negatively correlated with the level of defoliation and discoloration, as well as with an increase in xylophagous insect holes, and the presence of dehiscent cork surfaces. This surface area is, in fact, the port of entry for insect pests, and particularly for bark beetle attacks. In addition, mortality is strongly influenced by an increase in the area of cork dehiscence and infestation by xylophagous insects, thus showing a strong positive correlation with tree mortality. Matias et al. (2019) reported that the abundance of pathogens associated with tree density and the effect of rainfall determine tree mortality.

Oaks are capable of protecting themselves from death and dieback by vigorous regrowth of their stump shoots, which are usually found on trees that are 70 to 90 years old and up to 110 to 120 years old if the trees are in good condition (Marion 1956). In addition, the often abundant number of young natural seedlings in the sample plots promotes cork oak regeneration. This type of regeneration sometimes has a low yield and marked vulnerability to attacks by carpophagous insects, which affect the abundance of the acorns (Adjami et al. 2016).

According to the results, the natural seedling regeneration is best favoured in the presence of undergrowth and on northern exposures. This situation offers more moisture and shelter for the development of young seedlings. However, it has also been observed that the abundance of young seedlings has not necessarily ensured the reconstruction of cork oak forests due to multiple constraints (e.g., grazing, fire and droughts). For example, Hasnaoui (1992) found the absence of intermediate stages between seedlings and adult trees in a study of the cork oak regeneration in Tunisia.

## CONCLUSION

Cork oak is a species that occupies a limited natural area. Unfortunately, it is a forest patrimony that continues to deteriorate under the effect of many factors, leading to the disappearance of considerable areas. This disappearance is often at the origin of the problems of dieback, which can be quantified through a synthetic note of different parameters characterising the phytosanitary state of the trees.

For most forest areas showing this problem of dieback, the proportion of healthy trees is even more abundant. However, the gradual deterioration of the cork oak health is often a problem. In certain situations, it is seriously affected, leading to subsequent tree mortality under the impact of various intercorrelated factors.

Considering the infestation of trees by xylophagous insects, it is strongly correlated with bark harvesting, cracked trunks, and the presence of dehiscent cork surfaces, which are the origins of previous wounds. Certain categories of insects, including *Cerambycidae*, particularly attack the dead part of the wood, causing the weakening of the tree against physical forces (wind and weight of the tree). *Platypus cylindrus* and *Xyleborus sp.* are other categories of beetles that attack living wood and are even more dangerous. They are most often associated with trees that have been debarked in the previous year. These insects develop abundant cavities that grow in thickness and are sometimes the cause of fungal diseases and various types of flow.

Stationary descriptors certainly have an impact on dendrometric and exploitation characteristics. However, they do not necessarily have a significant effect on the degradation of the cork oak forest. Moderate to low slopes, associated with average al-

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titudes of about 600 m, will provide the most suitable trees in our case study.

Besides forest fires which have a strong impact, the most serious decline factors were the infestation by xylomycetophagous insects, the fungal diseases causing rotting and various flows, as well as the injuries of debarking that caused cracks and dehiscent cork surfaces. These factors have often affected specific categories of trees, which are generally older, larger in circumference or have a higher number of bark harvests.

The evaluation of the cork oak regeneration has informed us that it has the tendency of stump sprouting in the face of the deterioration of its health. Natural sowing is also an effective way of regeneration, given its abundance in the field, which will be even better in the presence of undergrowth and northern exposure.

Finally, being uncertain of the exact role played by each of the dieback factors, it is recommended that the contribution of each factor be further analysed and that appropriate management measures be taken. This particularly concerns the role of insect (defoliators and xylophages) and fungal (*Diplodia* and *Phytophthora*) attacks associated with inadequate cork exploitation, repeated fires, and grazing.

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