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EFFECTS OF ECOLOGICAL AND DENDROMETRIC PARAMETERS ON HOLM OAK DIEBACK IN CHETTABA FOREST (ALGERIA)

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Abstract

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Quercus ilex is a tree that shows severe symptoms of oak decline. The mechanisms causing the decline of holm oak stands were studied on a network of eight observation plots installed in the Chettaba forest in Constantine's southwestern area (Algeria). The methodology adopted was based on data collected in the field and analyzed statistically. The parameters studied were ecological (altitude, slope, and exposure), dendrometric, and sanitary (DEPEFEU protocol), in order to highlight potential interactions between these parameters. The results show that only 6.15% of trees have healthy crowns, 43.84% have moderately declining crowns, 31.15% have severely declining crowns, and 3.46% are moribund. Holm oak dieback is common at low altitudes, on steep slopes, and in east-facing exposures. Furthermore, there is probably no strong relationship between dendrometric parameters and dieback. The study of holm oak dieback in the Chettaba forest may contribute to the proposal of an appropriate management plan and the development of dynamic conservation strategies in relation to its present and future interests.

Key words: Chettaba, *Quercus ilex*, dieback, ecological, DEPEFEU.

Introduction

Forest area in Mediterranean countries stood at 88 million hectares in 2015. This represents around 2.20% of the world's forest area (FAO, 2020). It is stated that forest areas are unevenly distributed around the Mediterranean basin and are made up of a mosaic of forest species, mainly hardwoods. Oaks alone make up almost all the landscape types that are so characteristic of the Mediterranean world. Deciduous oaks are found in humid bioclimatic environments, particularly in the supra-Mediterranean zone. Sclerophyllous oaks, on the other hand, preferentially characterize the subhumid bioclimatic Eu mediterranean vegetation zone (Barbero et al., 1991).

Holm oak (*Quercus ilex* L.) is one of the species that occupy a large area on both shores of the Mediterranean basin, with more significant expansion in France, Italy, Greece, Spain, and Portugal. It is particularly abundant in North Africa, notably in Morocco and Algeria, where, along with Aleppo pine, it forms an integral part of the forest heritage (Barbero, Loisel, 1980; Roda et al., 1999). Holm oak, a sclerophyllous, evergreen species, is generally divided into two subspecies: *Q. ilex* sensu stricto, widespread from the Maritime Alps to Turkey, and *Q. ilex* sbsp. rotundifolia (Lam.), present from the Iberian Peninsula to North Africa. Populations in northwest Spain, Catalonia, Languedoc, and Provence are considered to have intermediate morphotype (Michaud et al., 1995). Due to its size and distribution over a large part of the hydrographic network, it is the best means of protecting dams and restoring soil (hydrobiological stability). Its geographical position on the edge of the degraded steppe gives it a dual role: pastoral, providing a vital forage reserve for livestock, particularly in times of shortage, and soil protection (Ezzahari, Belghazi, 2002). However, Algeria's potential area is estimated at 1,807,000 ha (Barbero et al., 1990). In 1955, it still occupied almost 700,000 ha (Boudy, 1955). Today, it covers just 354,000 ha (BNEF, 1984) or 108,200 ha (B.N.E.D.E.R, 1984), a reduction in area of between 50% and 85% in 30 years. Like many Mediterranean forests, the Holm oak forest in Algeria has been suffering from dieback in recent years as a result of several factors, including agricultural expansion, infrastructure (towns and roads), overgrazing, fires, and neglect due to lack of interest (Nasrallah, Khelifi, 2007).

Dieback mechanisms can be studied at different scales and can have different causes. First, we can distinguish between biotic and abiotic causes (Cailleret et al., 2011). With regard to biotic causes, dieback can be analyzed at tree level by correlating its health status (healthy, defoliated, and dead) and variables such as its height, circumference, or age or at the stand level by correlating the estimated defoliation/mortality rate on a plot and

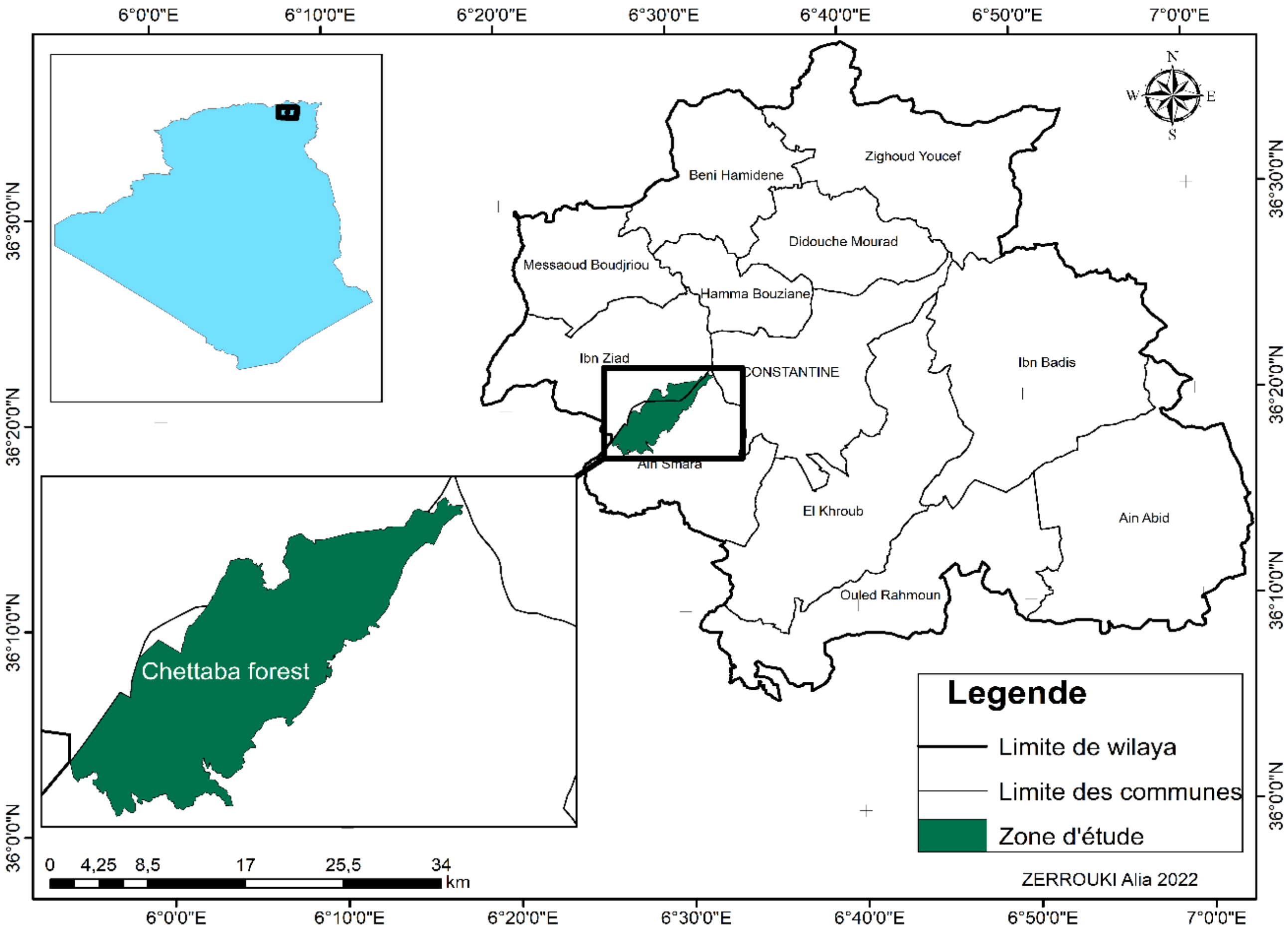

Fig. 1. Geographical location of Chettaba forest (Zerrouki et al., 2023).

the structure or degree of competition. Abiotic causes of dieback include climate and soil. The soil effect is more likely to be observed on a slope scale and corresponds to a plot effect. Climate can be subdivided into a microclimate effect (e.g., altitude effect at a slope scale) and a macroclimate which, combined with soil type, represents a site effect (Monmousseau, 2013). The Hardwood Dieback Indicator (DEPEFEU) is used to record, characterize, and monitor these diebacks. The DEPEFEU rating aims to assess the health status of the tree according to a Forest Health Department protocol based on the appearance of the crown and, more specifically, leaf deficit and mortality of perennial organs (Nageleisen, 2012).

Chettaba forest is a natural stand of 2398 ha, which is made up of a variety of forest species. The forest's main tree species are holm oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* Mill.), which are found in their bioclimatic stages (semi-arid and subhumid). The main aim of our study is to gain a better understanding of holm oak dieback in this forest, to understand the influence of ecological constraints (altitude, slope, and exposure) on the distribution of dying trees, and to characterize their state of health using dendrometric criteria (diameter, height, basal area, and average volume).

Material and methods

Presentation of the study area

Chettaba forest located at coordinates 36°17'41.76 and 36°21'33.47 north latitude and 6°26'3.60 and 6°32'5.61 east longitude (Fig. 1) was chosen as the study area. It covers an area of 2398 ha. The mean annual temperature is 18 °C, with the hottest month exceeding 35 °C and the coldest month varying between 1.25 and 3.05 °C (Zerrouki et al., 2022). Average annual precipitation is estimated at between 670 and 800 mm (Fig. 2). Two types of bioclimate can be distinguished in the Chettaba state forest: semi-arid with cool winters and subhumid with cool winters. The Chettaba forest is dominated by two species: holm oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* Mill.).

The decline inventory identified eight ecological plots covering an area of 0.09 ha (30 × 30 m) (Table 1). These plots meet the essential criteria for the objectives of our investigation. These objectives consist of assessing and studying holm oak dieback in relation to station parameters (exposure, altitude, and slope). These plots will be surveyed during the 2021 summer season (July–August). Two types of inventory were carried

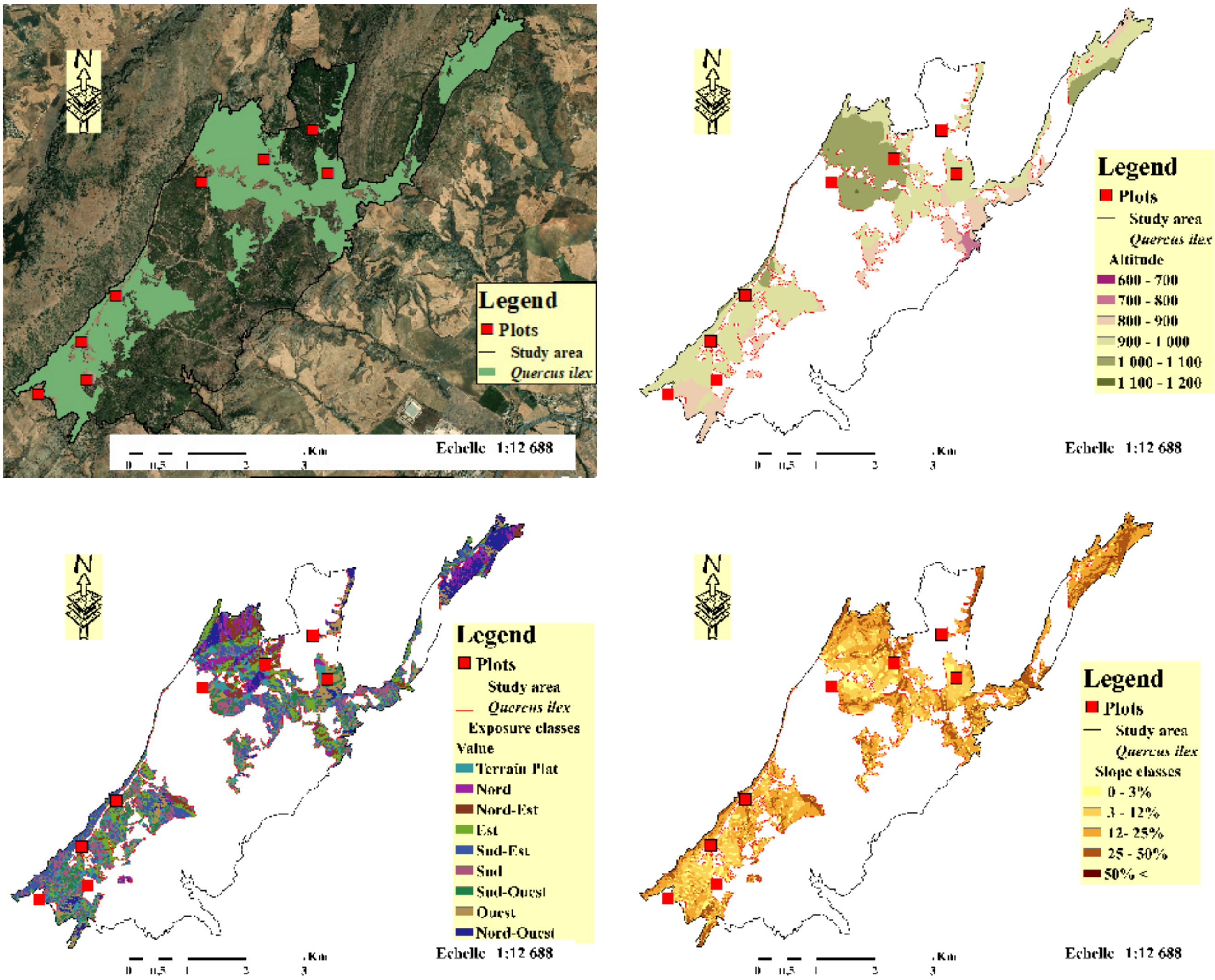

Fig. 2. Representative map of holm oak topography in the study area.

Table 1. Ecological and mesological characteristics of study sites.

Plot	Altitude (m)	Slope (%)	Exposure	Bioclimat	Type of stand
P1	919	3-12	SE	Semi-arid	*Crataegus monogyna, Quercus ilex, Philyrea augustifolia, Juniperus oxycedrus, Pinus halepensis*
P2	841	12-25	NW	Sub-humid	*Quercus ilex, Cupressus semervirens, Pinus halepensis*
P3	1093	12-25	E	Sub-humid	*Quercus ilex, Crataegus monogyna, Pinus halepensis*
P4	925	3-12	W	Sub-humid	*Quercus ilex, Juniperus oxycedrus*
P5	905	12-25	N	Sub-humid	*Quercus ilex, Cupressus semervirens, Juniperus oxycedrus*
P6	967	12-25	E	Sub-humid	*Quercus ilex, Pistacia lentiscus, Philyrea augustifolia, Juniperus oxycedrus*
P7	952	3-12	SW	Sub-humid	*Quercus ilex, Juniperus oxycedrus, Calicotome spinosa*
P8	1046	12-25	W	Sub-humid	*Quercus ilex, Pinus halepensis, Calicotome spinosa, Juniperus oxycedrus*

Notes: S - south; W - west; E - east; NW - northwest; SE - south east; N - North.

out on each plot: a dendrometric inventory and a sanitary inventory.

Collection of dendrometric data

Dendrometric measurements were taken for all trees on each plot:

- Diameter, measured with a tape measure at a trunk height of 1.30 m (Rondeux, 2021)
- The total height of each tree, defined by the length of the straight line joining the foot of the tree (ground level) to the end of the terminal bud of the stem.
- Basal area: This is the sum of the basal sections of all the trees found in the plots, expressed in m^2/ha (Ngom et al., 2013):

$$G = \frac{\pi}{4s}\sum_{i=1}^{n} d_i^2, \qquad (1)$$

where n is the total number of trees in plot, di is the diameter of tree i (m), and s is the area of plot.

- The volume of wood supplied by vegetation in a given area. It is given by the formula of Dawkins (1959):

$$V = \sum vi = [Gi * Hi] * 0.53, \qquad (2)$$

where n is the total number of trees in plot, di is the diameter of tree i (m), and s is the area of plot.

Tree crown appearance assessment method (DEPEFEU protocol)

In view of the complexity of the phenomenon under study, we have used a tree-by-tree inventory method for all affected oaks (Pardé, Bouchon, 1988; Rondeux, 2021). To this end, a sanitary inventory was carried out to take stock of dieback and mortality using the DSF DEPEFEU protocol. The symptomatic study of all the holm oak stems surveyed enables us to observe the degree of alteration of the external appearance of sample trees. This study is based on crown transparency, mortality of perennial organs (branches, twigs), and leaf mass distribution (Nageleisen, 2005; 2012). Based on the classification of Nageleisen (2005), a dying tree will progress from a healthy state with few crown symptoms to a weakly dying, moderately dying, and very dying state until tree death. Table 2 illustrates this classification.

Data processing and analysis

The dendrometric data were represented graphically in the form of histograms to give a better idea of the distribution of decayed trees in the various classes (altitude, slope, exposure, DEPEFEU rate, diameter, height). The dendrometric variables (total height and diameter) relating to decayed and healthy trees harvested at each station were statistically analyzed (mean, standard deviation). Post hoc comparison of means was performed using the Fisher test after single-factor analysis of variance (ANOVA). A principal components analysis (PCA) was performed to study the main parameters most influential on dieback.

The distribution of wilting trees in relative frequency (%) in the different DEPEFEU classes shows the dominance of the DEPEFEU 2 class (trees with light wilting) with a rate of 43.85% (Fig. 4). The DEPEFEU 1 class, representing healthy trees, came second with a rate of 31.15%. The other classes (DEPEFEU 0, DEPEFEU 3, and DEPEFEU 4) represent only 25% of the total. According to the results, the overall crown condition of holm oak trees in Chettaba forest is average despite the significant presence of standing dead and dying trees.

Relationship between dieback and site factors

Table 2. Tree crown appearance assessment classes.

Classes	Description
0	No symptoms
1	Thin, dried-out shoots on the periphery of the crown. Developed secondary branches.
2	Dried branches in the upper half of the crown, dead branches present, representing less than 50% of the crown. Secondary branches poorly developed.
3	Dead branches make up more than 50% of the crown.
4	Dead crown

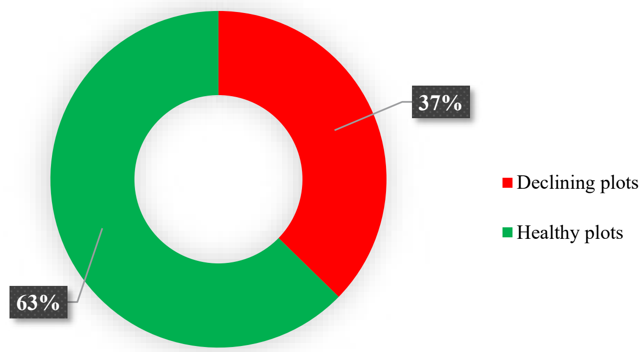

Fig. 3. Distribution of healthy and dying plots in the study area

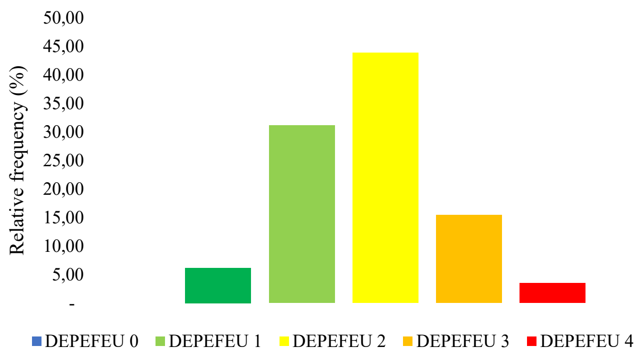

Fig. 4. Distribution of holm oak trees by DEPEFEU class.

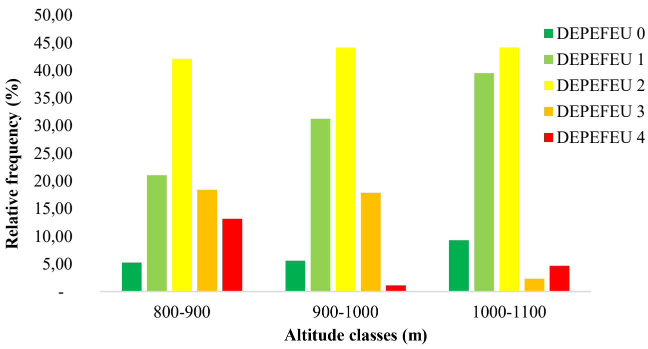

Fig. 5. Variations in holm oak dieback rate as a function of altitude.

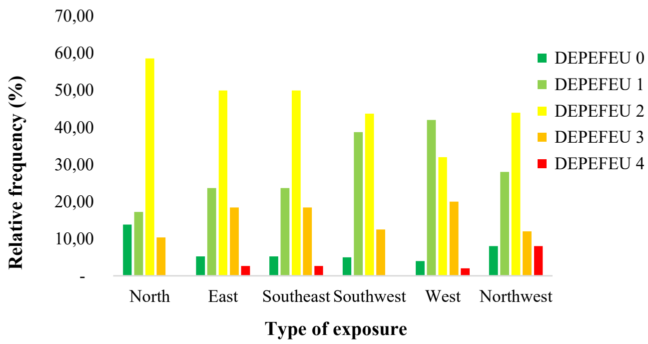

Fig. 6. Variations in holm oak dieback rate as a function of exposure.

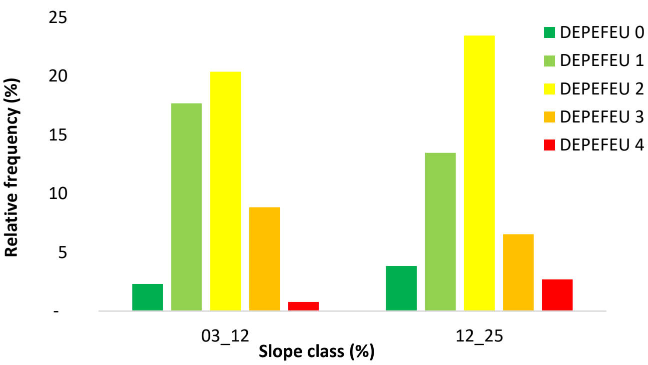

Fig. 7. Variations in holm oak dieback rate as a function of slope.

Results

The initial results obtained on vegetation health (percentage of dead branches per stratum, number of dead stems, leaf deficit, and abnormal coloration) indicated the level of dieback on all the plots studied. Based on dendrometric measurements, the percentage of living and dead stems on all plots provides information on forest composition and individual mortality. Of all the plots surveyed, holm oak accounted for 87.38%, of which 3.46% were dead. The results of the inventory showed that one third of the stands were in a good state of health, while two thirds of the holm oak stands have a high rate of dieback (Fig. 3).

The altitude values recorded on the study plots range from 800 to 1100 m. Based on the 100-m stratification, three altitude classes were selected, with the 1000–1100 m class having a relative frequency of only 16.54%. Holm oak, therefore, has a low proportion in the upper parts of the forest. The 900- to 1000-m stratum has the highest frequency at 68.85%. In fact, the plots studied at high altitude were less numerous than those at other altitudes. Dieback is frequent at lower altitudes. The altitudinal class 800–900 m is the most affected, with a rate of 73.68% (DEPEFEU 2, DEPEFEU 3, and DEPEFEU 4). The phenomenon decreases with altitude, with the lowest frequencies recorded in the last classes (altitude < 1000 m) at 51.16%. Altitude has a major influence on holm oak dieback (Fig. 5).

Exposure is an indicator of ecological factors that have a strong impact on climatic conditions and consequently on land development. Observations of the different exposures across the study plots show that most of the stands encountered grow on slopes with southwest (SW) exposure, that is, relative frequencies of 30.76%. Dieback is observed on all exposures, but exposures facing east and southeast (E and SE) are the most affected (Fig. 6).

The study plots have slope values ranging from 3% to 25%. They are grouped into two terrain classes: gentle slope (from 3 to 12%) and steep slope (from 12 to 25%). On the basis of this classification, we can see from Fig. 7 that half of the plots have gentle slopes, while others have steep slopes. The number of fallen trees is proportionally high according to slope. The relative frequencies of holm oak dieback in each slope class varied little. Thus, according to the results, over 65% of trees on steep slopes are moderately decaying crowns, severely decaying crowns, and dead crown (12–25%).

Relationship between dieback and dendrometric parameters

The results of the wood distribution of the plots show the existence of all diameter classes. The stands are mainly represented by perch and small wood (7.5–17.5, 17.5–27.5 cm), with densities of around 1,556 and 733 trees ha^{-1}, respectively, with smaller numbers of saplings (367 trees ha^{-1}) and medium wood (211 trees ha^{-1}); large wood and very large wood are almost rare or absent. Generally speaking, dieback is not specific to any particular class. Nevertheless, Fig. 8 shows that trees in the intermediate perch and small-wood diameter classes are the most affected by dieback. A comparison of tree diameters shows that dieback occurs across the different diameter classes, affecting both young stems and adults.

As far as trees are concerned, we can see that the majority of plots have average heights ranging from 2 to 8 m, that is, over 91% of the trees inventoried. In other words, the majority of stands are in a state of thicket-growth to high forest. Class 3 (4–6 m) is the most dominant with 40.38%, followed by class 2 (2–4 m) with 39.23% of trees observed. The fourth class (6–8 m) is less important than the previous ones, with a percentage of 12.3%, while the other classes are less frequent. Trees taller than 12 m are absent. Referring to Fig. 9, we note that dieback is reported in all total height classes, is not specific to any one class, and affects the 4- to 6-m class much more. By contrast, the smallest (2 < m) and longest (>8 m) holm oak classes show the lowest dieback, with relative frequencies of around 0.76 and 2.30%, respectively.

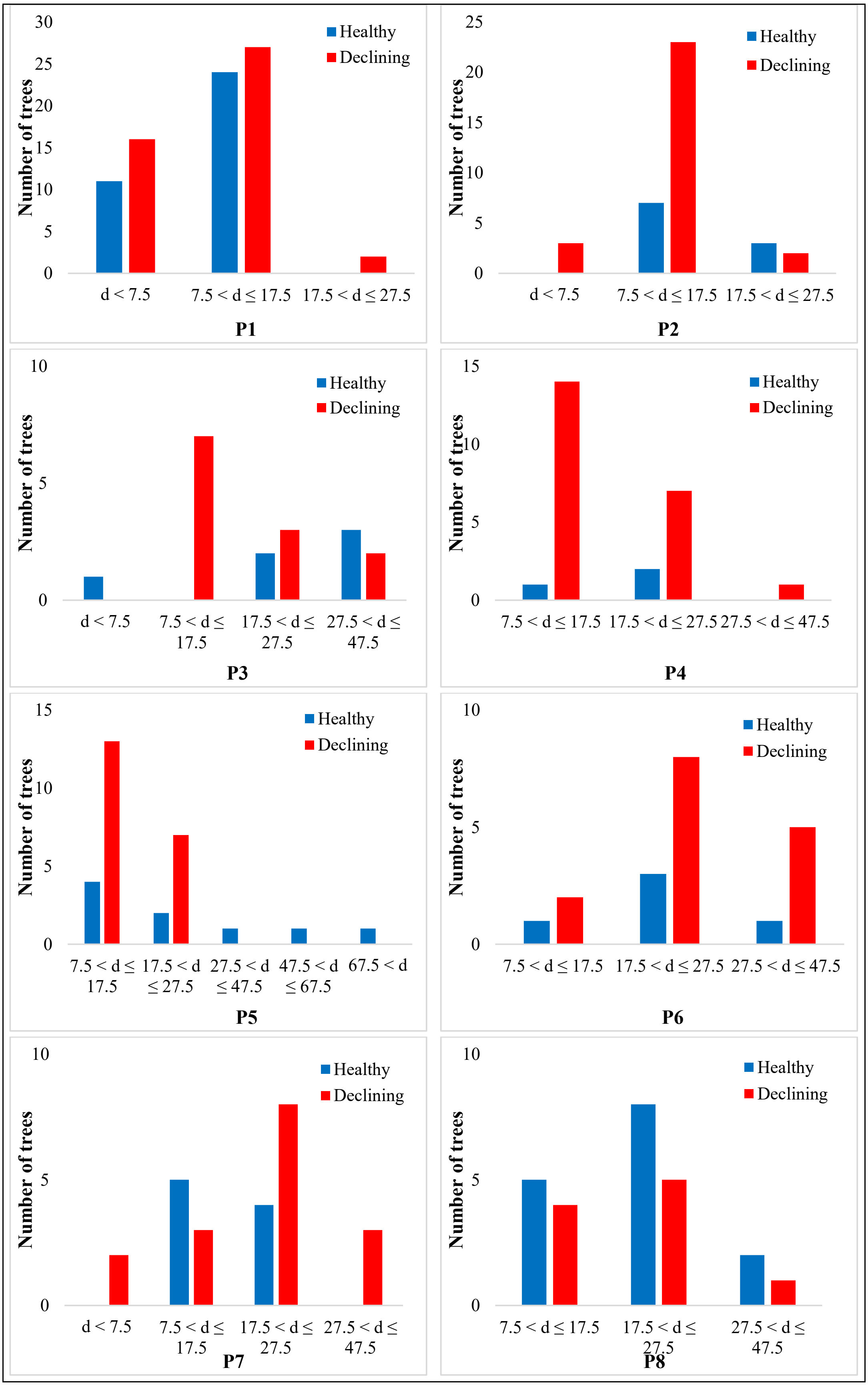

Fig. 8. Variations in holm oak dieback rate as a function of diameter..

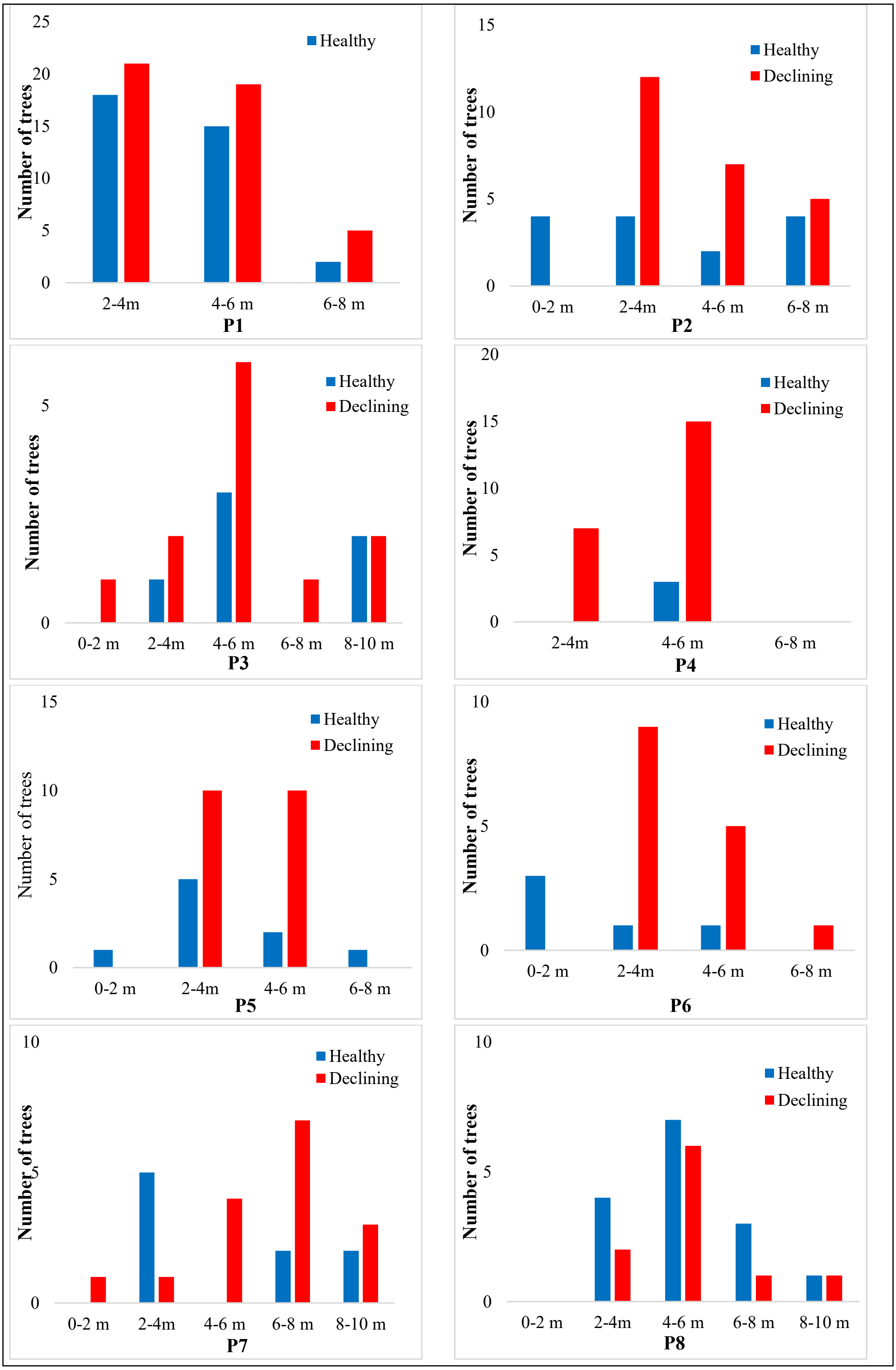

Fig. 9. Variations in holm oak dieback rate as a function of height.

Table 3. Tree averages and standard deviations by plot.

Parcelle	State	N (ha)	D (cm)	H (m)	G (m^2)	V (m^3)
P1	**Healthy**	35	9.88±4.06 d	4.17±1.35 ab	0.09±0.07 c	0.41±0.27 c
	Declining	45	10.60±4.10 e	4.17±1.35 d	0.11±0.07 d	0.18±0.18 e
P2	**Healthy**	10	14.34±4.32 cd	4.89±2 ab	0.19±0.11 bc	0.59±0.48 bc
	Declining	28	11.85±3.66 d	3.85±1.75 cd	0.13±0.08 cd	0.33±0.37 e
P3	**Healthy**	6	24.97±13.2 ab	5.85±2.52 a	0.67±0.61 ab	2.71±3.29 a
	Declining	12	18.35±12.44 bc	4.73±2.13 abc	0.41±0.56 b	1.43±2.53 abc
P4	**Healthy**	8	21.69±4.15 bcd	5.53±0.15 ab	0.42±0.14 bc	0.85±0.50 bc
	Declining	17	16.22±6.39 cd	4.29±0.79 bcd	0.26±0.20 bc	0.64±0.61 de
P5	**Healthy**	9	28.31±23.17 a	3.48±1.55 b	1.11±1.80 a	1.40±1.79 b
	Declining	20	17.47±8.10 bc	3.91±0.91 cd	0.32±0.32 b	0.70±0.89 cde
P6	**Healthy**	5	27.38±10.36 ab	4.3±1.49 ab	0.72±0.52 ab	1.85±1.89 ab
	Declining	15	25.94±7.59 a	5.68±1.27 a	0.63±0.39 a	2.06±1.64 a
P7	**Healthy**	9	18.64±6.88 bcd	5.03±2.48 a	0.33±0.22 bc	1.17±1.11 bc
	Declining	16	20.48±8.30 b	5.81±2.00 a	0.42±0.25 b	1.49±1.05 ab
P8	**Healthy**	15	18.93±7.30 bc	4.95±1.45 a	0.35±0.26 bc	1.08±1.04 bc
	Declining	10	18.50±8.20 bc	4.96±1.37 ab	0.35±0.31 b	1.11±1.38 bcd

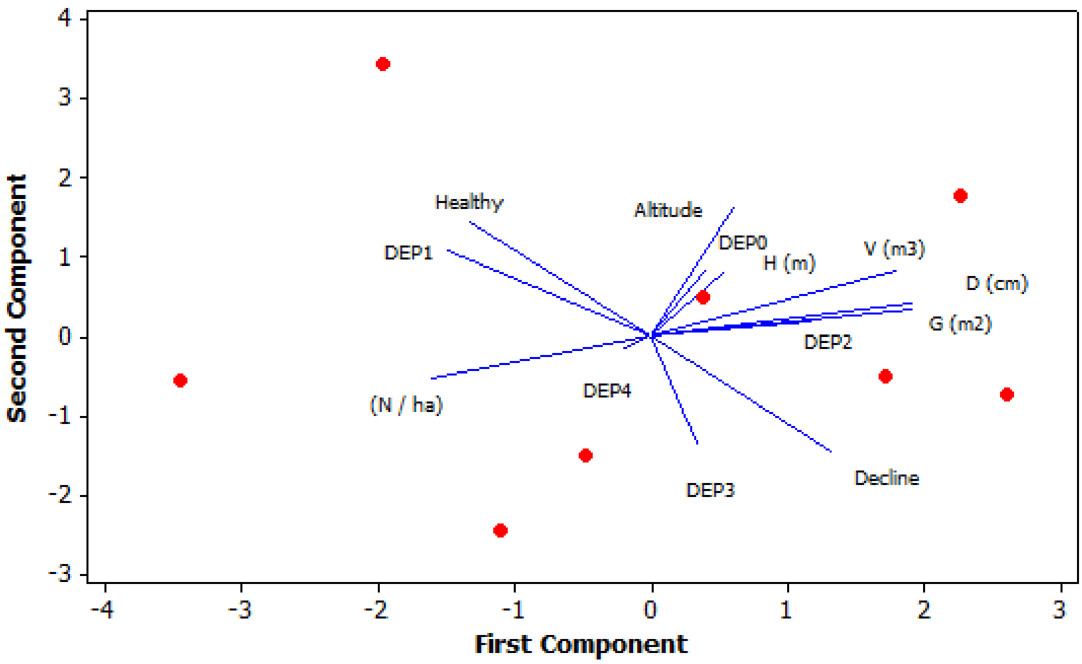

Fig. 10. Principal component analysis of observed variables.

The dendrometric parameter values for all trees (healthy and dying) show that the average heights, diameters, basal areas, and volumes of healthy trees are greater than those of dying trees in most plots (Table 3, Fig. 10). Analysis of variance for each parameter shows a highly significant difference ($P = 0.000$) between plots and decay status (healthy and decayed).

Dendrometric variables are indicators for identifying the structure of a given stand. In order to elucidate possible relationships between dieback classes and various dendrometric characteristics, Pearson's correlation test was used in this study. Through the results of this test, no correlation was recorded between the dendrometric parameters and the DEPEFEU 0, DEPEFEU 2, and DEPEFEU 3 classes. On the other hand, a negative correlation was recorded between the diameter of all plots and DEPEFEU 1 classes (r = 0.56, r = 0.67, and r = 0.52, respectively). Increasing these parameters increases competition between trees, which reduces health. The DEPEFEU 4 class is linked to height: the greater the height, the more trees with dead crowns can be distinguished.

Discussion

The study of the composition, distribution, and structure of forest stands is very interesting for illustrating the current state of the Chettaba forest holm oak with regard to the phenomenon of dieback. Indeed, the behavior of forest species depends mainly on slope, exposure, and altitude, as well as on competitive relationships between individuals.

The current status of holm oak stands using the DEPEFEU protocol shows that only 6.15% of trees have healthy crowns, 43.84% have moderately decaying crowns, and 31.15% have severely decaying crowns, with 3.46% being moribund. Healthy trees grow at a faster rate than dying stems (Amorini et al., 1996). A healthy tree with a full, green, well-developed crown would have a high level of carbon reserves enabling it to maintain radial growth (Cailleret, 2011). From the above results, we can see that the general crown condition of holm oak trees in the Chettaba forest is average despite the presence of a significant number of standing dead and dying trees. These results are entirely consistent with those of Rached-Kanouni et al. (2020) for holm oak stands in the Sidi Reghis forest of eastern Algeria and at odds with holm oak stands in the Arascués and Aragón forests of northeastern Spain (Camarero et al., 2015). This condition may be linked to climatic factors (winter frost, summer drought) and biotic factors such as insect pests or phytopathogenic fungi (Rodriguez-Galiano et al., 2012).

In recent years, oak stands seem to have entered a new phase of decline, with numerous cases of mortality reported in various regions. While it is usual to observe dieback after drought (Nageleisen, 2005), even this major climatic event is not the only one involved. In detail, oak species are affected by various factors such as lack of silviculture, frequent fires, and parasitic attacks. The processes involved are sometimes very different from one species to another and from one site to another. Among the latter, insect pests with different diets occupy first place. They are highly diversified on holm oak.

Holm oak dieback in the study area is frequent at low altitudes, on steep slopes, and in east-facing exposures. Holm oaks at lower altitudes receive less precipitation than those at higher altitudes, and it is through altitudinal gradation that climatic variations, particularly temperature, and rainfall are revealed to differ from lower to higher slopes (Seynave et al., 2004).

Exposure is an indicator of ecological factors that have a strong impact on climatic conditions and consequently on land development. Holm oak characterizes the mountain area, with its steep slopes (Barbero, Loisel, 1980). All exposures show dieback, but those facing east and southeast (E and SE) are the most affected. Dieback is less frequent across the lower slope classes. Site quality differs according to the steepness of the slope. The steeper the slope, the easier it is for solid particles or dissolved substances to be carried along, altering soil composition and making it difficult for plants to grow. On the other hand, when the slope is gentle, the situation is more favorable for plant growth, as the edaphic substrate is deep and rich (Duvigneaud, 1974).

Studying the composition of stands by tree size is a good indicator of their current and retrospective condition. The diameter structure of the forest stand has a negative exponential distribution, characterized by more small-diameter trees and fewer large-diameter trees. This structure is regressive. In uneven-aged stands, trees often have different canopies constituting strata (Olivier, Larson, 1996). Knowledge of diameter class distribution is essential to provide information on species ecology, potential silvicultural constraints, and resource status (Wiegand et al., 2007; Herrero-Jáuregui et al., 2012). In fact, an increased shortage in one of the height classes is considered a sign of imbalance. According to Matias et al. (2019), early detection of a change in stand structure can prevent decline before it becomes irreversible. These diameter and height distribution patterns resemble those of the Sidi R'Ghies forest (Rached-Kanouni et al., 2020). According to diameter and height analysis, the vegetation of the Chettaba forest is dominated by young trees. The abundance of young trees ensures the future of the natural formation, as it enables a constant renewal of the adults. Such a structure is typical of stable populations, which are capable of renewal through natural regeneration (Mbayngone et al., 2008).

Individual holm oaks in the forest of all sizes (height and diameter) show high rates of dieback. These results contradict those of certain studies which have noted that a tree's greater size increases its vulnerability to drought (Nageleisen, 1994; Le Meignen, Micas, 2008). Indeed, taller trees are often the most vulnerable to drought due to the physical constraints associated with their size to carry water to the top of the crowns (Bennett et al., 2015).

The diameter of holm oaks is not a good indicator of dieback. In fact, holm oaks grow mainly in coppices, so the diameter depends on the structure of the copse. In a coppice, all the branches are the same age and feed on the same roots, that is, at the same depth. The largest holm oaks are dominant and so are the tallest, while the smaller individuals take up fewer resources and are therefore less healthy (Vuillermet, 2019).

Conclusion

This work is (only) a contribution to the study of the phenomenon of holm oak dieback in Algeria, particularly in the Chettaba forest. At the end of this study, we can conclude that there is probably no strong relationship between dendrometric parameters and dieback. On the other hand, a more significant relationship with ecological factors (altitude, exposure, and slope) was recorded. Dieback in holm oak stands is moderate and affects all trees categories. Moreover, our results show that the sites with the lowest altitude and the most easterly exposure have the highest dieback rates. It seems that this phenomenon is linked to physiological problems on the trees due, on the one hand, to the water deficit of recent years and, on the other hand, to disturbances of the ecosystem caused by anthropic action (grazing), especially on low-altitude sites.

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